Abundance and Detection Probabilities of Florida Scrub-Jays at Merritt Island National Wildlife Refuge Using Spatially Replicated Counts

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Introduction

Merritt Island National Wildlife Refuge (MINWR) has conducted an annual Florida scrub-jay (*Aphelocoma coerulescens*) survey since 1999. The U.S. Fish and Wildlife Service began the survey in conjunction with a scrub-restoration and maintenance program, which relies on mechanical treatment and prescribed burning of scrub-oak habitats. The original objectives of the survey were to monitor changes in scrub-jay abundance, primarily in areas where habitat restoration and management were being conducted.

Scrub-jays at MINWR and adjacent government properties constitute a key population within the species' shrinking range. MINWR contains almost 8800 ha of potential scrub-jay habitat, but only about 13% of this was considered in optimal condition in 2000 (D. Breininger, Dynamac Corp., unpub. data). Little fire management occurred on MINWR prior to 1981, when extensive

wildfires prompted managers to accelerate a program of prescribed burning to reduce hazardous fuel loads (Adrian 2003). Since 1993 more emphasis has been placed on restoration and maintenance of wildlife habitat, but refuge managers face constraints on the timing and location of burns due to the associated fire and smoke hazards to Kennedy Space Center, which owns most land associated with the refuge. Within these constraints, managers must decide what frequency and intensity of fire in a collection of management units will best ensure the long-term persistence of the refuge's scrub-jay population. These decisions are difficult because of an incomplete understanding of fire dynamics, plant community succession, and the demographic responses of scrub-jays to controlled and uncontrolled environmental factors.

A cost-effective monitoring program for scrub-jays and their habitats is therefore needed to support effective management decisions across the breadth of scrub-jay habitats at MINWR. However, it is not clear whether the extant monitoring program is capable of detecting changes in abundance at the refuge scale or at smaller scales as a function of habitat-management activities. A thorough review of the survey protocol therefore seemed warranted. Thus, our objectives were:

a) to evaluate the adequacy of the existing survey protocol for estimating temporal and spatial patterns in scrub-jay abundance; and
b) to recommend revisions needed to correct any design and analysis problems, and to suggest modifications that might be necessary to support an adaptive program of prescribed burning of scrub-jay habitat.

Design and Evolution of Survey

MINWR originally established approximately 300 sample points for the purpose of monitoring variation in jay abundance. Permanent sample points were established along logging roads, fire breaks, and trails specifically created for the survey (referred to as "transects") within areas having good-quality scrub-jay habitat. Sample points were originally placed at 150-meter intervals along transects using a portable GPS unit, and then over-laid on satellite imagery of the refuge using ArcView (Fig. 1).

Survey protocol generally followed that prescribed by the U.S. Fish and Wildlife Service Southeastern Regional Office (http://www.fws.gov/northflorida/Scrub-Jays/Documents/General-FSJ-Survey-Protocol-041006.pdf). Two to three-person teams conducted surveys in the morning after sunrise and before noon during March or April. Counts of jays were tallied at each point regardless of the distance at which birds were observed (as opposed to fixed-or variable-radius point counts). In an attempt to attract jays (and thereby increase their detectability), survey routes were walked and at every sample site a cassette tape with territorial calls was played. Recordings were broadcast for at least 30 seconds and up to two minutes depending on whether any scrub-jays were observed. Surveys are generally conducted on calm, clear days, with winds <8 mph.

The number of jays and jay families (groups) were recorded at each sample point. Repeat observations of jays from previous sample points were excluded if they could be identified as

such. According to Fitzpatrick (1991) the average family includes a breeding pair and a helper, but groups can routinely be smaller or larger. A review of the literature and discussions with scrub-jay experts (D. Breininger, Dynamac Corp., pers. comm.) led us to believe, however, that distinguishing between two families may be extremely difficult for insufficiently trained observers on short forays into the field. Therefore, we restricted our evaluation to counts of individual jays.

Point counts usually are characterized by a large number of zeros and small counts (Royle 2004), as is the case with scrub-jays at MINWR where 64% of all counts were zero (Fig. 2). Too often, point counts are analyzed without regard to the underlying detection process that generated them. For example, do zero counts represent the absence of jays at sample sites or merely the failure of the observer to detect them? In response to this bias, counts are sometimes treated as an index to abundance by assuming that detection rate is constant. Let C be the count of animals from a survey, with β the probability of detecting an animal given that it is present. The expected value of the count statistic then is

$$E[C] = \beta N$$

where N is the actual population size. If $\beta < 1$ then the count C is proportional to (i.e., an index of) N *if and only if* β is constant (Williams et al. (2001:244). Sampling protocols are usually standardized in the hopes of minimizing variation in detection rate. However, many biotic and abiotic factors may affect detection rate and these factors often are unpredictable and uncontrollable. Many practical methods are now available for estimating detection rate and surveys that lack this feature provide only weak (and occasionally spurious) inference.

