

**Interdependence of Pinyon Pines and Pinyon Jays  
White Sands Missile Range, NM**

**2004-2005 Final Report**



**Pinyon Jay (*Gymnorhinus cyanocephalus*)**

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## Introduction

Ligon (1978) first pointed out the unique mutualism between pinyon pines (*Pinus edulis*) and pinyon jays (*Gymnorhinus cyanocephalus*). Pinyon trees provide occasional mast crops of highly nutritional seeds, which allow successful and productive nesting attempts (Marzluff and Balda 1992) in both late summer (August), supported by newly ripened seeds, and late winter (February), based on cached seeds. Although pinyon jays can nest in non-mast years, pinyon mast crops allow pinyon jays to produce bumper crops of young pinyon jays. These infrequent but explosive reproductive events may be crucial to the species' long-term viability (Marzluff and Balda 1992). Mast crops of pinyon seeds are so important to pinyon jay reproductive success that testis growth occurs in pinyon jays before the winter solstice, in response to abundant pinyon seeds. Even the presence of green pinyon cones can inhibit or reverse testis regression in late summer (Ligon 1978).

Pinyon pines are in turn adapted to exploit the caching behavior of pinyon jays. By synchronously producing huge seed crops at irregular intervals, the trees overwhelm vertebrate and invertebrate seed predators and increase the numbers of seeds that can be cached by the highly social pinyon jays. One pinyon jay can carry more than 50 seeds in its throat on a caching trip. A flock of 250 birds could theoretically cache over four million pinyon pine seeds between September and January (Ligon 1978). Pinyon jays are strong fliers and can carry large numbers of seeds over long distances. Unlike other pinyon seed predators, pinyon jays frequently cache far away from the seed source in open areas, probably to reduce competition with other seed predators confined to the pinyon-juniper woodland. To the trees' advantage, the jays retrieve only a portion of cached seeds, leaving some to become pinyon pine seedlings.

Since 2001, dramatic, rapid, large-scale mortality of pinyon trees has occurred in the southwestern US. Pinyon mortality due to drought, bark beetle (*Ips confusus*) infestations, fungus (*Leptographium wageneri*), and other diseases such as needle scale (*Matsucoccus acalyptus*) threaten this keystone species and other inhabitants of pinyon woodlands in the southwest. Populations of the pinyon pine's primary long-distance seed disperser, the pinyon jay, have been declining for 25 years (Sauer et al. 2004). Given the dependence of pinyon jay reproductive success on mast crops, widespread loss of pinyon trees will likely result in further population declines of the jays, which are crucial to the re-establishment of those very woodlands.

White Sands Missile Range (WSMR) is no exception to the pattern of pinyon mortality. Although pinyon mortality on WSMR has so far been less widespread than in some parts of northern New Mexico (USDA Forest Service 2004), considerable losses have occurred in these important woodlands in the San Andres and Oscura Mts. In response to concerns for the long-term viability of pinyon woodlands on WSMR, we are studying pinyon jays and pinyon pines there.

Here we report results from an abbreviated field season in late summer 2004 and the 2005 field season. The 2004-2005 goals were to:

1. find a suitable study site, where pinyon mortality was limited and pinyon jays bred;
2. begin to document, with field data and aerial photos, the health, stand structure, and cone production of pinyon pines on the study area;
3. begin capturing, banding, and radio-tracking pinyon jays on the study site;
4. determine breeding home range, caching sites, and winter movement patterns.

## **Methods**

### ***2004 Assessment of Potential Study Sites***

On 26 May 2004, David Ligon, Sandy Ligon, Kris Johnson, and Trish Griffin assessed pinyon-juniper woodland habitat on the San Andres National Wildlife Refuge (SANWR), in the San Andres Mts. On 27 May, DL, SL, KJ, TG, and David Griffin visited North Oscura Peak (NOP). On 9-11 August, KJ and Jackie Smith investigated the area in the vicinity of Hardin Ranch. On 11 August, KJ and JS moved to NOP, where we began developing methods for vegetation data collection. On 3 September we traveled the road to Jim Peak to assess pinyon health. We took photos to document large patches of pinyon morbidity/mortality, interspersed with healthy patches. On 20 September we returned to NOP to look for jays and cache sites.

### ***Tree Data***

#### **2004**

We collected vegetation data on 12, 24, and 25 August and 2 and 8 September 2004, on five transects in pinyon-juniper woodland habitat on NOP (Figure 1). Transects contained 12 (three transects) or 13 (two transects) points each. Using the point-centered quarter method, we collected data from the nearest tree over 1 m tall, in each quarter at each point on each transect, 248 trees in all. Points were approximately 50 m apart, resulting in approximately 550 m transects for the 12 point transects, and approximately 600 m transects for the 13 point transects. For each tree, we recorded distance from point to tree, estimated tree height, and measured diameter of root crown. Based on the point quarter data, we computed tree density and graphed size distribution as an indicator of stand structure.

For each tree, we also recorded any symptoms of disease (needle loss or discoloration, needle scale, popcorn sap, etc.). Vigor was assigned a ranking from 1-5 (1- dead/defoliated, 2- majority of needles lost or brown, 3- half or more of needles present and green, 4- few needles brown or lost, 5- vigorous). Standing 5m from the uphill side of the tree, we counted the number of cones within a binocular field, using the same binoculars for all counts. Counts were made for three fields in each tree, from areas of the tree containing the most cones. The three field counts were averaged for each tree to produce an index of cone production.

We noticed that many cone-bearing trees were located near roads or drainages. To test this hypothesis, we collected data on 10 additional transects along the large drainage east

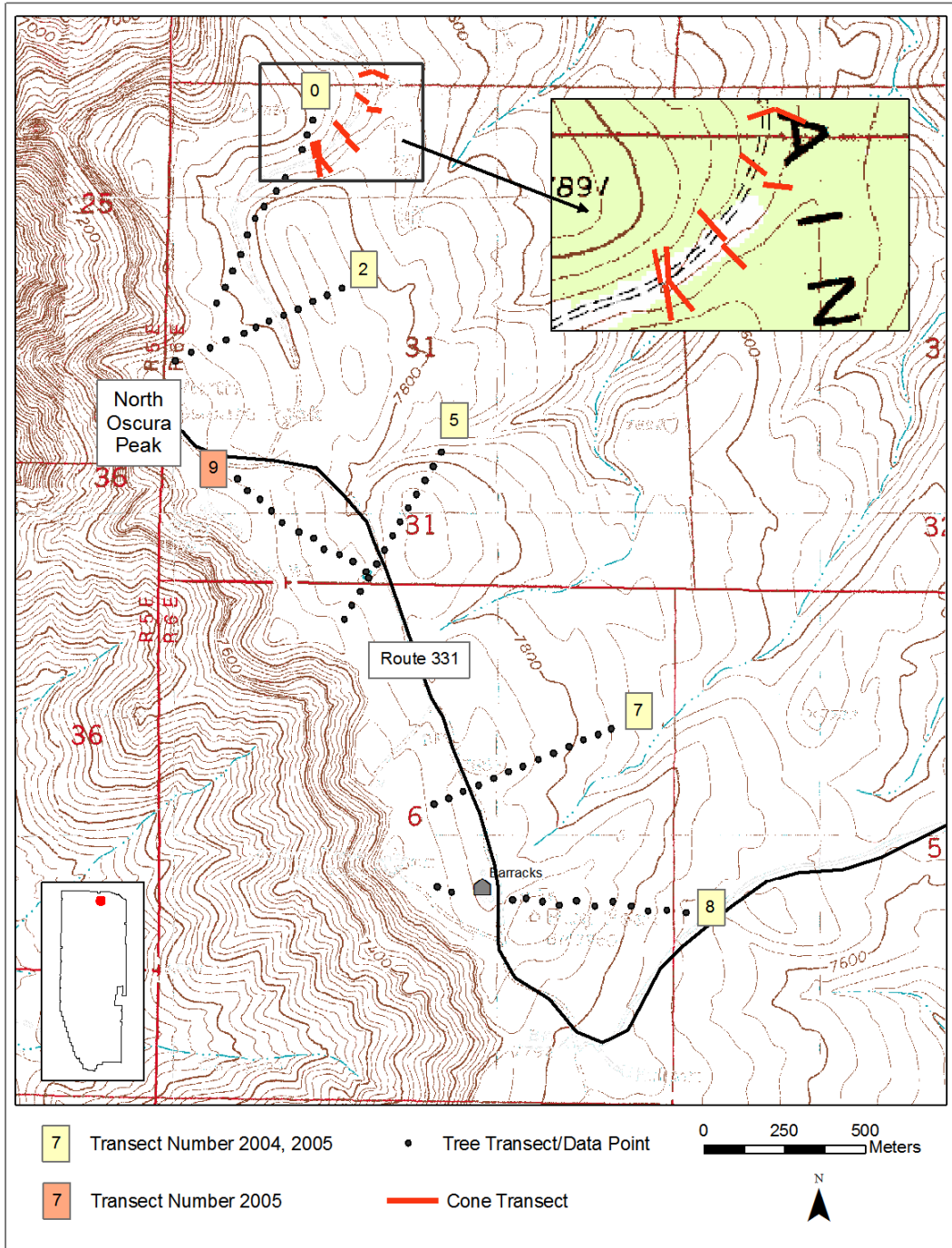


Figure 1. Tree transects (2004 and 2005 and cone transects 2004).



