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A Conservation Strategy for the Florida Scrub-Jay on John F. Kennedy Space Center/ Merritt Island National Wildlife Refuge: An Initial Scientific Basis for Recovery

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D. R. Breininger, V. L. Larson, R. Schaub, B. W. Duncan, P. A. Schmalzer, D. M. Oddy, R. B. Smith
Dynamac Corporation, NASA Biomedical Operations Office
John F. Kennedy Space Center, Florida

F. Adrian and H. Hill, Jr.
U.S. Fish and Wildlife Service, Merritt Island National Wildlife Refuge
Titusville, Florida

National Aeronautics and Space Administration
John F. Kennedy Space Center, Kennedy Space Center, Florida 32899-0001

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Abstract

The Florida Scrub-Jay (*Aphelocoma coerulescens)* is an indicator of ecosystem integrity of Florida scrub, an endangered ecosystem that requires frequent fire. One of the largest populations of this federally threatened species occurs on John F. Kennedy Space Center/Merritt Island National Wildlife Refuge. Population trends were predicted using population modeling and field data on reproduction and survival of Florida Scrub-Jays collected from 1988 - 1995. Analyses of historical photography indicated that habitat suitability has been declining for 30 years. Field data and computer simulations suggested that the population declined by at least 40% and will decline by another 40% in 10 years, if habitat management is not greatly intensified. Data and computer simulations suggest that habitat suitability cannot deviate greatly from optimal for the jay population to persist. Landscape trajectories of vegetation structure, responsible for declining habitat suitability, are associated with the disruption of natural fire regimes. Prescribed fire alone can not reverse the trajectories. A recovery strategy was developed, based on studies of Florida Scrub-Jays and scrub vegetation. A reserve design was formulated based on conservation science principles for scrub ecosystems. The strategy emphasizes frequent fire to restore habitat, but includes mechanical tree cutting for severely degraded areas. Pine thinning across large areas can produce rapid increases in habitat quality. Site-specific strategies will need to be developed, monitored, and modified to achieve conditions suitable for population persistence.

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Executive Summary

The Florida Scrub-Jay (*Aphelocoma coerulescens*) occurs only in the peninsular portion of Florida. It was listed as a threatened species by the U.S. Fish and Wildlife Service (USFWS) in 1987. The primary reasons for this species imperiled status are loss of habitat and habitat degradation. Scrub on John F. Kennedy Space Center (KSC) provides habitat for one of the three remaining population cores of the Florida Scrub-Jay. Most KSC habitat is managed by the USFWS as Merritt Island National Wildlife Refuge (MINWR). Some habitat is also managed as Canaveral National Seashore (CNS) by the National Park Service (NPS). The KSC/MINWR population is contiguous with the Cape Canaveral Air Station (CCAS), which also has potential for a large Florida Scrub-Jay population. These areas can be referred to as the Cape Canaveral/Merritt Island ecosystem. This document is specific to KSC/MINWR.

The purposes of this document are: 1) to describe the decline in the Florida Scrub-Jay population and scrub habitat quality on KSC/MINWR, and 2) to formulate a general strategy towards recovery of the jay population and the scrub ecosystem. The document provides a detailed review and biological basis for the Florida Scrub-Jay population decline and recovery. Detailed habitat inventories are needed to develop site-specific recovery plans, but are not required to initiate many recovery efforts. Implementation of the recommendations from this document will lead towards stabilizing the KSC/MINWR Florida Scrub-Jay population and will improve the overall quality of the scrub ecosystem.

Reproductive and survival data, from seven years of study of color banded jays on KSC/MINWR, were incorporated into a population risk model to quantify population trends and extinction risks. Landscape changes that resulted in declining Florida Scrub-Jay habitat suitability were evaluated using habitat models and photointerpretation of historical and recent photography.

Most of the KSC/MINWR Florida Scrub-Jay population has been declining for at least 10 years and is expected to decline by 40% within the next 10 years. The KSC/MINWR population is endangered with extinction in 50 years, if habitat and population trajectories continue because of poor habitat quality. The Florida Scrub-Jay is an indicator species of suitable habitat conditions for many other scrub species. Nearly all scrub species of conservation concern require frequent fires to maintain suitable conditions within scrub and marshes; no scrub species of conservation concern are known to prefer long unburned habitat conditions. Continued forestation will have negative impacts on the Gopher Tortoise (*Gopherus polyphemus*), Eastern Indigo Snake (*Drymarchon corias couperi*), Florida Mouse (*Podomys floridanus*), Florida Gopher Frog (*Rana capito aesopus*), Loggerhead Shrike (*Lanius ludovicianus*), and other species. Extinction of these species of conservation concern would impact on local, regional, and global biological diversity because KSC/MINWR is the largest scrub reserve along Florida's Atlantic coast.

Prior to European settlement, frequent fires kept KSC/MINWR an open landscape with short vegetation characteristic of marshes and scrub. Early agricultural practices resulted in soil disturbance. Native plant species became established in many agricultural areas after they were abandoned. However, the vegetation structure and composition differed from undisturbed sites by having discontinuous fuels that influenced fire patterns. Disturbed areas burned poorly, becoming forests prior to acquisition of KSC/MINWR by federal agencies in the 1960s. The development of the space program led to increased habitat fragmentation by roads and facilities. Fire suppression occurred during the 1960s and 1970s. During this time, many patches of scrub and marsh became forests, and most open sandy areas in scrub became closed. Shrub height and pine densities increased. Fires no longer caused pine mortality, and pine seedlings became established in high densities in areas with soil disturbance. Fuel loads increased, resulting in the potential for catastrophic fires under certain weather conditions. As a result of these changes, fuel structures developed that would most likely burn only under extreme conditions.

Prescribed fire management has been conducted through the 1980's and 1990's, but has not reestablished habitat conditions that can sustain Florida Scrub-Jay populations. Smoke management, safety considerations, and meteorological conditions limited the range of conditions suitable for burning. Fires will not return most forested areas to scrub or marsh.

Prescribed fires alone have not returned scrub to optimal habitat suitability. Florida Scrub-Jay populations continue to decline in scrub landscapes fragmented by forests or other areas of tall shrubs. Florida Scrub-Jays require a complex mosaic of openings among scrub oaks. Natural openings among scrub oaks do not remain long after fire in most areas that have been subject to fire suppression. Man-made edges provide suitable habitat for jays but do not adequately replace natural openings because they can be systematically searched by predators.

Other management tools are suggested to improve scrub habitat quality. Several experimental restoration efforts have been conducted, and their results have been promising. These efforts have primarily involved the mechanical cutting of trees followed by prescribed fire. Restoration efforts need to be implemented on a larger scale. Many years of study have quantified relationships among fire, vegetation, habitat structure, habitat use, and reproductive success and survival of Florida Scrub-Jays. These findings indicate that the continued decline in habitat suitability can be reversed with intensive management. Reversing landscape and population trajectories resulting from practices of the past half century requires a long-term commitment.