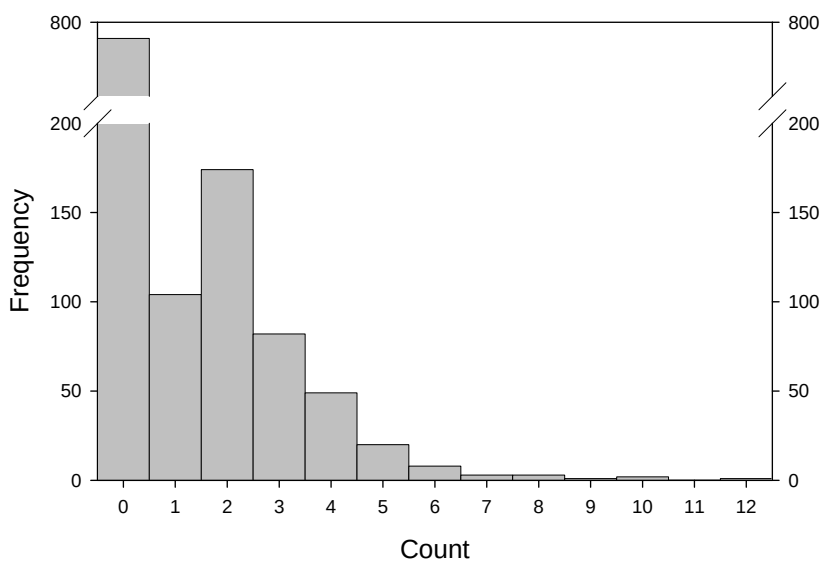

Fig. 2. Frequencies of scrub-jay counts at sample sites at MINWR, pooled over point counts conducted during 1999-2002.

Counting animals without regard to their individual identity is a convenient means of sampling and forms the basis of many important monitoring programs. These surveys often yield a number of spatially indexed counts, which if temporally replicated, can provide estimates of both detection probability and actual abundance (Royle 2004). In 2003, MINWR sampled a subset of points on four occasions over a relatively short period of time (Table 1). These replicate counts were motivated by the desire to assess within-site variability in counts, but at the time there was no expressed intent to estimate detection probabilities. In 2004, the number of temporal replications was reduced to three, although the number of replicated sample points was increased (Table 2). Based on a preliminary evaluation of the scrub-jay survey, MINWR increased the number of replicate point counts again in 2006, eliminated all un-replicated sampling sites, and spaced sample sites a minimum of 450m apart (Fig. 3).

Table 1. Number of sample sites (R) and dates (T) on which replicate counts of scrub-jays were conducted at Merritt Island National Wildlife Refuge, 2003-2006.

Year	R	T_1	T_2	T_3	T_4
2003	65	Mar 17-20	Mar 25	Apr 3-4	Apr 7-10
2004	89	Mar 23	Mar 30	Apr 6	
2005	89	Mar 25	Mar 29	Mar 31	
2006	125	April 25	April 26	April 27	

Table 2. Number of point counts used for monitoring abundance of Florida scrub-jays at MINWR.

Year	Un-replicated point counts	Replicated point counts	Total
1999	289	0	289
2000	315	0	315
2001	316	0	316
2002	316	0	316
2003	251	65	316
2004	245	89	334
2005	227	89	316
2006	0	125	125

A critical assumption of point counts is that sampling areas do not overlap; i.e., the same bird is not counted at more than one site during a sampling occasion. Unfortunately, we could not know the extent to which observers were able to keep track of birds which were counted at previously visited sites. We believed the potential for double-counting of jays was relatively high due to the proximity of sample points so observers were asked to record sightings of individually marked (color leg-banded) individuals at each sample site in 2005 and 2006. Observers were asked to record all marked individuals at every site regardless of whether they had been seen at previous sites.

Because we believed that detection rate might be related to vegetation height, observers were asked in 2004 and 2005 to visually classify scrub height in the vicinity of the sample site as short, optimal, tall, or mixed. Short scrub included all vegetation <120 cm tall, while optimal had short (< 120cm) and medium-height (120-170 cm) scrub. Tall denoted an entire area with vegetation >170 cm. A combination of either tall and short, or tall and medium-height scrub was classified as mixed.