**Figure 2. Feeder used to attract pinyon jays for capture.**



**Figure 3. Welded wire walk-in trap used to capture pinyon jays in 2005.**

of NOP (Figure 1). Each 50m cone transect began at the edge of the drainage and extended up the adjacent hill. Transects were set up in pairs, such that for each transect there was a transect facing the opposite direction. Transect pairs were north- and south-facing (2), northwest- and southeast facing (1), or east- and west-facing (2), depending on the meander of the drainage. For every tree encountered within 5m of each transect, we recorded distance from start of transect, number of cones on the uphill side of the tree, and presence or absence of pinyon jays. We analyzed the short transect data to determine the effect of drainages on cone production. All tree data were entered into an Access database.

## **2005**

On 23 July 2005, we collected data on an additional 11-point transect (approximately 450-m) that crosses the nesting colony site. On 24 and 29 July and 5 and 19 August, we collected a second set of tree vigor and cone count data on the other five transects. Tree size and density measures were not expected to differ appreciably from 2004 and were therefore not taken in 2005. We did not collect any data on cone transects in 2005.

### ***Digital Aerial Photography***

In September 2004, WSMR provided us with color, 1-ft resolution, 2003, aerial photos of the NOP study site in geo-tiff format. We viewed known areas of the study site in the photos to determine if pinyon mortality was apparent.

### ***Capturing and Banding***

On 12 August 2004 we set up two standard glass and wood seed feeders (13 x 17 x 43 cm, mounted on 1.5 m pole; Figure 2), along the road between the barracks and the top of NOP. Birds did not start using the feeders before the birds disappeared from the area in mid-September. Feeders blew down and were picked up for the winter. We set them up again on 19 April 2005. With help from Stan Sessions, an engineer stationed at NOP, feeders were filled with a mixture of cracked corn and pinyon seeds three to four times each week through the 2005 breeding season.

On 23, 24, and 26 July, we captured jays in welded wire walk-in traps (1.18 x 0.72 x 0.2 m; Figure 3) set under feeder 2. We removed birds from traps, placed them in closed cardboard boxes, and transported them to the barracks for processing. We took the following data on each bird: age, sex, weight, tarsus, and culmen. Each bird was banded with a US Fish and Wildlife Service numbered aluminum band and a unique combination of three color bands (except for one bird that received only one color band). Although it is not possible to unequivocally determine the sex of hatch-year (HY) pinyon jays (Pyle 1997), for our information, we attempted to assign sex using a combination of weight, tarsus, and culmen, as we have done for adult and second-year (ASY and SY) pinyon jays. Because they were not definite, sexes of HY birds were not reported to the Bird Banding Lab.

We affixed radio transmitters to five birds; two HY males, two SY/ASY males, and one HY female. We used 2.5 g, glue-on transmitters from Advanced Telemetry Systems. We attached transmitters using figure-eight harnesses made of 0.5 mm and 0.8 mm elastic



beading cord and super glued to the transmitter (Mennill 2000, Rappole and Tipton 1991).

Transmitters sat on top of the synsacrum, with the antenna extending past the end of the tail. All birds flew away when released, although most birds with radios flew shorter distances and stayed near the release site for several hours. By the next day, all birds appeared to be moving normally.

We tracked birds with a TRX-1000 receiver from Wildlife Materials International, Inc. We attempted to locate all birds with radios once or twice a week from late July until all transmitter batteries had failed in early September. Each time we radio tracked birds to the flock, we noted which radios were present, took a GPS location, and noted flock behavior. We recorded GPS points wherever we observed substantial numbers of ripening pinyon cones. We used comments on transect data sheets and cone GPS points to create cone maps for 2004 and 2005.

### ***Red Rio***

On 23 September 2005, we visited Red Rio Bombing Range to see a pinyon jay flock reported by The Nature Conservancy (TNC) field technicians who had been conducting rare plant surveys in the area. We followed the techs to an area where they had observed pinyon jays harvesting cones and caching. We recorded locations where birds were harvesting cones and observed behavior for about two hours.

### ***Analyses***

We performed statistical analyses using Minitab 13. We plotted pinyon jay and cone locations using ArcGIS. Minimum convex polygon (MCP), 50% kernel, and 90% kernel home range analyses were performed using the Animal Movement extension (version 2) in ArcView 3.3 (Hooge and Eichenlaub 2000).

We used ArcGIS to create a predictive breeding season range map for the flock on NOP. First, using the WSMR vegetation map (Muldavin et al. 2000), we found that pinyon jays had been found primarily in the Pinyon Pine/Wavyleaf Oak or Scribner's Needlegrass Montane Woodland vegetation type. Within their home range very small areas of Pinyon Pine/Gambel's Oak Montane Woodland and Mountain Mahogany/Blue Grama or Sideoats Grama Montane Shrublands also occur. To determine important habitat features within this vegetation type, we overlaid pinyon jay detection points onto parts of the WSMR stand structure map (Muldavin et al. 2003) in these vegetation mapping units. Our detection points were found primarily in stands with 60% or greater total canopy cover. We then identified areas having the same vegetation and structure types that were outside and adjacent to locations where we had detected jays. We created a polygon surrounding these areas. This predictive habitat map encompasses areas on NOP where pinyon jays might be expected, based on vegetation type and stand structure.

We used our distance measurements from the point quarter data to evaluate Muldavin's (2003) stand structure map. We divided our data points according to the stand polygons they fell into. We performed Pearson correlations between values assigned to the

polygons on the stand map and our field data. For the correlation, we compared values for percent total canopy assigned to the stand map to our measured distances between trees, and percent emergent canopy to percent trees estimated to be over 6 m tall.

## Results

### ***2004 Assessment of Potential Study Sites***

San Andres National Wildlife Refuge. The habitats at SANWR were relatively dry, and pinyon pines were sparse and only moderately tall. Most trees appeared to be diseased, but symptoms suggested needle scale rather than bark beetles (green needles at tips of bare twigs, lesions on needles, and small insects flying up from trees). We detected no pinyon jays and assigned the area low priority as a potential study site, due to the marginal nature of the habitat, absence of jays, and inaccessibility of the site.

Hardin Ranch and Vicinity. KJ and JS saw a flock of 20-25 pinyon jays south of Hardin Ranch, flying in a tight flock from NW to SE. On 10 August, KJ, JS, and TG walked up the arroyo leading to Gyp Spring. We saw two pinyon jays flying over Big Gyp Mt., followed by five more apparently heading toward pinyon habitat west of Big Gyp Mt.

Later that day, KJ and JS visited the pinyon habitat in a canyon on the west side of Big Gyp Mt., where we noted many green cones on healthy trees and saw three pinyon jays flying. We concluded that Big Gyp Mt. had moderate potential for a study site, due to the abundant green cones and presence of jays (Figure 4), but that its isolation would present logistical difficulties. On 11 August, we checked Bear Den Canyon, which contained abundant fruiting barberry bushes and large numbers of phainopeplas (*Phainopepla nitens*), but almost no pinyon trees.



**Figure 4. West side of Big Gyp Mountain, showing green cones on pinyon trees. We saw and heard three pinyon jays in the area.**



**Figure 5. Jim Peak Road, photo point 1, showing dead and sick pinyon trees. One pinyon jay was heard from this location.**



**Figure 7. Jim Peak Road, photo point 4.**



**Figure 6. Jim Peak Road, photo point 3.**



**Figure 8. Jim Peak Road, photo point 6.**



**Figure 9.** NOP, pinyon tree with many green cones and perched pinyon jay.

Jim Peak. Along the road to Jim Peak we observed pinyon trees in varying degrees of health (Figure 5). Widespread illness and mortality was apparent on the lower, east-facing slope, with 70-80% of trees lacking most of their needles (Figure 6). Slightly higher up and further south, trees looked healthier (Figure 7), but still further south we encountered more sick trees (Figure 8). There were a few patches of healthy trees with green cones, but these were less common than affected trees.