Habitats for population persistence must be recently burned (less than 15 years from the last fire) and must represent wide vistas where most Florida

Scrub-Jay territories are surrounded by other territories. Four major landscapes, designated as scrub reserve units (SRUs), should be restored and managed as optimal habitat. These SRUs are Shiloh, Happy Creek, Schwartz Road (south of the Vehicle Assembly Building), and the Southern Pinelands (south of the KSC/MINWR Industrial Area). Because Florida Scrub-Jays have limited dispersal and are vulnerable to predation when they are outside of optimal habitat, corridor regions are identified within the KSC/MINWR population SRUs and between CCAS. No large scrub areas on the Florida mainland can be connected to KSC/MINWR. The CCAS population has undergone a severe decline, but it represents a potential large population center. All corridors within the Cape Canaveral/Merritt Island ecosystem need habitat restoration. The scrub within the SRUs and corridors is approximately 7,000 ha. This could result in a population of 700 Florida Scrub-Jay territories if all habitat could be restored to optimal suitability. Recovery to this population size can only occur if reproductive success exceeds the mortality rate over many decades.

Studies show that all conditions must be optimal for Florida Scrub-Jay reproductive success to exceed or equal mortality rates. Achieving optimal habitat conditions quickly by extensive restoration is unlikely. Therefore, it is important to manage for a large population size in order to attain low extinction risk. Questions remain about the exact habitat and landscape requirements essential for population persistence. Some habitat has become so degraded that it will be uneconomical or impossible to restore to optimal conditions. Much habitat that is not restored will have negative impacts on the surrounding scrub by limiting the dispersal abilities of jays and their ability to detect predators. Thus, restoration of the population to 700 territories is likely to be a lengthy process involving adaptive management practices.

Restoration of fire frequencies need to be adapted to site-specific fire history, past soil disturbance, and the amount and distribution of accumulated underground biomass. Restoration efforts need to include frequent burning for at least 10 years and the additional mechanical treatment of forests. It is important not to burn all scrub within a unit at once in order to provide cover, acorns, and nest sites for resident jays. Prescribed fires need to occur under narrow meteorological conditions, for smoke and safety reasons, so that multiple fires may be needed within some units to accomplish objectives. Generally, most burn units (BUs) within the core reserve need to have 20-40% of the area burned every one to three years depending on the extent of habitat degradation within the BUs. A less frequent fire management regime can probably be used once the initial intensive treatments have been completed.

Mechanical tree cutting is needed for oaks that have grown too large and pines that have grown too dense. Careful logging of pines along man-made edges and other disturbed areas can result in rapid improvements in habitat suitability. The mechanical cutting of oaks may yield slower improvement.

Intensive and expedited restoration techniques and monitoring will be needed in several landscapes, because it will be difficult to achieve optimal habitat conditions quickly in most areas. These experimental landscapes can be used as models for finely tuned restoration of the remaining habitat needed for population recovery. Continued monitoring of vegetation and the Florida Scrub-Jay population is essential to establish the management techniques and the range of habitat conditions essential for population persistence.

The greatest additional effort needed is to increase the frequency of prescribed burning for at least 10 years. This must be supplemented with the equipment and personnel needed for the mechanical cutting of trees. A burning team is needed whose leaders plan and evaluate burns on a daily basis and supervise burns whenever weather and operations permit. Without such efforts, the KSC/MINWR population will become endangered with extinction.

Acknowledgments

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1.0 Introduction

The Florida Scrub-Jay (*Aphelocoma coerulescens*) is a cooperative breeding bird, endemic to Florida, that is a federally listed threatened species (Woolfenden and Fitzpatrick 1984, 1991). The Florida Scrub-Jay is one of North America's most habitat-specific birds. It lives in an ecosystem important to more than 100 species of conservation concern (Breininger et al. 1994 a). Scrub, like many of North America's fire-maintained habitats, is imperiled across Florida due to the disruption of natural fire regimes, and its destruction for agriculture and human habitation. The Florida Scrub-Jay population on Kennedy Space Center/Merritt Island National Wildlife Refuge (KSC/MINWR) is designated as one of the three core populations for the species range-wide (Fitzpatrick et al. in press, Stith et al. in press). Core populations are contiguous populations that exceed 400 territorial pairs. Such populations provide a high probability of survival, if the habitat is managed properly (Fitzpatrick et al. 1991).

Florida Scrub-Jays are territorial. Breeders spend their entire lives within an area that is defended throughout the year (Woolfenden and Fitzpatrick 1984, 1991). Typically, all periodically burned scrub is defended by permanently monogamous breeding pairs (Woolfenden and Fitzpatrick 1984, 1991; Breininger et al. 1995, in press). Most dispersals are within 300 and 1000 meters for males and females, respectively. Young usually remain with their parents for greater than one year, "helping" to detect and mob predators, defend the territory, and care for subsequent offspring (Woolfenden and Fitzpatrick 1984).

Scrub once dominated natural upland communities on east coast barrier islands and along most of the Atlantic Coastal Ridge of eastern mainland Florida, but are now among the most endangered communities (Snodgrass et al. 1991, Larson 1992, Bergen 1994, Cox et al. 1994, Swain et al. in preparation). Here scrub includes native shrub communities dominated by saw palmetto and mesic shrubs on poorly drained soils and dominated by scrub oaks on well drained soils (Schmalzer and Hinkle 1992 a, b). Natural fires burned frequently in these landscapes and maintained their habitat structure and species composition (Vogl 1973; Campbell and Christman 1982; Means and Campbell 1981; Mushinsky 1985; Abrahamson and Hartnett 1990; Myers 1990; Schmalzer and Hinkle 1992 a, b; Breininger and Smith 1992).

All other species of conservation concern that depend on scrub (e.g., Gopher Tortoise, Eastern Indigo Snake, Florida Mouse) also require frequent fires (Speake et al. 1978; Layne 1990; Auffenberg and Franz 1982; et al. 1991 b, 1994 a, 1994 b; Ostertag and Menges 1994, Hawkes and Menges 1995). Many of these species are threatened with regional extirpation without restoration and management of the few remaining large reserves (Noss and Labisky 1991). The only large remaining tracts of scrub within the Atlantic Coast scrub subregion occur on federal properties (Fitzpatrick et al. in press). Smaller tracts in the subregion occur on Jonathan Dickinson State Park and private lands considered for acquisition in Brevard County (Swain et al. in preparation). Federal properties include KSC/MINWR, Cape Canaveral Air Station (CCAS), and areas of Canaveral National Seashore (CNS) that extend beyond KSC/MINWR (Figure 1, Appendix A). This document emphasizes KSC/MINWR which is under jurisdiction of National Aeronautics and Space Administration (NASA), U.S. Fish and Wildlife Service (USFWS), and the National Park Service (NPS). Other CCAS and CNS lands also have significant population potential, but have poor habitat quality and a declining Florida Scrub-Jay population (Percival et al. 1995).