Modeling Scrub-Jay Counts

We used methodology described by Royle (2004) and Dodd and Dorazio (2004) to estimate both detection probability and abundance of scrub-jays at MINWR. We let x_{ij} denote the count of jays at site $i = 1, 2, \ldots, R$ on sample occasion $j = 1, 2, \ldots, T$, and then made two distributional assumptions:

$$\left[x_{ij} \mid N_i, \theta\right] \sim Binomial\left[N_i, \theta\right],$$

with probability mass function $f\left(x_{ij} \mid N_i, \theta\right)$, and

$$\left[N_i \mid \lambda\right] \sim Poisson\left[\lambda\right],$$

with probability mass function $g\left(N_i \mid \lambda\right)$, and where θ is the probability of detection, N_i is the number of jays available for detection at site i, and λ is the mean abundance of jays over all sample sites (Dodd and Dorazio 2004).

We used Bayesian methods to estimate detection probability and jay abundance by first defining the likelihood function:

$$L\left(\theta, \lambda \mid X\right) = \prod_{i=1}^{R} \left\{ \sum_{N_i = \max\left(x_{ij}\right)}^{\infty} \left(\prod_{j=1}^{T} f\left(x_{ij}; N_i, \theta\right) \right) g\left(N_i; \lambda\right) \right\}$$

A non-informative, uniform prior distribution was used for detection probability $\pi(\theta)$, and a vague normal prior was used for the log of jay abundance $\pi(\lambda)$:

$$\theta \sim Uniform\left(0,1\right)$$
$$\log\left(\lambda\right) \sim Normal\left(0,100\right)$$

The joint posterior distribution for parameters θ and λ is:

$$\pi\left(\theta, \lambda \mid X\right) = \frac{\prod_{i=1}^{R} \left\{ \sum_{N_i = \max\left(x_{ij}\right)}^{\infty} \left(\prod_{j=1}^{T} f\left(x_{ij}; N_i, \theta\right) \right) g\left(N_i; \lambda\right) \right\} \pi\left(\theta\right) \cdot \pi\left(\lambda\right)}{h\left(X\right)}$$

where $h(X)$ is the normalizing constant that depends only on the $R \times T$ matrix of point counts X.

For the two years in which scrub height was recorded, we modeled the detection probability at site *i* as dependent on scrub height, so:

$$\theta_i = z_i \alpha$$

where z_i denotes an indicator of scrub height at site *i* such that $z_i = [1 \quad 0]$ for short and optimal scrub (hereafter, short) and $z_i = [0 \quad 1]$ for mixed and tall scrub (hereafter, tall), and the detection probabilities are given by $\alpha = \begin{bmatrix} \alpha_{short} \\ \alpha_{tall} \end{bmatrix}$. Thus, the joint posterior distribution is:

$$\pi(\alpha_{short}, \alpha_{tall}, \lambda \mid X, z) = \frac{\prod_{i=1}^{R} \left\{ \sum_{N_i = \max(x_{ij})}^{\infty} \left(\prod_{j=1}^{T} f(x_{ij}; N_i, z_i, \alpha) \right) g(N_i; \lambda) \right\} \cdot \pi(\alpha_{short}) \cdot \pi(\alpha_{tall}) \cdot \pi(\lambda)}{h(X)}$$

All analyses were run in public-domain software, using *R* and the *R2WinBUGS* package to access *WinBUGS*. Samples of the posterior distributions of θ or α, and λ were obtained using 60,000 iterations of one Markov chain, a "burn-in" of 10,000 iterations, and then thinning the remaining samples by five (for a net sample size of 10,000).

Detection and Abundance of Scrub-Jays

Using the model in which the probability of detection was assumed to be constant, estimates of detection rate ranged from 0.17 to 0.25 during 2003-2006 and the upper 95% credible limit was always ≤ 0.31 (Table 3). We were surprised by these low rates given the overt territorial behavior of scrub jays and the relatively open habitat (we occasionally observed scrub-jays at distances >100m). Therefore, we believe our results suggest that the effective sampling area at each site was relatively large, although the area cannot be estimated without additional information.

The estimated mean number of jays per sample site under the constant-detection-rate model ranged from 4.39 in 2003 to 11.82 in 2005. The estimate of mean abundance in 2006 suggests that there were a *minimum* of 999 (95% CI: 774 – 1322) scrub-jays present on MINWR during the time of the survey ([# sample sites = 125] · [λ]). Precision of the estimates was sufficient to detect an increase in jay abundance during 2002-2005. However, this conclusion should be viewed cautiously because:

- inference only applies to the sample sites, which were not located randomly with respect to scrub-jay habitat and which changed to some extent over the time frame; and

- we believe there was a relatively high potential for individual jays to be counted at more than one site, especially during 2003-2005 when sample sites were only 150m apart.