NOP. The woodland on NOP contains some very large, old-growth pinyon trees, as well as "doghair" stands of uniformly small trees. The woodland is somewhat denser than is typical for optimal pinyon jay habitat but is still quite suitable. On 27 May, we noted moderate numbers of green cones on pinyon trees and little pinyon mortality in the highest elevations on NOP. We detected a small flock of about 15 pinyon jays calling and foraging. This area showed promise, due to the high quality of the habitat and presence of the

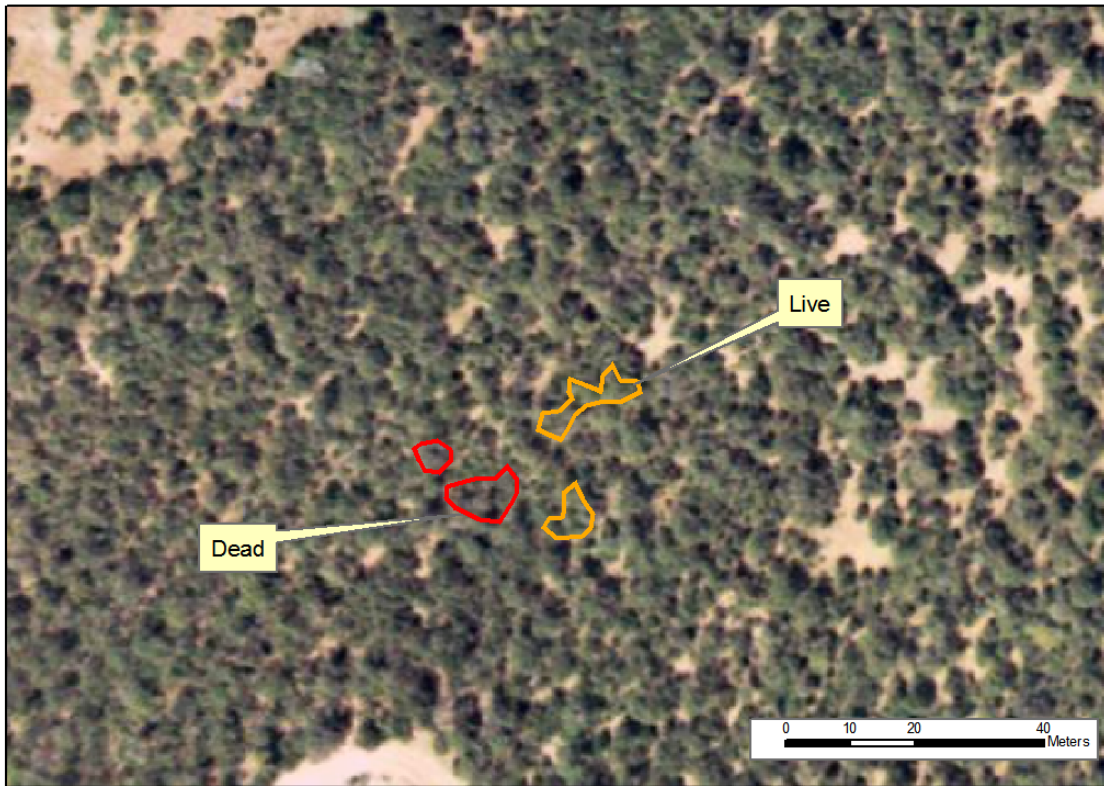
jays in May, which suggested that it included traditional nesting grounds.

On 12 August we counted 75 jays foraging on ripening pinyon cones on top of NOP. Smaller numbers of pinyon jays were foraging on NOP and in the northeast drainage (Figure 9) on 23, 24, and 25 August and 2, 3, and 8 September. On 20 September, we detected no pinyon jays in the usual locations. Stan Sessions confirmed that pinyon jays had been absent for about a week. We concluded that the last birds left the area between 8 and 20 September.

Based on the above reconnaissance, we concluded that NOP was the most promising study site, for several reasons. The structure of the pinyon-juniper woodland there provides the best habitat for pinyon jays we observed at WSMR. Pinyon mortality had occurred in nearby areas, such as Jim Peak and at lower NOP elevations, but mortality was limited on top of NOP. This provided an opportunity to track vegetation and bird changes if trees began dying at the study site. A small cone crop was produced in fall 2004, which provided the opportunity to observe caching behavior. The presence of jays in May 2004 and breeding in May 2005 suggest that NOP is a traditional nesting colony site. Finally, NOP is close to Albuquerque, and the barracks provided accommodations and work space.

### ***Digital Aerial Photos***

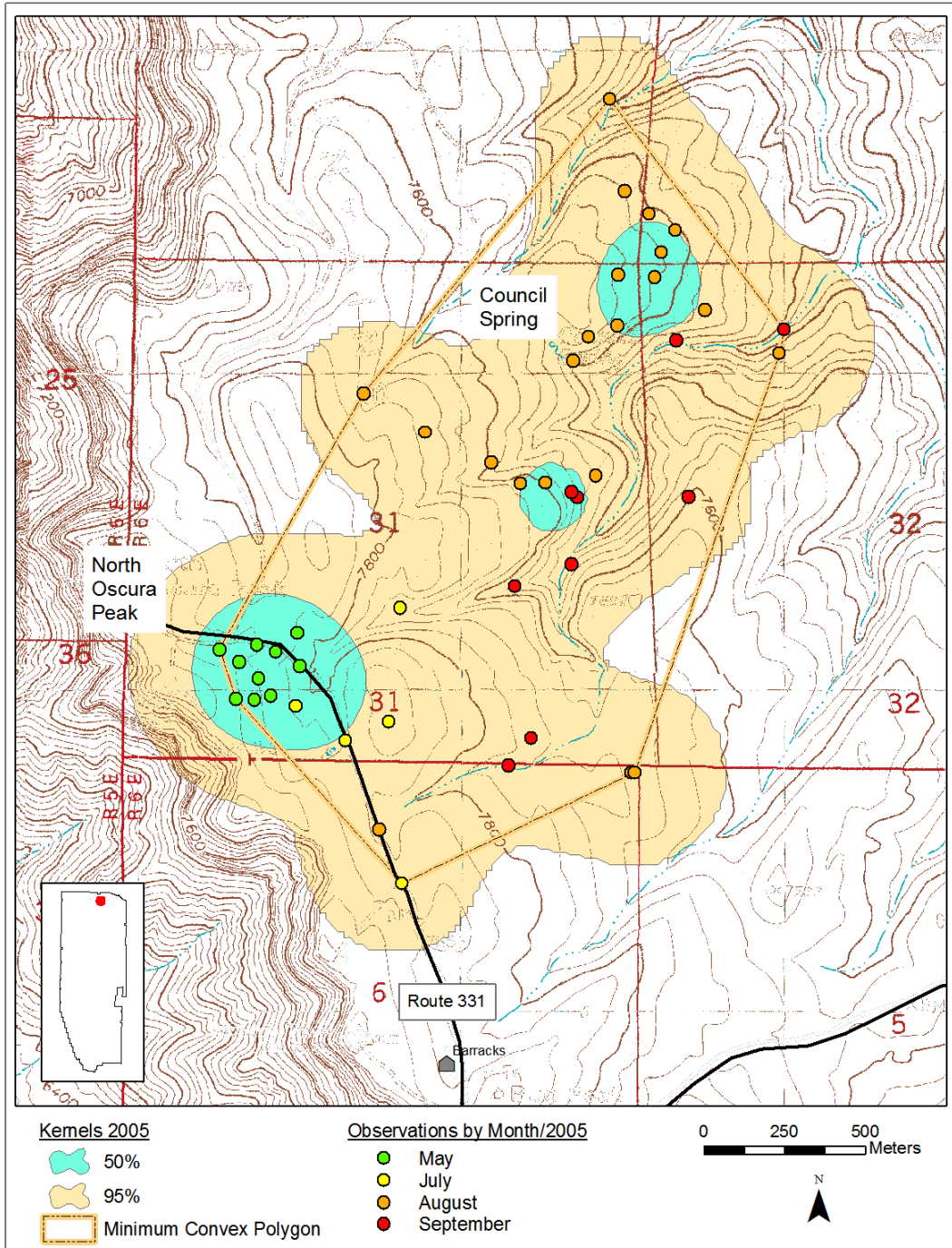
The digital photos clearly depict individual trees, and dead and diseased trees can be distinguished from healthy trees by color (Figure 10). Trees that have dropped their needles are gray, while healthy trees are dark green. Perusal of the aerial photographs suggests that they can provide information on the health of pinyon-juniper woodlands at WSMR and can serve as a valuable tool for assessing pinyon health and monitoring spread of pinyon mortality over large, difficult-to-access areas of pinyon-juniper woodland. We were able to identify clusters of dead trees on the photos in areas we knew had lost trees. However, the extent of mortality on the 2003 photos appeared limited compared to what we observed on the ground in 2004. In late 2006, 0.5 m resolution, 2005 digital orthophoto quadrangles (DOQs) of the state became available. We will attempt to acquire these images for comparison with the 2003 imagery obtained from WSMR.