1.1 Optimal Florida Scrub-Jay Habitat

Much of what is known about scrub ecology has been learned at the Archbold Biological Station (Archbold), located on the Lake Wales Ridge in central Florida. Applied and theoretical studies have been conducted at

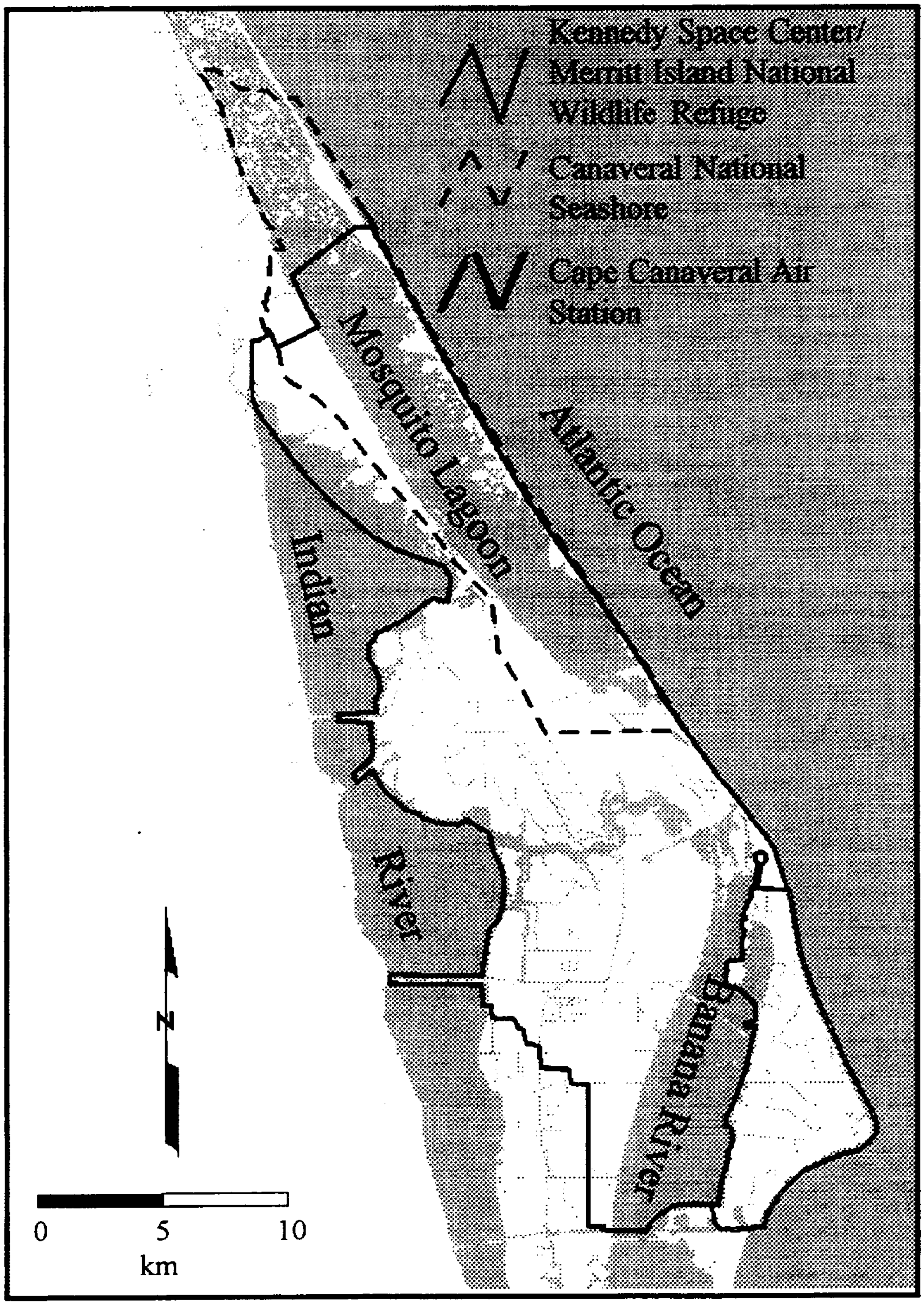


Figure 1. Boundaries of John F. Kennedy Space Center, including Merritt Island National Wildlife Refuge, Canaveral National Seashore, and Cape Canaveral Air Station.

Archbold for more than 25 years. At Archbold, optimal management for Florida Scrub-Jay habitat includes burning every 8-20 years where not all habitat is burned at once (Fitzpatrick et al. 1991, Woolfenden and Fitzpatrick 1991). This fire regime is suitable for the Lake Wales Ridge but is not frequent enough for KSC/MINWR, at least not to restore KSC/MINWR scrub that was unburned for greater than 20 years. KSC/MINWR scrub has a higher water table, more nutrients, and a more poorly drained matrix than mainland scrubs (Schmalzer and Hinkle 1987, 1992 b; Breininger et al. 1991 a, 1995). Although there are similarities in scrub ecology on the Lake Wales Ridge and KSC/MINWR, there are also distinctions. Our ability to predict the dynamics of KSC/MINWR has only begun after 15 years of management and 10 years of applied studies here.

1.1.1 Landscape Characteristics

Florida Scrub-Jay territories typically average 10 ha in size within undisturbed habitat (Woolfenden and Fitzpatrick 1984, Breininger et al. 1995). The landscape attributes of habitat most preferred by Florida Scrub-Jays can be described as low and open (Woolfenden and Fitzpatrick 1984). Florida Scrub-Jays occur in landscapes where scattered pines are common, although they avoid areas with high pine densities (Woolfenden 1974, Woolfenden and Fitzpatrick 1984, Breininger et al. 1995).

Florida Scrub-Jays avoid typically areas near forests (greater than 65% tree cover) (Breininger et al. 1995), because there they have reduced abilities to spot and evade woodland hawks (i.e., accipiters). Accipiters are predators on adult Scrub-Jays (McGowan and Woolfenden 1989) and evidence suggests that jays are especially vulnerable to accipiters (i.e., Cooper's Hawk [*Accipiter cooperii*] and Sharp-shinned Hawk [A. striatus]) on KSC/MINWR (Breininger et al. in press). Florida Scrub-Jay mortality results mostly from predation (Woolfenden 1974, Woolfenden and Fitzpatrick 1984). Florida Scrub-Jays not only do not use pine forests (Cox 1984) but avoid Blue Jays (*Cyanocitta cristata*) which are competitors and nest predators (Woolfenden and Fitzpatrick 1984, 1991). Blue Jays are common in woodlands (greater than 20% tree cover) and near forests but are rare in recently burned scrub (Breininger 1990, Breininger and Schmalzer 1990, Breininger and Smith 1992).