A disadvantage of the current protocol is that it is not possible to generate an estimate of total abundance (rather than a minimum) because the area sampled per site is unknown. The usual remedy is to use fixed-radius point counts or to measure distances to detected birds to estimate density, and then estimate total abundance by area expansion (Bibby et al. 2000). However, we don't believe this is feasible because jays move in response to the observer and detection is often a consequence of this movement. Given the response by jays to the observer, we see no alternative to the current point counts. Nonetheless, λ is still an estimate of mean abundance per sample site, and can be useful in studies involving temporal changes and their underlying causes if the closure assumptions of the model are met (Royle 2004).

Table 3. Estimated detection rate (θ) and abundance (λ) (posterior means and 95% credible intervals) of Florida scrub-jays at MINWR. Estimates were based on *i* point counts, replicated *j* times.

Year	$\bar{\theta}$	95% CI (θ)	$\bar{\lambda}$	95% CI (λ)
2003	0.22	0.16 – 0.28	4.39	3.30 - 5.92
2004	0.22	0.16 – 0.29	6.77	5.08 - 9.14
2005	0.17	0.11 – 0.23	11.82	8.25 - 16.62
2006	0.25	0.18 – 0.31	7.99	6.19 - 10.58

For years when scrub height was recorded at sample sites (2004 and 2005) we estimated detection rates for the two classes of scrub height. There was broad overlap of the posterior distributions of detection rate for the two scrub–height classes (Table 4). This result was somewhat unexpected and may have more to do with inconsistencies in the way in which observers classified scrub height in the vicinity of the sample sites than a true lack of difference in detection rate. In any case, we have begun to investigate remote-sensing methods (e.g., low-level aerial photography) to more consistently and accurately classify scrub height.

Table 4. Estimated detection rates (posterior means and 95% credible intervals) of Florida scrub-jays at MINWR in relation to scrub-height classes. Estimates were derived from three replicates of 89 point counts.

Scrub height	2004		2005	
	$(\bar{\alpha})$	95% CI (α)	$(\bar{\alpha})$	95% CI (α)
Short-optimal	0.23	0.17 - 0.30	0.16	0.11 - 0.22
Mixed-tall	0.22	0.17- 0.29	0.12	0.08 - 0.17

Survey Design Considerations

Model assumptions

The model we used for estimating detection rate and abundance is based on the assumptions that (i) local (i.e., site-specific) populations of jays were distinct (i.e., non-overlapping) and closed to demographic processes such as recruitment, mortality, and movement during the sampling period; (ii) there was a random distribution of jays throughout the sampled area, and (iii) there was no double-counting of birds. We were concerned about possible violation of these assumptions.

In 2003 there was an average of 2.2 (range: 1 -16) sampling sites per scrub-jay territory, based on maps of 59 jay territories supplied to us by Dynamac Corporation (D. Breininger, pers. comm.) (Fig. 4). We believed this increased the potential for double counting as jays of the same family moved among different stations to defend their territory. Even if double counting were not a problem, movement of jays among stations represents a violation of the closure assumption. Therefore, we modified the survey in 2006 to increase the minimum distance between stations to 450 meters and thus decrease the mean number of sampling stations per territory to approximately one. We also conducted the survey later in the breeding season when jays are more sedentary (D. Breininger, pers. comm.)

In 2005, observations of marked jays resulted in 121 sightings deemed acceptable for analysis. Some records were discarded because they were incomplete (i.e., labeled as missing one or more leg bands), the sequence of bands on the jay's legs was not clear, or there was uncertainty about leg-band color. We emphasize that errors could remain in the 121 records we analyzed because most were collected by untrained observers and accurate reading of leg bands is difficult even for those with experience (D. Breininger, Dynamac Corp., pers. comm.). Of the 121 sightings of marked jays, 59 were of individuals observed on only one occasion. Twenty-four individuals were observed on multiple occasions, with the majority (15) being observed twice. One individual was observed 9 times at 9 consecutive stations.

In 2006, observations of marked jays resulted in 160 sightings deemed acceptable for analysis. The 2006 data are deemed more reliable because more training was provided to observers. Of the 160 sightings of marked jays, 99 were of individuals observed on only one occasion. Sixty-one individuals were observed on multiple occasions with 30 being observed twice, 30 being observed on three occasions, and one observed on four occasions.

We used a Chi-square test of homogeneity to determine whether the greater distance between sample sites in 2006 than in 2005 was successful at reducing the potential for overlapping sample areas and for double-counting (Table 5). The test yielded a $\chi^2 = 44.2$ ($P = 1.4 \times 10^{-9}$) and thus we concluded that the proportion of re-sightings of the same individuals at different sites was lower in 2006. This result suggests that the closure assumptions of the model were better met with changes in sampling protocol, although it appears that some overlap in sample area remains (a third of re-sightings in 2006 were at different sites).