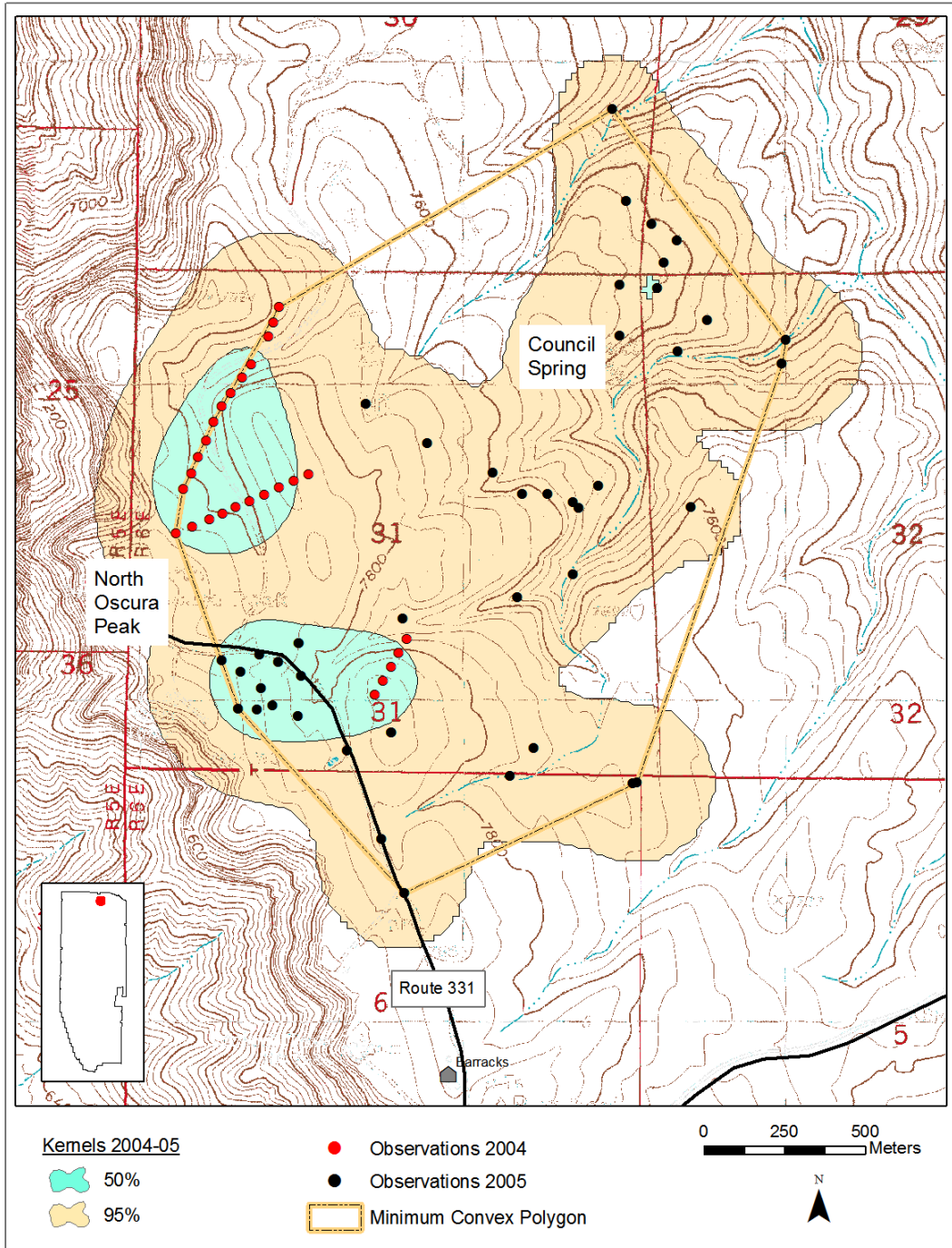
**Figure 10. Digital aerial photo image from area of transect 8. Green trees are healthy (outlined in orange); gray trees are ill or dead (outlined in red).**

### ***Pinyon Jay Home Ranges***

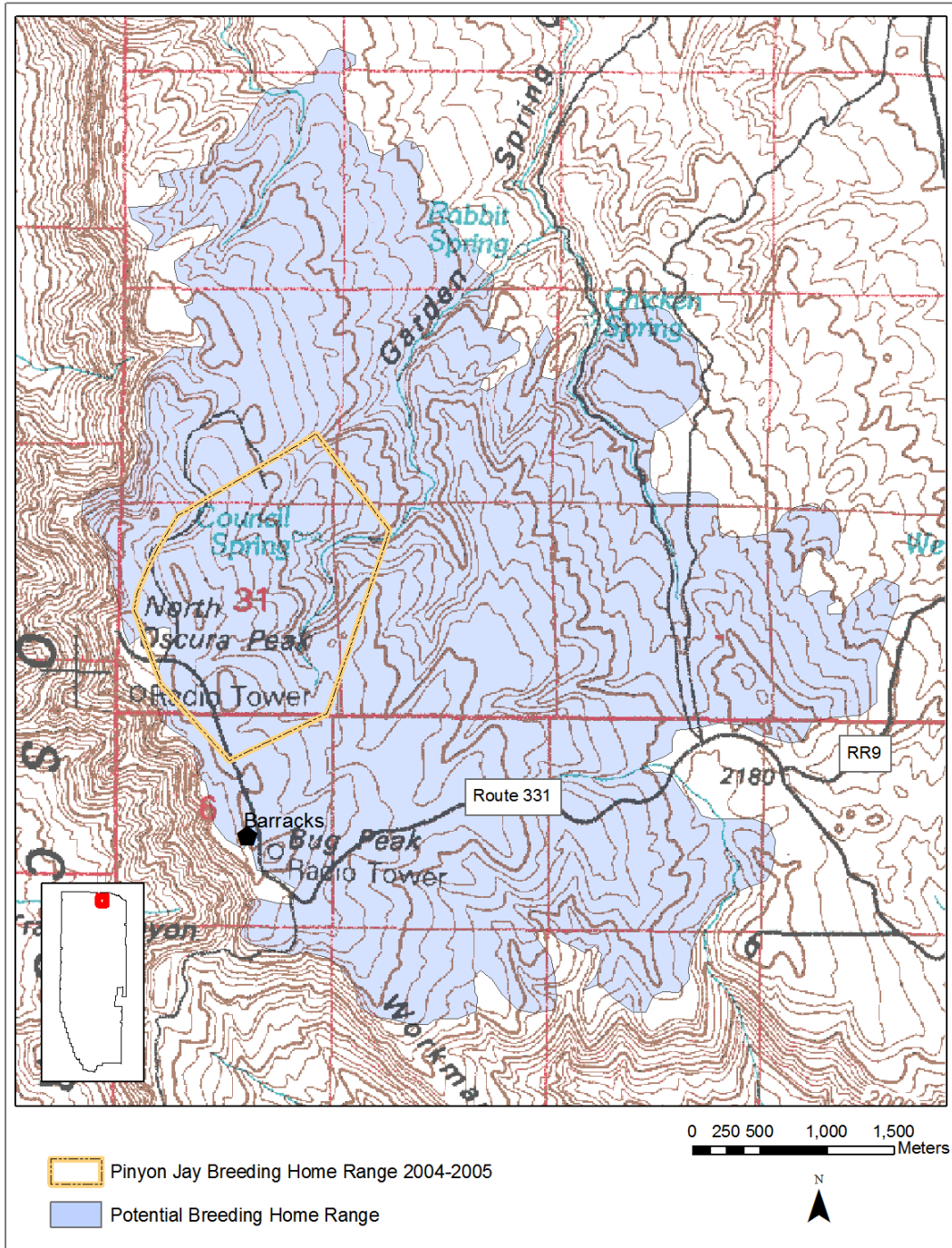
We used fixed kernel home range estimates because they have been shown to compare well to other home range estimators on such criteria as sample size, sensitivity to outliers, etc. (Kernohan et al. 2001). Minimum convex polygons were also computed for comparison.



**Figure 11. Breeding season home ranges of NOP flock, 2005. Minimum convex polygon, 50% kernel, and 95% kernel polygons are shown. Observation points are not shown for June, because nesting birds were detected in same area as May (green points).**



**Figure 12. Breeding season home ranges of NOP flock, using 2004 and 2005 data combined. Minimum convex polygon, 50% kernel, and 95% kernel polygons are shown.**



**Figure 13. Potential breeding season home range map for NOP flock, based on vegetation community and stand structure. Breeding home range shown is the MCP.**

The minimum convex polygon home range for 2005 covered 236 ha (Figure 11), and the MCP made using 2004 and 2005 detection points covered 290 ha (Figure 12). The 2005 95% and 50% kernel home ranges covered 329 ha and 33 ha, respectively (Figure 11).