Nest predation is a primary factor influencing the Florida Scrub-Jay's preference for landscapes dominated by frequently burned scrub (Schaub 1990, Schaub et al. 1992). Vegetation that characterizes open (recently burned) scrub allows Scrub-Jays to monitor a large area while providing refuge and the opportunity for Florida Scrub-Jays to be inconspicuous in their activities. Florida Scrub-Jays may not be effective at deterring predators once the predator has found the nest (Lohrer 1980, Patterson et al. 1980, Webber 1980, Woolfenden and Fitzpatrick 1984). However, mobbing may alter the course of foraging predators (Francis et al. 1989). Terrestrial predators (e.g., Eastern Coachwhip (*Masticophis flagellum)* and Eastern Indigo Snakes) are important predators on adult Florida Scrub-Jays (McGowan and Woolfenden 1989), and the openness of recently burned scrub may also facilitate the detection and avoidance of terrestrial predators.

The fragmentation of scrub landscapes results in an increase of woodlands and forests. Disturbances related to human development, fire suppression, and other disruptions of natural fire patterns have made many edges of habitat fragments unsuitable for jays. Forests not only replace scrub within habitat fragments but negatively influence the suitability of nearby habitat (Breininger et al. 1995). Landscapes, fragmented by woodlands, forests, and tall shrubs, no longer allow Florida Scrub-Jays to scan large areas for predators.

1.1.2 Focal Habitat Patches

Optimal Florida Scrub-Jay habitat (Westcott 1970; Woolfenden 1974; Cox 1984; Woolfenden and Fitzpatrick 1984, 1991; Breininger 1992 b; Breininger et al. 1995; Duncan et al. 1995 a) occurs as patches (focal habitat) with the following attributes:

a) 10-30% of the area comprised of bare sand or sparse herbaceous vegetation,

b) greater than 50% of the shrub layer comprised of scrub oaks (*Quercus* spp.),

c) a shrub height of 120-170 cm,

d) less than 15% pine canopy cover, and

e) greater than 100 m from a forest.

Florida Scrub-Jays have adapted to frequent fires by defending large territories increasing the probability of having enough patches in optimal condition within a territory (Woolfenden and Fitzpatrick 1984). Oak scrub represents the potential focal habitat, but not all of it is necessarily in optimal condition at the same time (Woolfenden and Fitzpatrick 1984, Breininger et al. 1995). Patches of oak scrub vary in quality depending on the time since fire. Historical photographs suggest that very little oak scrub on Merritt Island remained unburned for long periods (see Section 2.3).

1.1.3. Matrix Habitat

Most potential Florida Scrub-Jay habitat on KSC/MINWR occurs as patches of oak scrub within a matrix of little-used habitat of palmetto-lyonia (*Serenoa repens, Lyonia lucida)* and swale marshes (Breininger et al. 1995).

These native matrix habitats provide prey for Florida Scrub-Jays and habitat for other species of conservation concern (Moler and Franz 1987, Breininger et al. 1994 a, b). The flammability of native matrix habitats is important for spreading fires into oak scrub that often burns poorly (Webber 1935). Saw palmetto, gallberry holly *(Ilex glabra)*, and grasses, which dominate saw palmetto-lyonia and marshes, are more flammable and accumulate fuel more rapidly than scrub oaks (Abrahamson 1984 b, Abrahamson and Hartnett 1990, Myers 1990, Schmalzer et al. 1991; Schmalzer and Hinkle 1992 a).

Degradation or replacement of native matrix habitats with habitat fragments and industrial areas adds predators of Florida Scrub-Jays, such as Fish Crows (*Corvus ossifragus*), that are rare in most regularly burned (every 3-15 years), native matrix habitats (Woolfenden and Fitzpatrick 1991, Breininger and Smith 1992). Matrix habitats often develop into woodlands and forests when there is a disruption of fire regimes. These woodlands and forests are not suitable for Florida Scrub-Jays, decrease the habitat suitability of nearby scrub, and further disrupt fire patterns (Schmalzer et al. 1994).

1.2 Past Habitat Management Overview

Logging, ditching, land clearing, and agriculture altered natural habitat on KSC/MINWR prior to NASA ownership and USFWS and NPS jurisdiction (Appendix B). The MINWR and CNS were established after NASA purchased the land in the 1960s. Fire suppression occurred in the 1960s and 1970s when few wildfires occurred and fuel loadings accumulated to dangerous levels. A prescribed fire program has been conducted in the 1980s and 1990s by the USFWS (Adrian 1992). Initially, the primary objective of prescribed burning was to manage fuel loadings to reduce the hazards and costs associated with suppressing wildfires. Habitat management, for a variety of species, has become another primary objective of the current prescribed fire program (Adrian and Farinetti 1995).

2.0 Florida Scrub-Jay Population and Habitat Status

Detailed data on reproductive success, survival, and territory densities are available from 3-8 years of study of color banded Florida Scrub-Jays from several sites (Figure 2) (Larson et al. 1993; Smith et al. 1994; Breininger et al. 1995, in press, in preparation; Schaub unpublished data). Remote sensing and spatial analyses are being used to quantify changes in habitat and landscapes from those features that are identifiable on sequences of aerial photography dating from the 1940s (Section 2.3).

Potential habitat on KSC/MINWR, based on the acreage of scrub, could provide for a Florida Scrub-Jay population of 700-800 families (Breininger 1989, Breininger et. al. 1991 a). Much of the scrub has become, or is in transition to, xeric hammock because of the disruption of natural fire regimes. Consequently, the existing population, especially north of Haulover Canal (Section 3.5), is much smaller than that based on habitat potential. Documented declines in Florida Scrub-Jay population size on KSC/MINWR have occurred in several long-term study sites.

2.1 Risk Assessments

Population risk models predict future trends in populations using data on reproductive success and survival (Burgman et al. 1993). The "primary" model for Florida Scrub-Jays is summarized in Figure 3 and is presented in greater detail in Appendix D (and see Breininger et al. unpublished ms.). The model incorporates stages from independent young through adult, breeder experience, and presence of helpers. Another model was developed for KSC/MINWR data sets that had insufficient sample sizes to distinguish novice from experienced breeders. This second ("simple") model distinguished only two classes of breeders (breeders with helpers and breeders without helpers).