Table 5. Observed (bold) and expected counts of individually marked scrub-jays at sample sites on MINWR in 2005-2006. Expected counts were derived under the assumption that the proportion of jays re-sighted at the same and different stations was the same in both years.

Individual jays re-sighted at:	2005	2006	Total
Same stations	**0** 16.06	**42** 25.94	**42**
Different stations	**39** 22.94	**21** 37.06	**60**
Total	**39**	**63**	**102**

Selection of sample sites

In evaluating the selection of sample sites, we relied on a classification of habitat suitability at a scale the size of an average scrub-jay territory (10 ha). The classification and mapping was conducted by Dynamac Corporation and was provided to us for use in this project and for other scrub-jay management activities. Primary (1º) habitats include oak scrub on well drained-soils and function as population sources under optimal fire regimes. Secondary (2º) habitats are dominated by oak-palmetto scrub and have at least one scrub ridge that is ≥0.4 ha, but that do not overlap well-drained soils. These habitats can serve as sources or sinks depending on fire regime and other factors. Tertiary (3º) habitats are dominated by palmetto-oak scrub, do not have any scrub ridges that are ≥0.4 ha, and do not overlap well-drained soils. These habitats are usually sinks and may undergo considerable fluctuations in population size if they are occupied. Tertiary (4º) habitats are dominated by palmetto with few or no oaks and cannot sustain scrub-jay populations, although jays may occasionally occupy them.

The 137 management units at MINWR intersect 2,350 10-ha square plots laid out on a regular grid (Fig. 2 and 3). Of the 137 management units, 120 intersect jay habitat classified as 1º, 2º, 3º or 4º. Tertiary habitat was the most abundant type (46%), followed by primary habitat (23%) (Table 6). Sample sites were not allocated proportionally by habitat type, with 1º & 2º habitat accounting for 94% of all sample sites during 2003-2005.

In 2006 we revised the survey to reduce the potential for double-counting and to help match the percentage of habitats to the percentage of habitat represented at sampling sites. The percentage of sample sites in 1º and 2º habitats was decreased to 82% and the percentage of sample sites in 3º and 4º habitats was increased to 18%. Also, new sampling stations were added and all sites were located such that they were a minimum of 450 meters from each other.

Table 6. Distribution of scrub-jay sample sites relative to habitat availability as classified by 10-ha square plots laid out on a regular grid at MINWR.

Habitat type	% habitat at MINWR	# of sampling sites, 2002-2005	% habitat type in 2002-2005 sample	# of sampling sites, 2006	% habitat type in 2006 sample
1º	22.9	70	64.8	70	56.0
2º	17.5	31	28.7	32	25.6
3º	45.6	7	6.5	22	17.6
4º	14.0	0	0.0	1	0.8
Total	100.0	108	100.0	125	100.0

Number of replicates vs. the number of sites

We used data from the 2003 survey to investigate how the number of replicate counts affected the precision of estimates of θ and λ. We first estimated θ and λ using all four sample occasions at 65 sites, and then re-estimated the parameters after eliminating the fourth count and then the third count. The precision of the parameter estimates markedly improved with three counts compared to two, but the addition of the fourth count had a negligible effect (Table 7). Based on these results, we suggest that MINWR conduct a minimum of three counts at every sample site. However, more counts per site likely would be needed to identify sources of variation in detection rate (e.g., through the use of habitat covariates) (MacKenzie et al. 2006).

However, if the primary objective of the survey is to detect changes in scrub-jay abundance at a relatively large spatial scale (e.g., refuge-wide), and if the number of replicate counts per sites is limited by the number of days observers are available (as we believe to be the case), then we suggest that MINWR: (i) increase the number of sampling sites, and (ii) continue to work toward increasing the types of habitats under-represented in the sample. The number of sample sites can be increased without additional observers or time by decreasing the amount of time spent at each station from 15 minutes to 10 minutes, and by limiting team size to two individuals (i.e., continue to conduct counts on three separate days but increase the number of sites visited per day). This could have led to an increase of approximately 70 stations for 2006. At least some of the additional stations should be added to 3° and 4° habitats because changes in total population size may be more related to changes in abundance in sink habitats than in source habitats (Breininger and Carter 2003).

Table 7. Estimates of detection rate and abundance of scrub-jays at MINWR in 2003 as related to the number of replicate counts conducted at 65 sample sites.