The kernels computed from 2004 and 2005 data combined covered 351 ha and 41 ha, respectively (Figure 12). Because these polygons were rather small for such a strong flier and they did not encompass adjacent similar habitat, we created a predictive breeding season home range map to determine the potential extent of the jays' breeding season home range. The predictive breeding season home range map for pinyon jays encompasses 2414 ha of pinyon pine woodland on NOP (Figure 13).

### ***Pinyon Jays 2005***

Pinyon jays nested from April-June 2005 in the colony area (denoted by green points on Figure 11). On 29 April, we heard begging calls in the colony site, which suggests that males were feeding incubating females on the nest. By the first week of May we observed birds flying into the site for brief visits, then flying out the way they came, again suggestive of males feeding females. On 10 May we observed a pair with nesting material, and we found one active nest on 20 May.

On 24 May we found a group of eight to ten flying and non-flying fledglings with their parents, 15-20 birds in all, in pinyon trees on both sides of the road at the colony site. We also observed flying and non-flying fledglings on 25 May in the same area. On 15 June we found four new fledglings with bright pink bill marks, at least two of which were flying poorly. On 18 June, we found at least eight new fledglings, accompanied by adults. We concluded that the birds fledged young in two batches, first in the third week of May and again in the second week of June. Based on our observations of nesting adults and counts of fledglings with adults, we estimated that about 18 pairs produced an average of 2 fledglings each (about 72 birds), which is consistent with our count of 70-75 birds flying in a flock on 26 July. On 12 August 2004 we had observed 75 birds in the same area. However, on 19 August 2005 we counted 90 birds in the flock, which suggests that the flock was slightly larger than we estimated or that outside birds had joined the flock. In Arizona, dispersal by yearling pinyon jays typically begins in August and peaks in September (Marzluff and Balda 1992).

We trapped 16 pinyon jays on 23, 24, and 26 July 2005. Two trapped birds were second-year or adult (SY/ASY) birds (both males) and 14 were hatch-year (HY) birds. Although it is not possible to definitively determine sex of hatch year birds (Pyle 1997), we assigned tentative sexes to the HY birds (seven males, seven females), based on a combination of size measures we had previously found effective in sexing pinyon jays (Marzluff and Balda 1992, Johnson unpublished data). We also attached radio transmitters to five birds, two probable SY males and three HY birds (two probable males and one probable female).

Each week from 26 July until 2 September, we followed the transmitters to find the flock. The birds were usually found in or near a large canyon northeast of the colony site (orange points on Figure 11). The flock was sometimes dispersed over an area of a few square kilometers, but birds were typically found in areas with green cones (Figures 11, 12, 14). We were frustrated in our attempts to find cache sites, as birds alarm-called and left the immediate area when we arrived. By 2 September, transmitter signals were too

weak to detect the flock at a distance, but we found the flock in the same canyon on 16 September.

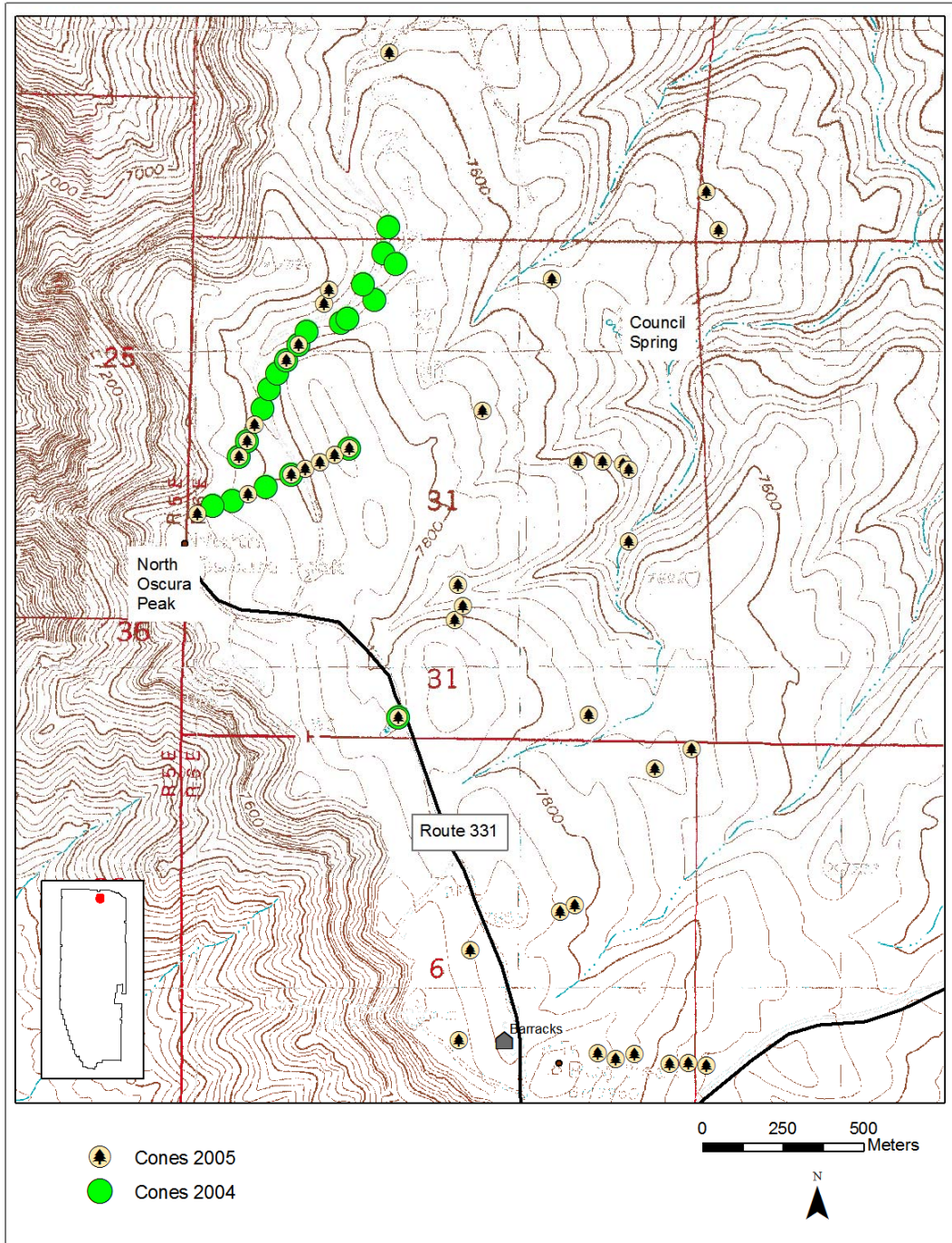


Figure 14. Locations of cone-bearing trees, 2004 and 2005.

On 23 September, we visited Red Rio, where we found a flock of 110 birds harvesting cones on a pinyon-covered west-facing slope and flying back and forth, apparently caching to the northwest. We believe the Red Rio flock to be a different flock, because of its size and because the NOP flock was at NOP every time we visited until they left the area on 20 October.

On 20 October, Stan Sessions observed 75-100 pinyon jays at the NOP colony area. The flock was flying in circles, diving, and calling. He noted this unusual behavior. The next day, we searched the study area, including the canyon where the birds had been in September, and found no pinyon jays. We speculate that the unusual behavior was staging behavior and that the flock left the area on 20 October. Stan observed no pinyon jays in the area through the winter, and we found none when we searched on 10 February. We returned to the traditional colony site in April 2006 to determine if the birds had returned to breed (2006 report, currently in preparation).

### ***Tree Transects***

In 2004, we measured 248 trees on five transects. In 2005, we added a sixth, 11-point (44 tree) transect through the nesting colony area. The percent of cone-bearing trees per transect varied from 3.8% to 52.1% (Table 1), and the mean number of cones counted on individual trees (in three binocular fields) varied from 0 to 46.67. Means of tree measures varied among the five transects (Table 1).