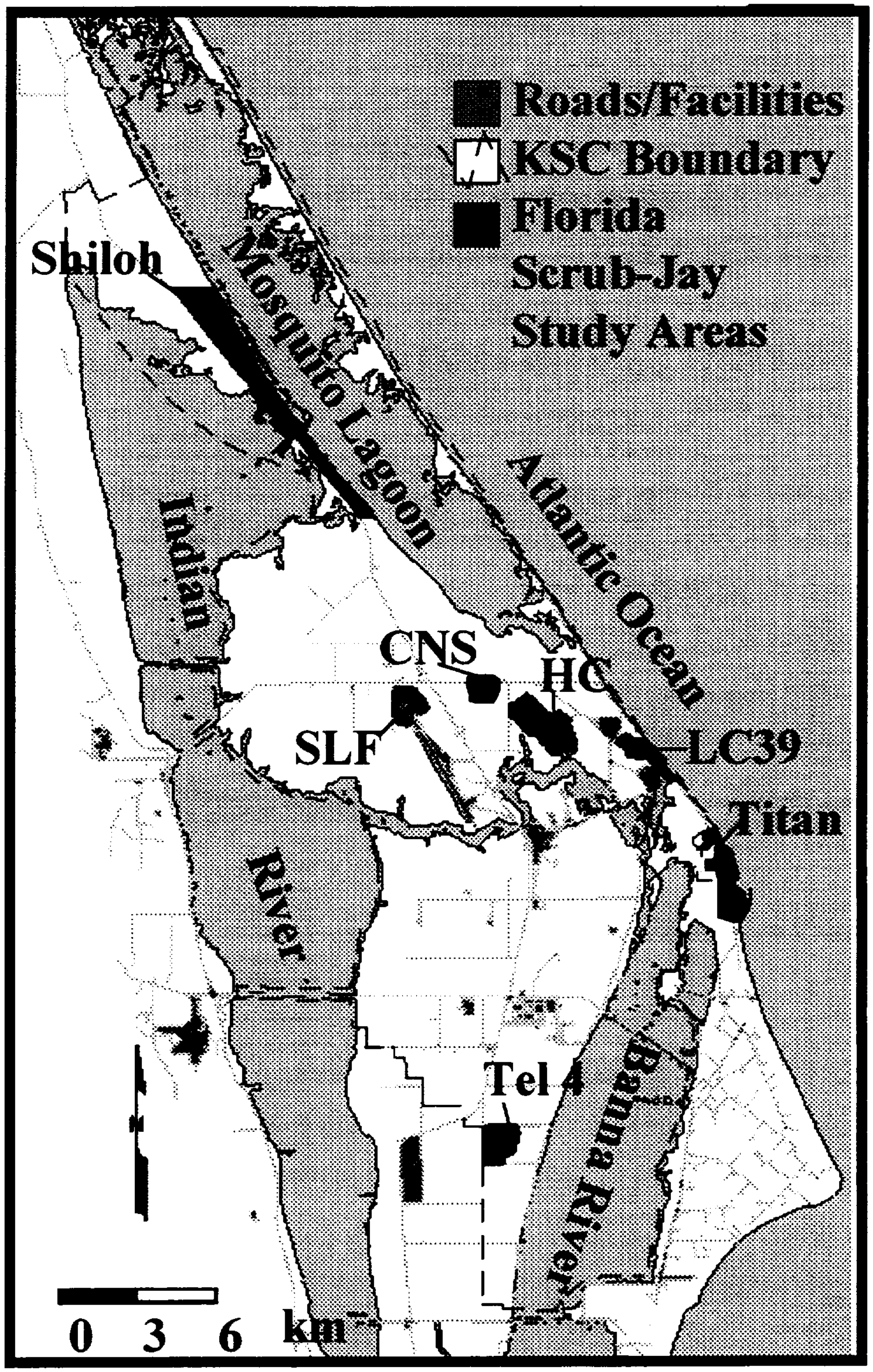
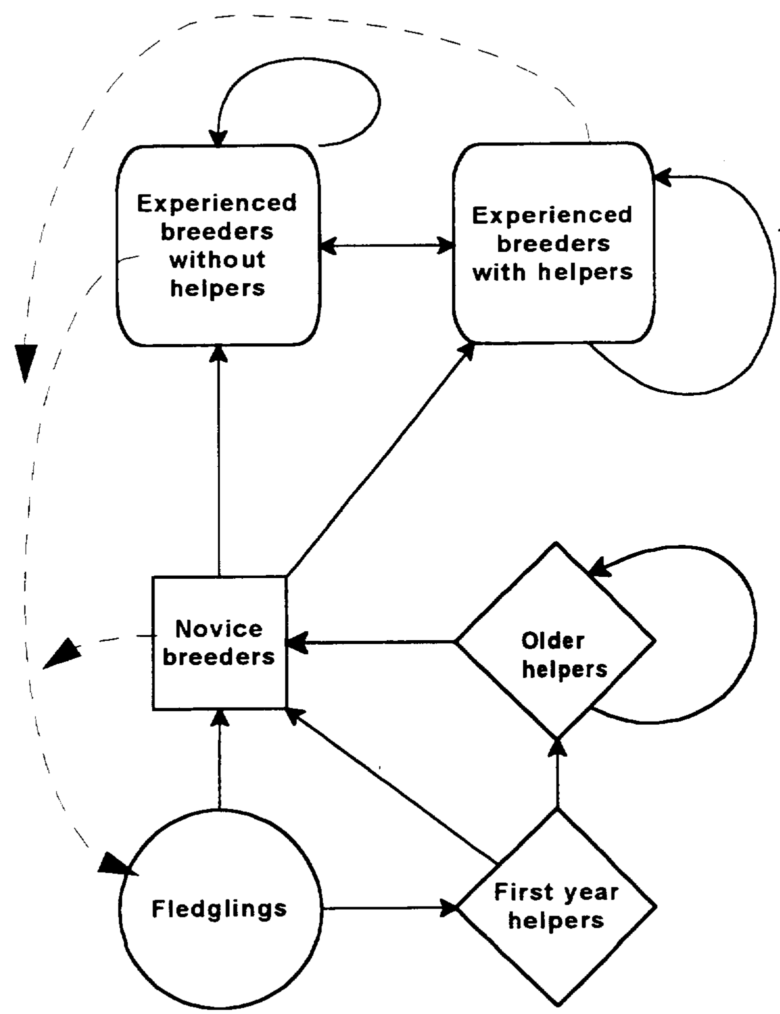


Figure 2. Florida Scrub-Jay study areas. CNS-Canaveral National Seashore, HC-Happy Creek, SLF- Shuttle Landing Facility, LC39- Shuttle Launch Complexes.