Replicate counts	$\bar{\theta}$	95% CI (θ)	$\bar{\lambda}$	95% CI (λ)
2	0.10	0.02 – 0.32	9.03	2.35 – 34.70
3	0.23	0.15 – 0.33	3.83	2.54 – 5.77
4	0.21	0.14 – 0.28	4.04	2.86 – 5.70

Monitoring to support adaptive management of scrub-jay habitat

The resources currently dedicated to the annual jay survey could permit MINWR to conduct three counts at approximately 200 sites. Assuming a representative distribution of these sites throughout the refuge, and assuming that the assumptions of the model are met, we believe a survey of this intensity would be sufficient to detect ecologically important changes in population size. However, an understanding of how jay abundance responds to prescribed burning, which occurs at relatively small spatial and temporal scales, may not be feasible with a point count survey for at least three reasons:

- Large-scale changes in jay abundance are likely influenced by many factors besides those associated with burning a relatively small area of the refuge every year. Thus, the ability to predict changes in abundance at the large scale (say at the refuge level) as a function of limited management actions at a small scale likely would be very poor.

- More intensive sampling at smaller spatial scales (e.g., at the level of a management unit) is likely not feasible because of the number of sites required to estimate θ and λ for a given area. Overlap of sample areas appears to remain a problem even when sample sites are $\geq$450m apart (using this minimum distance would hold the number of sites that could be located within management units below the number needed to provide estimates with acceptable precision).

- It is not clear how mean abundance per sample site based on point counts relates to jay abundance or fitness at small spatial scales. Ideally we would like to know how the number of breeding females (or pairs or territories) and their demographic performance changes as a function of variation in habitat conditions (which in turn are dependent on prescribed-burning strategies). However, observers cannot typically distinguish males from females, nor breeders from non-breeders ("helpers"), nor whether multiple jays observed at a site represent one or more families (a breeding pair + helpers). Moreover, many sample sites undoubtedly fall near the boundaries of territories where counts likely are comprised of jays from more than one territory.

The need to identify the demographic attributes of jays most responsive to burning of oak scrub, and the need for a practical data-collection program that can monitor those attributes, is perhaps the greatest challenge facing the development of a viable adaptive management program for scrub jay habitat at MINWR. As a first step, we suggest that the territory mapping and demographic studies being conducted by Dynamac Corp. at selected sites since 1988 could serve as a valuable resource in this regard if the fire and vegetative history of the sites could be reconstructed. Fortunately, Dynamac Corp. (with funding from the U.S. Geological Survey, the U.S. Fish and Wildlife Service, and the Florida Wildlife Conservation Commission) is reconstructing the fire history of MINWR using classification of Landsat imagery. This project ultimately will provide a spatial mapping of all fires on the refuge during 1984-2004. We are also working with Dynamac Corp. to consider methods for remotely-sensing important scrub attributes that could be modeled as a function of the presence or absence of fire.

Acknowledgements

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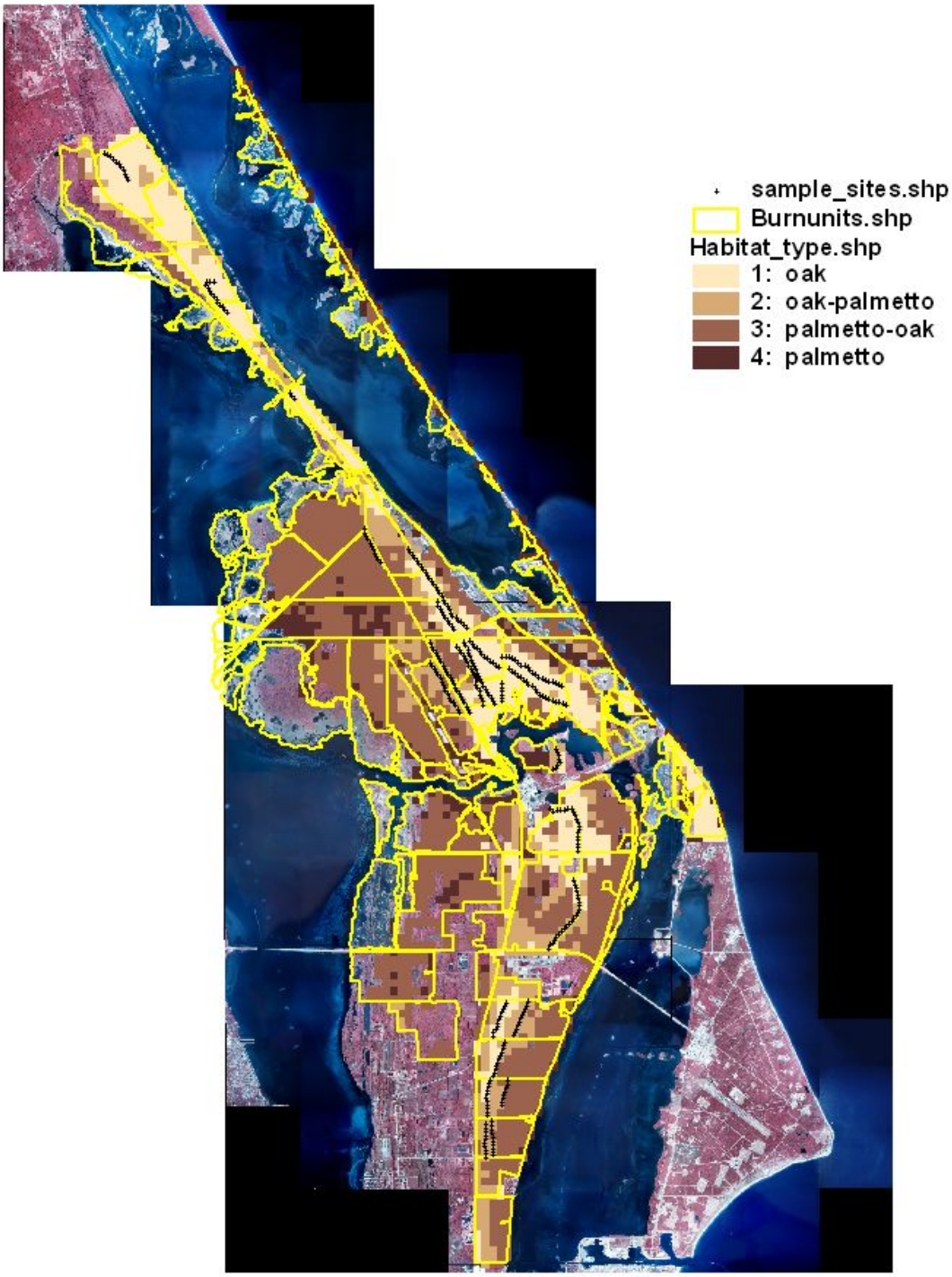