We performed one-way ANOVAs to investigate differences among transects on the tree measures. Distance, height, vigor, and average cone number differed significantly among transects, but root crown diameter (RCD) did not (Tables 1, 2). Individual comparisons among transects showed that transects 7 and 8 differed from transects 0, 2, and 5 in

Transect	Dist. (m)	Ht. (m)	Diam. Root		Cone Avg.	% Trees w/ Cones	Trees/100m <sup>2</sup>	N
			Crown (cm)	Vigor (1-5)				
0	6.48	3.41	18.76	4.61	2.59	52.1	2.38	48
2	6.18	3.59	20.22	4.67	1.81	47.9	2.62	48
5	5.13	4.21	19.43	4.22	1.54	17.3	3.80	52
7	2.75	4.89	17.64	4.31	0.10	14.6	13.26	48
8	2.70	4.53	17.14	3.65	0.03	3.8	13.72	52
9	3.75	4.78	19.57	3.35	0.05	9.1	14.03	44
							<b>Total</b>	248.00

**Table 1. Mean measures for all trees, by transect, 2004. Transect 9 data were collected in 2005.**

Measure	Anova F	Anova P	Significant Differences
Distance	9.10	<0.001	0, 2, 5 vs. 7, 8
Height	3.04	0.018	0 vs. 7
Root Crown	0.58	0.677	none
Vigor	10.2	<0.001	0, 2, 5, 7 vs. 8
Average Cone	3.97	0.004	0 vs. 7, 8

**Table 2. ANOVAs comparing five transects on all 2004 tree measures. Last column indicates significant comparisons among transects.**

Measure	Anova F	Anova P	Significant Differences
Vigor	2.44	0.043	0, 2 vs. 9 2 vs. 0, 5, 7, 9
Average Cone	4.66	0.001	8 vs. 9

**Table 3. ANOVAs comparing six transects on 2005 vigor and average cone measures. Last column indicates significant comparisons among transects.**

distance between trees and from transect 0 in average number of cones. Transect 7 had significantly taller trees than transect 0, and trees on transect 8 were significantly less vigorous than trees on the other four transects. In addition, we detected no pinyon jays on transects 7 or 8 during tree data collection.

In 2005, we re-measured vigor and cone production on the five old transects and measured the new transect 9 for the first time (Table 3). The overall ANOVA showed that transects differed significantly on both measures. In individual comparisons, transects 0 and 2 were significantly more vigorous than transect 9. Transect 2 had more cones than transects 0, 5, 7, and 9, and 8 had more cones than 9.

The 2004 transect comparisons suggested that cone production might be related to tree density or maturity; therefore, we investigated relationships among variables for the entire data set. Mean number of cones recorded per tree was significantly correlated with distance from point to tree, tree height, RCD, and vigor (Table 4). The strongest correlation occurred between number of cones and distance. However, tree maturity probably also determines cone production. To control for the effects of tree maturity on cone production, we computed partial correlation coefficients between cone production and distance, holding tree size measures constant. The partial correlation of cone and distance, holding root crown constant, was 0.336 ( $P < 0.001$ ). The partial correlation of cone and distance, holding tree height constant, was 0.358 ( $P < 0.001$ ). The partial correlation coefficients were only slightly smaller than the overall correlation ( $r = 0.362$ , Table 3), indicating that the correlation between cone production and tree density occurs regardless of tree size.

	Distance	Height	Root Crown	Vigor
Height	0.06			
Root Crown	0.172*	0.524**		
Vigor	0.184*	0.06	0.11	
Cone	0.362**	0.2*	0.24**	0.183 *

**Table 4. Pearson correlations among 2004 tree measures, \*P<0.01, \*\*P<0.001.**

Predictor	Coef	SE Coef	T	P
Constant	-3.519	1.116	-3.160	0.002
Distance	0.282	0.053	5.300	0.000
Root Crown	0.040	0.024	1.660	0.099
Height	0.189	0.109	1.740	0.083
Vigor	0.442	0.247	1.790	0.074

S = 3.671    R-Sq = 18.6%    R-Sq (adj) = 17.2%

Source	DF	SS	MS	F	P
Regression	4	746.65	186.66	13.85	0
Residual Error	243	3275.42	13.48		
Total	247	4022.07			

**Table 5. Results of multiple regression of average cone number on 2004 distance to center point, root crown, height, and vigor.**

We performed a multiple regression to determine effect of the combined tree variables on cone production. The regression equation was average cone = - 3.52 + 0.282 distance + 0.0395 root crown + 0.189 height + 0.442 vigor (Table 5).

Distance to center point, a measure of tree density, was the only significant variable in the model. However, we also tested the increment in  $R^2$  added by each variable, starting with the one-variable regression of cone number on distance. The addition of root crown added a significant increment in  $R^2$  ( $F=10$ ,  $P<0.005$ ). Height and vigor did not add significantly to the  $R^2$  (height:  $F=2.94$ ,  $0.1<P<0.2$ ; vigor:  $F=3.24$ ,  $0.1<P<0.2$ ). This analysis suggests that tree density is the most important variable in determining cone production, and that tree maturity, as indicated by root crown diameter, also influences cone production (Figures 15, 16).

The distribution of RCDs of all trees suggests that smaller trees (1-10 cm, Figure 17) are under-represented. However, we did not measure trees under 1 m tall. The smallest RCD we recorded was 3.5 cm, and all others were at least 5 cm. Thus, by measuring only 1 m tall trees, we eliminated at least half of the trees in the 1-10 cm RCD size class.

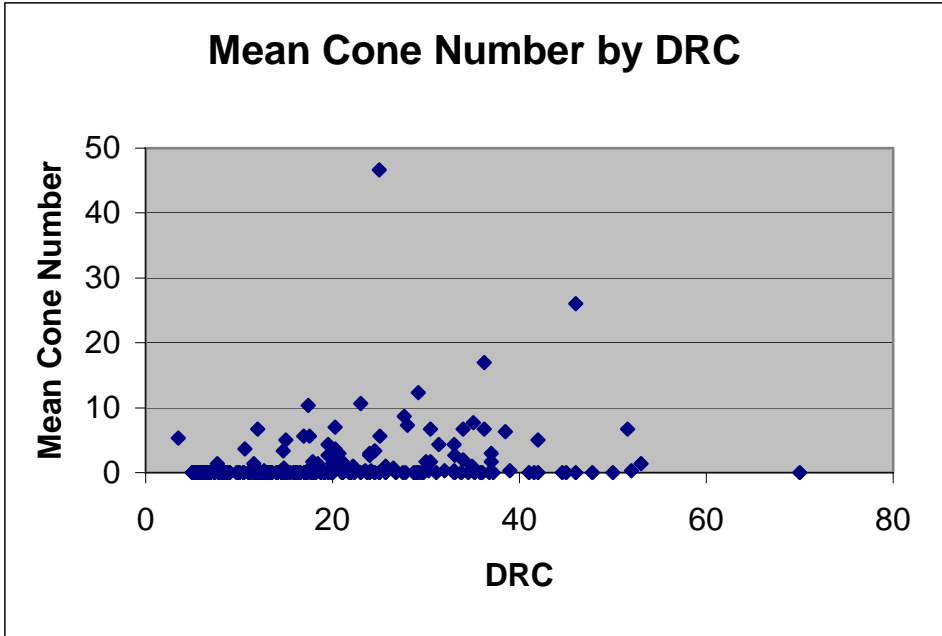


Figure 15. Scatter plot of mean cone number by diameter root crown, 2004.

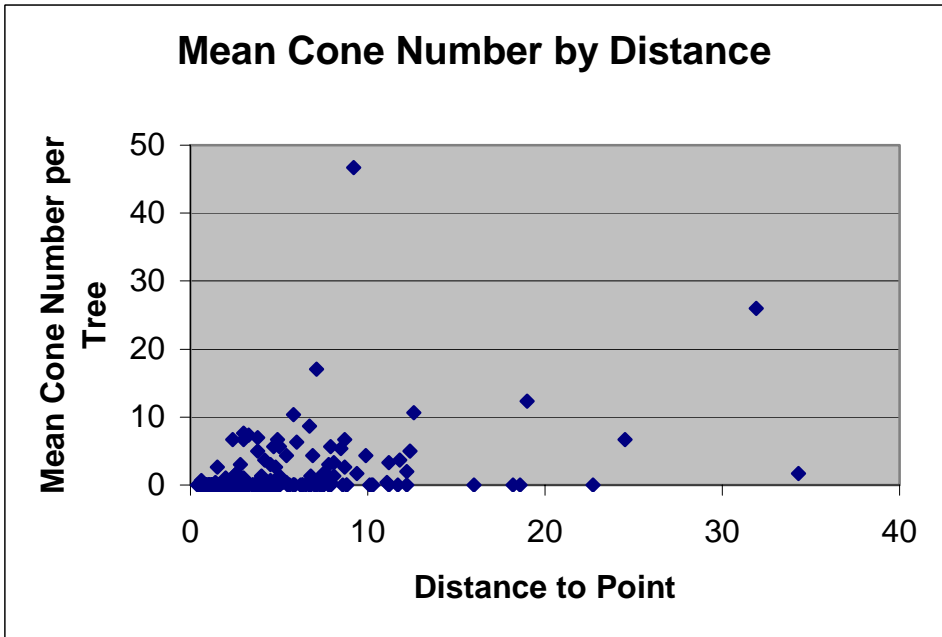


Figure 16. Scatter plot of mean cone number by distance from point to tree, 2004.