Figure 3. Florida Scrub-Jay population risk model. The model incorporates features of Florida Scrub-Jay sociobiology. The model implements Monte Carlo simulations using the means and variances of reproductive success and survival of six stages the Florida Scrub-Jay. Model assumptions: 1) nonbreeders include fledglings and two helper stages; 2) there is a ceiling on the number of breeders based on habitat acreage; 3) novice breeders that survive become experienced breeders after one year of breeding; 4) the number of nonbreeders becoming novice breeders is dependent on the number of breeding vacancies attributed to breeder mortality; 5) older helpers have the first chance to breed, followed by first year helpers; 6) fledglings that survive can become first year breeders if breeding vacancies are unfilled by helpers; 7) the number of nonbreeders is dependent on the survival of nonbreeders from the previous years, the number of nonbreeders that have no chance to breed because there area no vacancies, the survival of fledglings, and the ceiling on the total number of helpers based on habitat. The dotted lines represent reproduction and the solid lines represent survival and transitions from one stage to another.



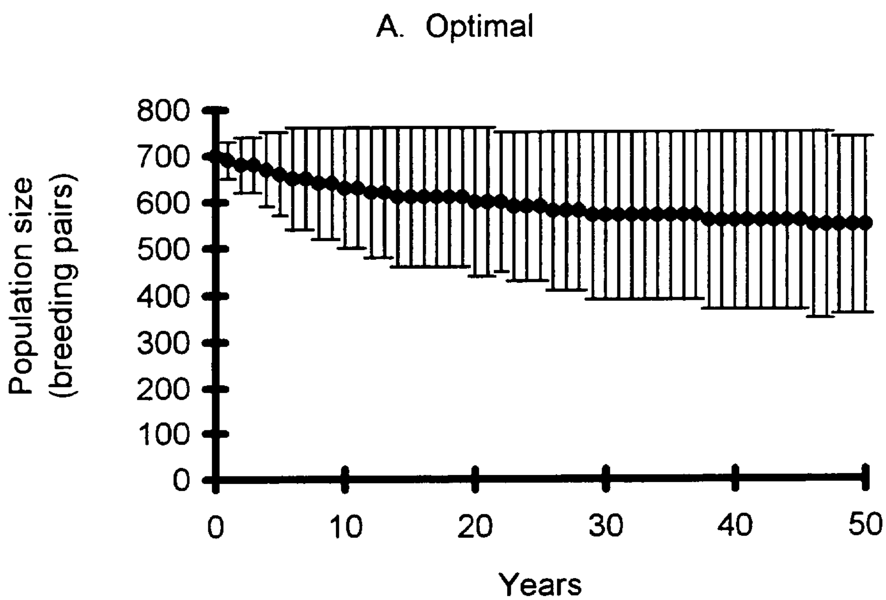
Both models perform Monte Carlo simulations where mortality and fecundity are sampled from distributions based upon empirical data. Population ceilings, attributed to strict territorial behavior, are placed on the total number of breeders and helpers and are ultimately based on the amount of habitat.

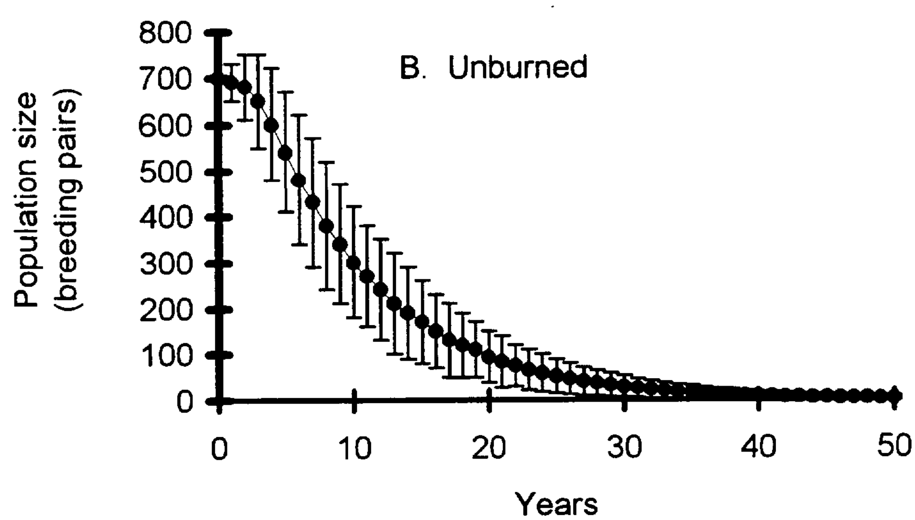
2.2 Population Trajectories and Extinction Risks

The risk model was used to predict population trajectories based on data collected at Archbold, five study sites on KSC/MINWR (Larson et al. 1993; Smith et al. 1994; Breininger et al. 1995, in press, unpublished ms.; R. Schaub unpublished data). Ten years of demographic data collected at Archbold (Woolfenden and Fitzpatrick 1984, 1991) provide a standard comparison for KSC/MINWR data. The primary model was used to simulate populations at Archbold, Tel 4, Happy Creek, and Titan complexes. The simple model was used to simulate populations at Shiloh and CNS.

The population trajectory based on optimal Archbold habitat is presented in Figure 4A and is very similar to observed population trends (Woolfenden and Fitzpatrick 1991, Fitzpatrick et al. 1991). Populations in the optimal, periodically burned habitat showed a slight decline Figure 4A. Reproductive success exactly matched mortality (population growth rate (λ)=1.00) in optimal Archbold habitat without catastrophes (Woolfenden and Fitzpatrick 1984). A severe epidemic occurred during one of 20 years of study at Archbold and resulted in high mortality of adults and helpers; few juveniles survived the epidemic (Woolfenden and Fitzpatrick 1984). Consequently, a reasonable estimate of epidemic probability is 0.05 per year (Woolfenden and Fitzpatrick 1991, Fitzpatrick et al.

Figure 4. Population trajectories using reproductive success and survival data from A) optimal and B) unburned Archbold habitat. Mean and standard deviations of 1000 simulations represented. Assumes that epidemics occur with a yearly probability of 0.05. Other catastrophic events are excluded.





1991). A slight decrease in population trajectories is common when epidemics or catastrophes are incorporated into a population model (Burgman et al. 1993).

It is not appropriate to conclude that Florida Scrub-Jay populations will decline based on the slight decline in the above trajectory. Few population risk assessments have long term empirical data that results in an exactly stable population growth rate ($\lambda = 1.00$), but population risk assessments typically need to predict for periods longer than the available empirical data. Very slight changes in vital (reproductive success and survival) rates from 1.00 result in population growth rates that increase or decrease. Extensive sensitivity analyses of the population model showed that a few percent increase in vital rates or lower epidemic frequency result in a stable population prediction for optimal Archbold habitat (Breininger et al. unpublished ms.). The epidemic frequency of 0.05 was maintained throughout the remaining analyses (unless otherwise noted), acknowledging that the frequency of epidemics may be higher or lower than modeled.