Fig 2. Scrub-jay sample sites (black dots) during 2003-2005 in relation to management unit boundaries and scrub-jay habitat type (based on mapping by Dynamac Corp.).

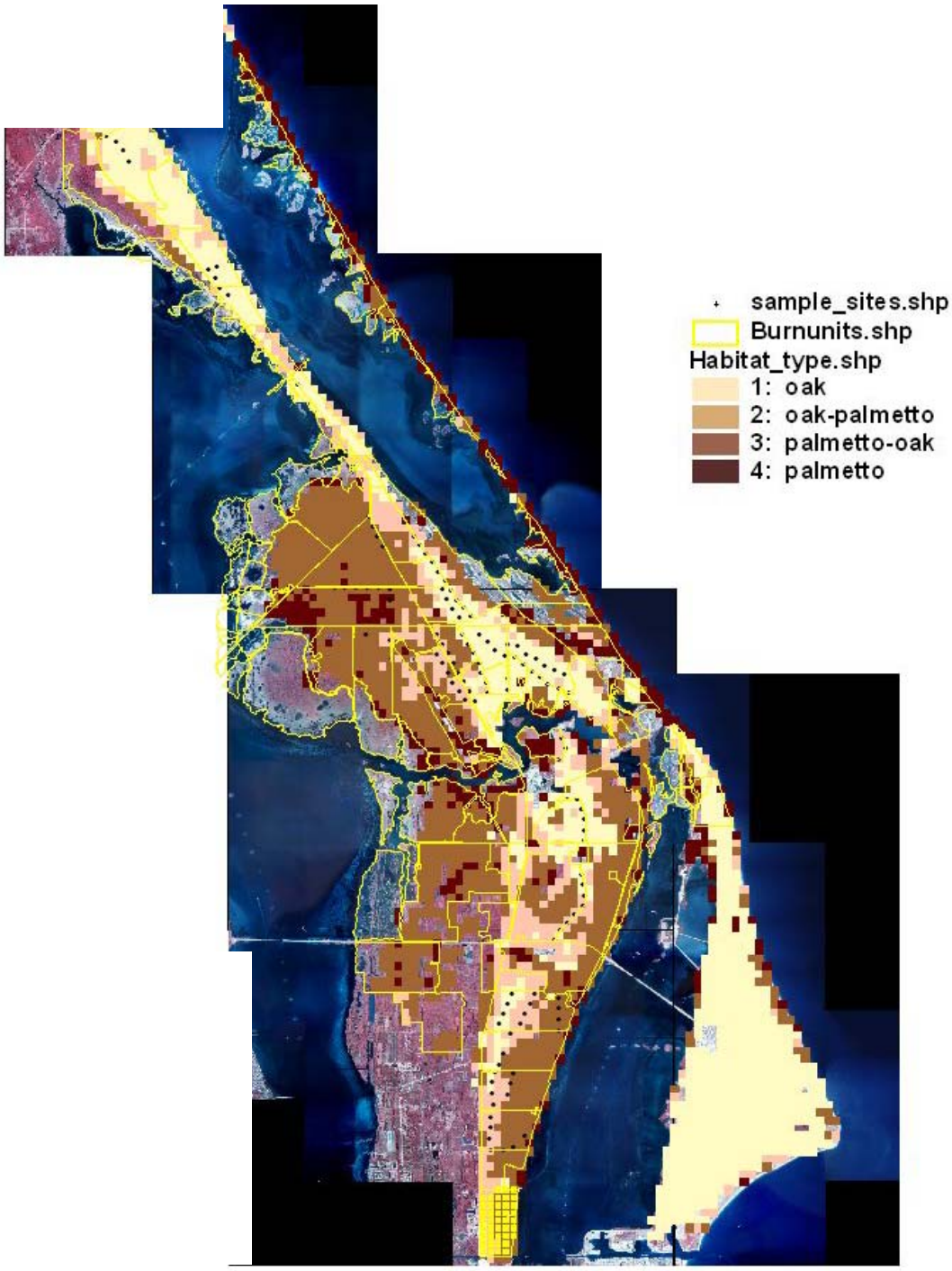

Fig 3. Scrub-jay sample sites (black dots) in 2006 in relation to management