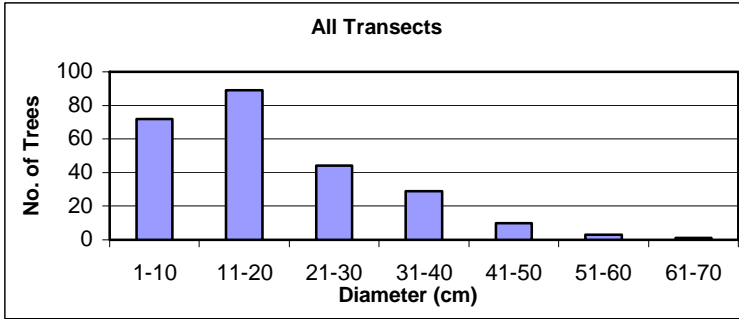
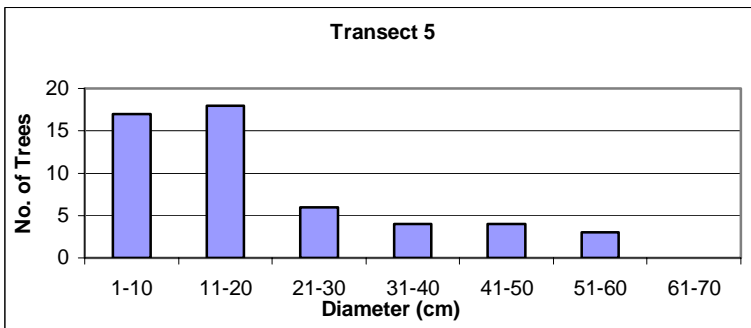
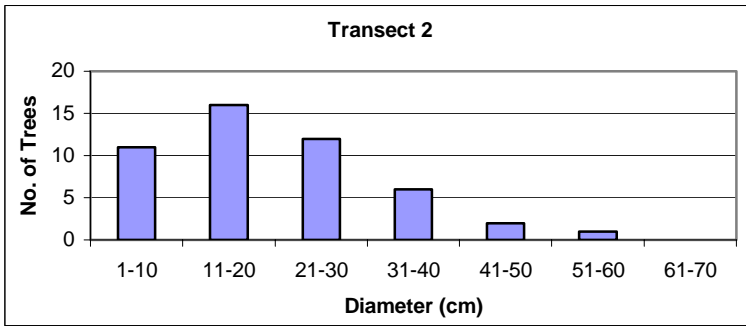
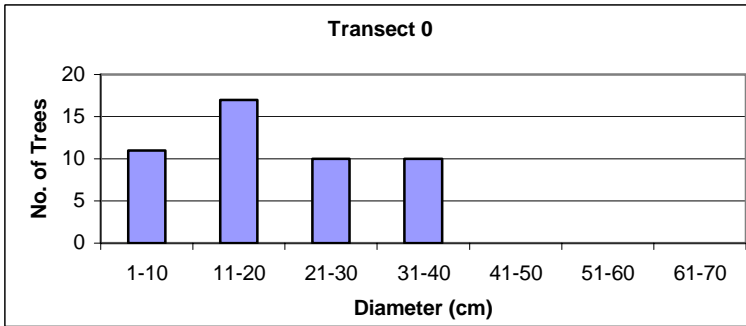
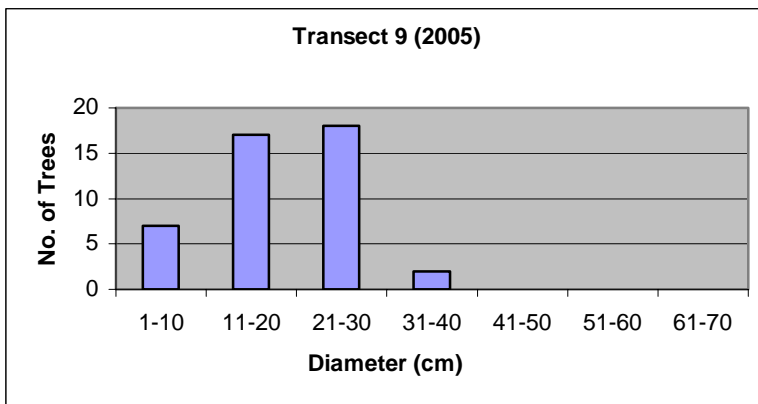
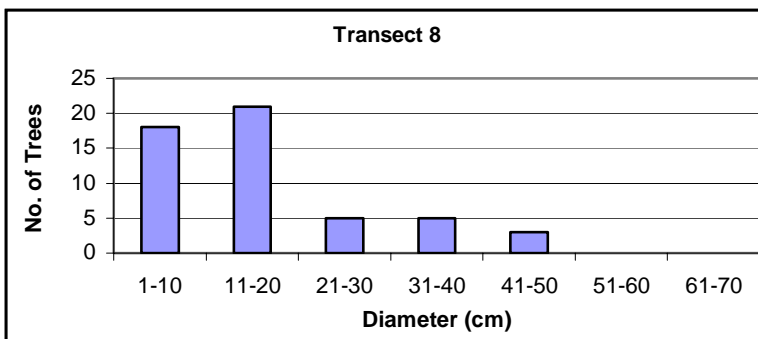
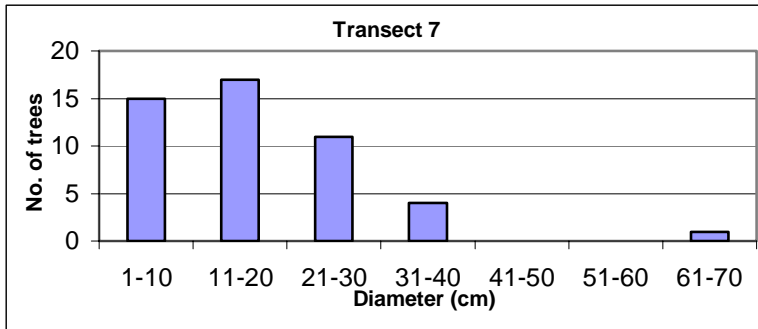


Figure 17. Distribution of RCD on all 2004 transects combined.





**Figure 18. Distribution of RCDs by transect. Transect 9 was measured in 2005, all others in 2004.**

Distribution of RCDs differed somewhat among transects. Transects 0 and 9, for example, were dominated by mid-sized trees, from 11-40 cm RCD and had no trees over 41cm RCD. Transect 7 lacked larger trees in the 41-50 and 51-60 classes, and transect 8 lacked the largest trees in the 51-60 and 61-70 classes (Figure 18).

Because we did not measure any trees smaller than 1 m tall, we defined saplings as 1-3m in height or 5.5-15 cm in diameter. Mature trees are defined as 3-15 m tall and >15 cm



diameter. Transects 7 and 8, which had the highest tree densities, had smaller proportions of saplings, based on height, but this was not true based on root crown (Table 6). This result is consistent with the finding that transect 7 and 8 trees are taller and thinner than those on other transects (Table 1). Transect 9 had the smallest percentage of saplings by both RCD and height and was also the densest transect. In contrast to transects 7 and 8, transect 9 had relatively tall, large-diameter trees, closely packed.

Transect	Saplings by Ht.	% Saplings by Ht.	Saplings by RCD	% Saplings by RCD
0	20	0.42	23	0.48
2	21	0.44	17	0.35
5	23	0.44	27	0.52
7	16	0.33	24	0.50
8	14	0.27	28	0.54
9	8	0.18	14	0.32

**Table 6. Proportion of saplings versus mature trees, by transect. Saplings are 1-3m tall or >15 cm RCD.**

### *Cone Transects*

To determine whether trees near roads and drainages produced more cones than trees farther from these disturbances, we performed correlation analyses between number of cones and distance from the drainage on cone transects. The correlation between distance and number of cones was not significant ( $r=-0.209$ ,  $P=0.092$ ). Cone number might differ among transects due to orientation of the transects, with drier, south-facing transects expected to have fewer cones. We therefore performed correlations on subsets of the data, such that N/NW-, S/SE-, W-, and E-facing slopes were analyzed separately. With Bonferroni adjustment to account for multiple tests ( $\alpha=0.0125$ ), none of the correlations was significant ( $r=-0.321$ ,  $P=0.110$ ;  $r=-0.119$ ,  $P=0.662$ ;  $r=-0.591$ ,  $P=0.043$ ;  $r=0.248$ ,  $P=0.437$ , respectively).

### *Comparison of 2004 and 2005 Tree Measures*

For the five transects measured in both years, we compared differences between years in vigor and cone production. For all transects, mean vigor measures were higher in 2004 than in 2005 (Table 7). Between-year differences in vigor were barely significant for all transects combined ( $F=2.66$ ,  $P=0.042$ ). Individual comparisons showed the between-year change for transect 8 to be significantly smaller than that for transects 0 and 2.