The population decline and extirpation associated with habitat unburned for 25-40 years at Archbold (Woolfenden and Fitzpatrick 1991) was also consistent with the simulations using vital rates within such habitat (Figure 4B). The decline and extinction of Florida Scrub-Jays in unburned habitat occurs throughout Brevard County (Swain et al. in preparation) and statewide (Fitzpatrick et al. 1991).

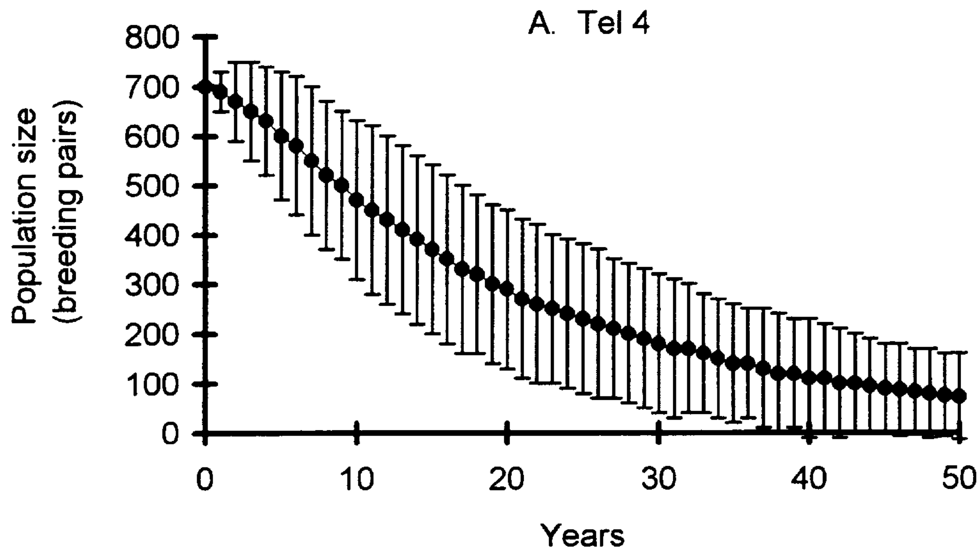
2.2.1 Tel 4

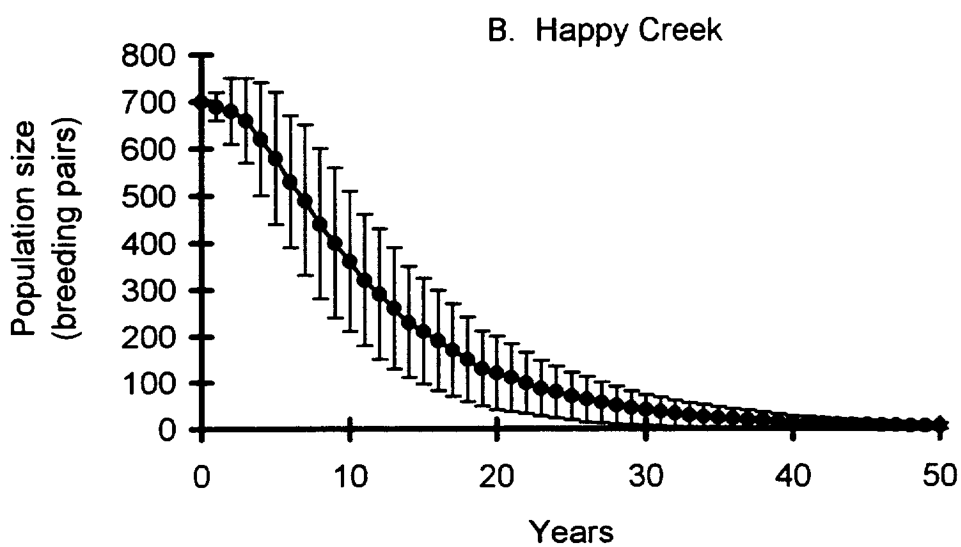
The Tel 4 site (Figure 2) was burned by at least one wildfire during the fire suppression period and did not lose openings among scrub oaks, although forests developed in several areas once used for agriculture. The study area burned five times since 1979. Prescribed burns at Tel 4 were effective at keeping shrubs from exceeding optimal height and maintaining openings among scrub oaks in most areas (Duncan et al. 1995 b, Duncan et al. in press). The Tel 4 study site was adjacent to private lands where scrub has undergone habitat destruction and fire exclusion.

The population trajectory, using the primary model, for Tel 4 suggested a 25% decline within 10 years (Figure 5A). A decrease in the number of territories or birds has not been documented (Breininger et al. in press). The decline in the Tel 4 trajectory was sensitive to model assumptions in contrast with other trajectories below. The Tel 4 study site has higher habitat suitability for Florida Scrub-Jays than most areas on KSC/MINWR because there are few tall shrubs and an abundance of openings. Population dynamics within subpopulations are dependent on demography in nearby subpopulations and the dispersal of individuals from other subpopulations. Population declines are not always obvious in subpopulations where mortality exceeds reproductive success, if these populations have higher habitat suitability than their surroundings (e.g., Pulliam 1988, Howe et al. 1991, Pulliam et al. 1992, Dunning et al. 1992). Therefore, extinction risk is not always realized until extinction is inevitable (Howe et al. 1991, Pulliam and Danielson 1991).

High immigration of Florida Scrub-Jays resulted in abnormally high Florida Scrub-Jay densities that may have lowered survival (see Watkinson and Sutherland 1995). Most immigrants appeared to be from adjacent private property where habitat has been destroyed for housing or has remained unburned for long periods (Breininger et al. in press). The data suggested that a density dependence relationship (at least at very high jay densities) may influence survival at Tel 4 but more data are needed to confirm this relationship.

Figure 5. Population trajectories using reproductive success and survival data from A) Tel 4 and B) Happy Creek. Mean and standard deviations of 1000 simulations represented. Assumes that epidemics occur with a yearly probability of 0.05. Other catastrophic events are excluded.





Some evidence also suggested a negative influence of helper densities on breeder survival at Archbold (Woolfenden and Fitzpatrick 1984). Density dependence of survival rates could have been incorporated into the model. But logistic and similar density dependence formulations should not be used without strong evidence for such forms of density dependence because they can seriously underestimate extinction risk (Ginzburg et al. 1990). Sensitivity analyses of these density dependence models (i.e., Beverton-Holt, logistic or Ricker equations) confirmed that extinction risk was underestimated for habitat conditions (and associated vital rates) where Florida Scrub-Jay populations failed to persist.