unit boundaries and scrub-jay habitat type (based on mapping by Dynamac Corp.).

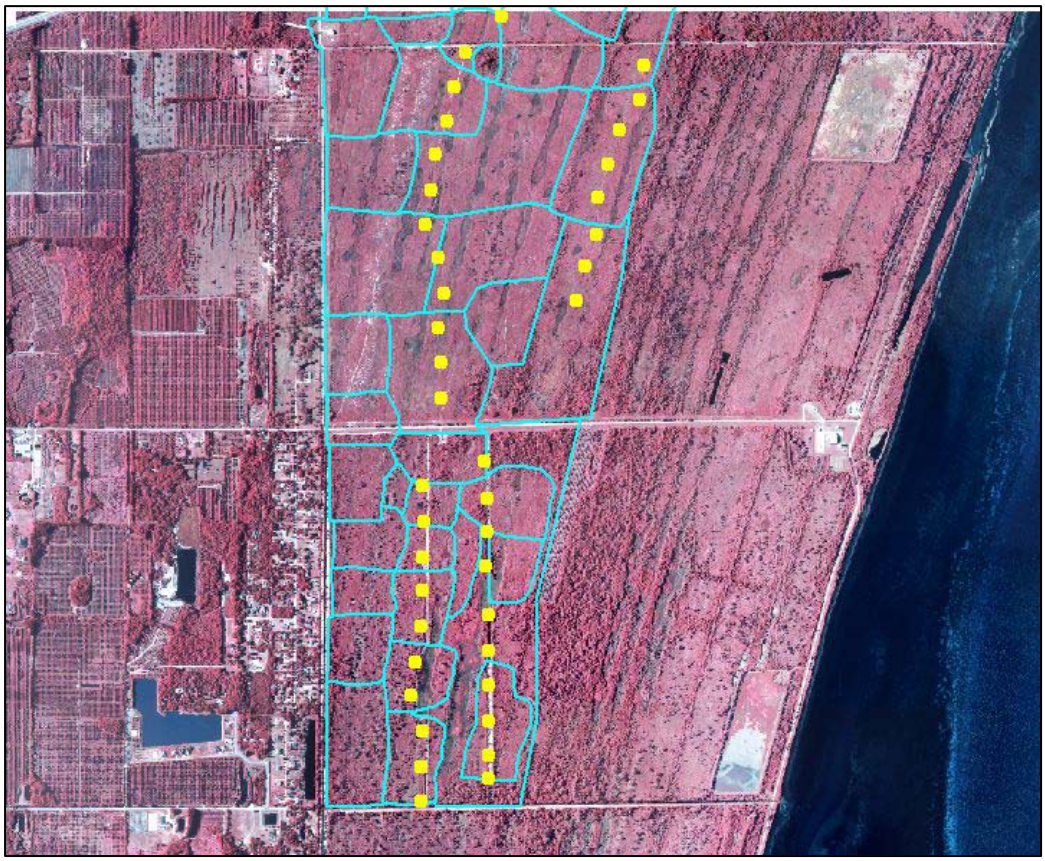

Fig. 4. An example of 2003 scrub-jay sample sites (yellow dots) in relation to jay territories (blue outlines). (Territory boundaries were provided by Dynamac Corp.)