Mean cone production was higher in 2004 on some transects and higher in 2005 on others (Table 7). Thus, there was no significant trend in cone production between the two years.

Transect	Mean Vigor 04-05	St Dev Vigor 04-05	Mean Cone 04-05	St. Dev. Cone 04-05
0	0.62	0.38	1.31	2.61
2	0.63	0.61	-1.83	4.96
5	0.34	0.60	0.76	5.39
7	0.48	0.31	-0.65	0.93
8	0.04	0.64	-2.28	2.26

**Table 7. Mean differences in vigor and cones by transect between 2004 and 2005.**

### ***Stand Structure***

Our point quarter measurements and tree height estimates provided data to evaluate the fire (stand structure) map for NOP. Total canopy cover estimated by Muldavin et al. (2004) using photo interpretation was significantly negatively correlated with average distances between trees at our transect points ( $r=-0.63$ ,  $P=0.005$ ) and significantly positively correlated with average percent of tall trees at our points ( $r=0.55$ ,  $P=0.018$ ). This suggests that the total canopy cover values on the map are a relatively accurate representation of stand density and percent tall (emergent) trees.

If percent emergent canopy values from the stand map were accurate, they should be related to the percent of tall trees in the area, but the two were not significantly correlated, suggesting that the emergent canopy values from the Muldavin et al. (2003) map are not as reliable as the total canopy values.

## **Discussion**

### ***Pinyon Jays***

On WSMR, pinyon jays appear to be locally abundant in response to ripe pinyon cones. We have detected three apparent flocks, a small one west of Hardin Ranch, and two larger flocks at Red Rio and on NOP. Although the Red Rio flock was large enough to merit study, access to Red Rio is limited to September. We therefore focus on the NOP flock for this study.

The NOP flock was present during the late spring through summer in 2004 and 2005 and bred there in 2005. The birds left the area for the winter in both years, during the second or third week of September in 2004 and on 20 October 2005. In both years, pinyon jays harvested the limited numbers of pinyon seeds produced in their home range and apparently cached some of those seeds. We observed more caching behavior in 2004 than in 2005, perhaps because cone production was more concentrated along roads and drainages, and we were able to observe birds making repeated trips to a ridge east of the cone area, presumably for caching.

The NOP flock has left the area two winters in a row, and we have little idea where they spend the winter. We had hoped to detect larger-scale movements using radio transmitters, but this may be more difficult than we originally thought. Pinyon jay flocks can move hundreds of miles when conditions are poor, and there are several mountain ranges within the range of such strong fliers; e.g., Sacramentos (SE 65 km), Gallinas (NE 75 km), Magdalenas (NW 75 km), Capitans (E 90 km), and San Andres (SSW 95 km). We found the transmitter range to be 1-1.5 km, depending on terrain, clearly too short to allow detection of large movements. Searching from the air could increase this distance. If funding is renewed, we may attempt to apply transmitters closer to the time of dispersal and track dispersing birds from the air. Given the difficulty of predicting when the birds will depart, the surest way to understand winter movements may be to band large numbers of jays and hope for band returns. Given the huge potential area the birds could cover in winter, this method also presents slim odds.

We counted about 75 birds before dispersal in 2004, but found only about half that many breeding adults in the spring of 2005. This suggests that at least half the flock disappeared over the winter of 2004-2005, possibly more than half if young birds from other flocks dispersed into the flock and balanced losses. If high mortality and dispersal rates are not balanced by recruitment, the NOP flock can be expected to decline. It will be interesting to see if the pattern of over winter mortality holds in 2006. If so, we would expect about 40 ( $\pm 5$ ) birds to return in 2006.

High recruitment is thought to occur in pinyon jay flocks only in pinyon mast years, but pinyon jays do reproduce in non-mast years, based on alternative food sources such as insects (Ligon 1978, Marzluff and Balda 1992). Although we do not have precise recruitment numbers, we estimate that about two fledglings per breeding pair were recruited into the NOP flock during late May and mid-June 2005. Given the current dry spell and obvious pinyon mortality near NOP in recent years, it may be years before the NOP flock sees a bumper pinyon crop. It is important to continue to monitor the relationship between pinyon tree productivity and pinyon jay recruitment.

### ***Trees***

In 2004, variation occurred across the study site in tree density, stand structure, tree vigor, and cone production. In a year when cone production was limited, production was lowest on the two densest transects (7 and 8), and trees were least dense on the transect with the highest cone production (0). Tree vigor was significantly lower on the densest transect (8). Including all transects, the most important predictor of cone production was tree density, but RCD, indicating age, also added a significant increment to the overall  $R^2$ . Thus, it is not clear whether transects 7 and 8 produced fewer cones because the trees were more crowded or because they were younger. To discriminate between the relative effects of density and maturity, we will need precise age data for the trees at the study site.

The relatively high morbidity and mortality on transect 8 was apparently due to competition among trees. However, transect 8 was also the furthest south and nearest to other areas of pinyon disease, which suggests that bark beetles or other disease may simply be moving northward. It comes as no surprise that pinyon jays were detected on all transects except 7 and 8, the two transects with almost no cone production.

Looking at all transects combined and taking into consideration that we did not measure all trees in the 1-10 cm category, the age structure of pinyon trees on the entire study site appears to approximate a J-shaped distribution, as expected. However, the variation among transects indicates that age structure is not uniform across the study site. The absence of larger trees on transects 0, 7, and 8 is notable. Potential causes for the absence of particular age classes are higher mortality, lower seed production, or lower establishment rates. Any of the three could occur due to drought. In addition, failure of an age cohort to establish could result from poor seed dispersal. Thus, fluctuations in pinyon jay populations at the study site could conceivably affect establishment rates of cohorts. Age data for trees would provide more insight into why stand structure varies

spatially and the importance of age structure versus density in determining pinyon pine health, mortality, and cone production. All three can ultimately impact pinyon jay populations.

Analysis of cone transect data did not yield significant results, but, as noted by Ligon (1978) it still appears that trees situated near roads and drainages produce more cones than trees located in the middle of an undisturbed patch, presumably because water drains into these areas and trees are less crowded there. Cone transects were done in September after the jays had been harvesting cones for several weeks; thus cone counts may have under-estimated the actual numbers of cones produced.

Our dataset of tree measurements, along with Muldavin et al.'s (2003) stand structure map, make clear that stand structure is quite variable across the relatively small area of the study site. The area on NOP has been little impacted by fire suppression or grazing and as such is a relatively natural pinyon woodland (Muldavin pers. comm.). The presence of extremely large trees is evidence that historical fire, if present at all, has been confined to small patches. Livestock grazing has not historically been heavy at NOP, but it has not been permitted at NOP for over 60 years. Where areas of small, dense, similar-sized trees occur, they appear to be self-thinning. Thus, although stand structure varies across the study area, there is no reason to believe that management of the woodland on NOP would be desirable. One year's data suggest that larger, more sparsely situated trees produce more cones. However, given the variable nature of pinyon cone production, many years of cone data may be required to gain an understanding of the optimal stand structures for pinyon jays.

### ***Digital Aerial Photos***

High-resolution, digital aerial photos show good potential for documenting pinyon pine mortality over large landscapes. The extent of mortality on the 2003 photos appeared limited compared to that observed on the ground in 2004, probably because pinyon mortality is more widespread now than it was when the images were made. Thus, the 2003 imagery provides a good baseline record of the health of the pinyon-juniper woodland on NOP in 2003, before significant mortality had occurred in the area.

Our tree data suggest that pinyon mortality was still limited on NOP in 2004. It will be interesting to compare vegetation changes between the 2003 and subsequent imagery. High resolution, color, digital orthophoto quadrangles taken in 2005 became available in late 2006. We will attempt to acquire this imagery for analysis in early 2007.

### ***2006 Goals***

Funding for 2006 is currently uncertain. If funding is not renewed, we will at least attempt to determine flock size in early summer, fledgling recruitment, and cone production in 2006. If funding is renewed, we will trap and band more birds and apply radio transmitters later in the season, in an attempt to determine winter movements. If we are able to trap in 2006, we will use a different trapping method, a modified Australian crow trap (Johnson et al. 2000). We expect crow traps to be more effective at retaining birds than the walk-in traps, from which some jays were able to escape.

At this writing (February 2006), small green cones are abundant on many trees at the study site. Whether or not these cones develop will depend on weather in the coming months. At the same time, spreading pinyon mortality threatens the study site and the birds. Whatever the outcome, 2006 should be an interesting year for pinyon jays at NOP.

Our access to the study site is limited by the WSMR testing schedule. Even with increased funding, we would probably be unable to collect data regularly enough to find all nests and monitor nest success for the entire flock. Fortunately, pinyon jay fledglings are very conspicuous, which helps compensate for limitations in funding and study site access.

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