Habitat improvements at Tel 4 and in surrounding areas are needed for long term stability of the Tel 4 population. The Florida Scrub-Jay population outside KSC/MINWR property on Merritt Island is less than 20 pairs (Swain et al. in preparation), and these jays have little chance for population persistence. Immigration attributed to jays leaving these areas is temporary. Variation in demographic success has been attributed to variations in habitat suitability at Tel 4 that could be altered readily by restoration (Breininger et al. 1995; Duncan et al. 1995 a). Soil disturbances in the 1940's and 1950's have resulted in many forest edges that can be restored by tree cutting. Restoration is needed in adjacent landscapes or else competition by Florida Scrub-Jays will continue for the few quality sites, such as Tel 4.

2.2.2 Happy Creek

The Happy Creek area (Figure 2) is one of the largest potential population centers on KSC/MINWR (Breininger et al. 1991 a). The Happy Creek site was subjected to 20 years of fire suppression before 1979. Photographic sequences (1943-1979) showed that natural openings disappeared from Happy Creek, and the landscape became increasingly forested. The study area burned five times since 1979. Prescribed burns at Happy Creek have not effectively reduced shrub height in many areas and natural openings have not returned (Schmalzer and Hinkle 1992 a).

The population trajectory for Happy Creek suggested a decline by 50% within 10 years (Figure 5B). Sensitivity analyses indicated that minor changes in demographic data or epidemic frequency have little influence on the trajectory. Actual declines in mean family sizes and territory densities have been observed (Breininger et al. in press). Conspicuously, poor reproductive success represents one causative factor in the population decline (Breininger et al. in press).

The loss of natural openings among scrub oaks, increase of tall shrubs, and the replacement of marsh and scrub by forest has been characteristic of this landscape for nearly 20 years. The population decline in the Happy Creek area has probably been occurring for decades. Although most Happy Creek scrub is of low to moderate quality, it is in better condition than many other areas on KSC/MINWR. Therefore, a decline at Happy Creek might have been masked by immigration until there were no more immigrants, if color banding studies had not been conducted.

2.2.3 Titan Complex

Study areas surrounding the Titan launch complexes (Figure 2) have had a history of fire suppression for greater than 35 years. A few unplanned fires occurred but they were extinguished rapidly and these fires did not burn large areas. There has been little or no evidence for launch impacts to Florida Scrub-Jays (Larson et al. 1993). Photographic sequences (1943-1989) showed that natural openings among scrub oaks disappeared and most of the landscape became a woodland or forest.

The population trajectory for Titan launch complexes suggested a population decline by of 50% within 10 years (Figure 6A). Sensitivity analyses indicated that minor changes in demographic data have little influence on the trajectory. Actual declines in Florida Scrub-Jay population have occurred (Larson et al. 1993, D. Oddy, unpublished data). Declines have probably occurred for longer periods than have occurred at Tel 4 and Happy Creek.

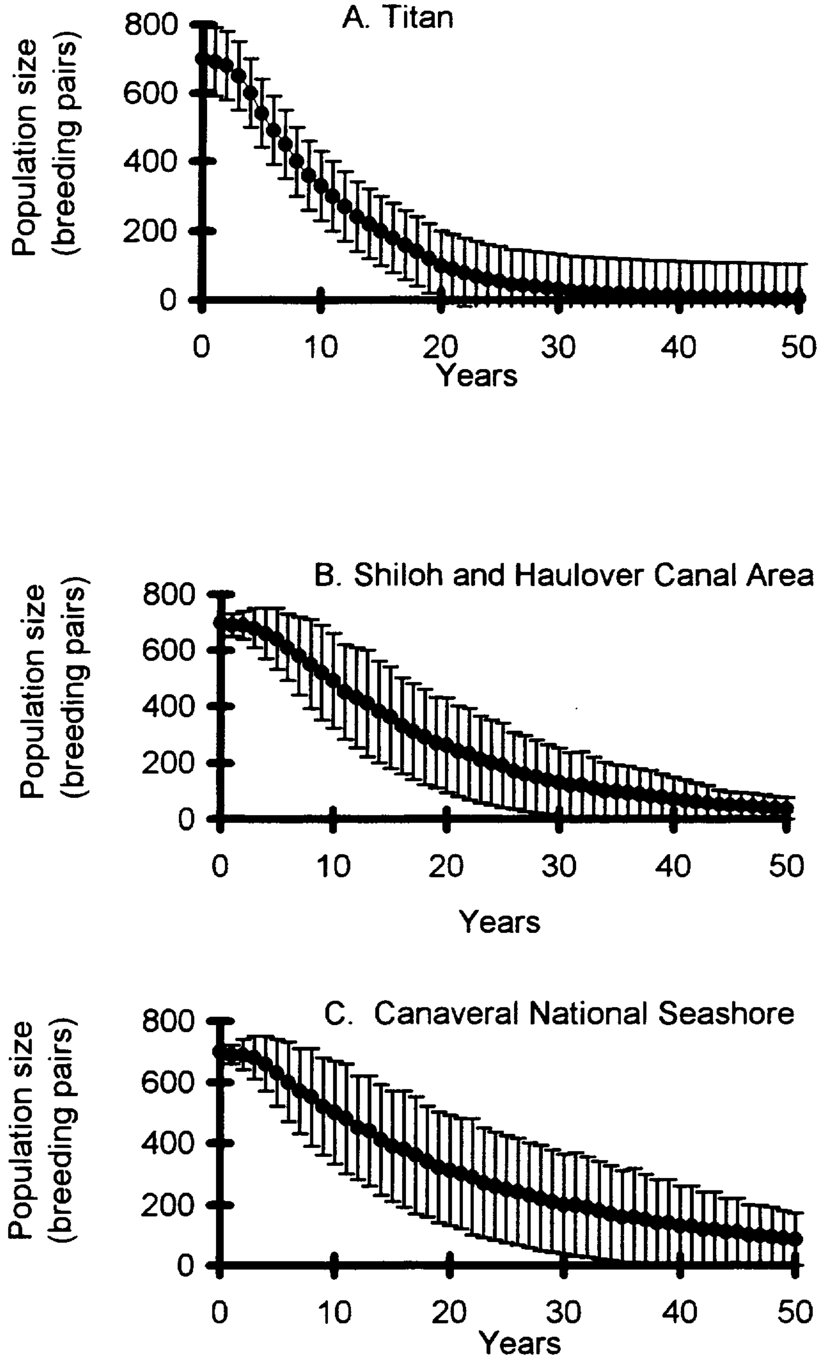
The Titan launch complexes occur along a narrow stretch of coastal habitats that connect KSC/MINWR and CCAS. The population on CCAS is more vulnerable to extinction due to a long history of fire suppression. Ongoing studies indicate that the CCAS population is only a portion of its potential and that reproductive success and breeder survival on CCAS is especially poor (Percival et al. 1995).

2.2.4 Shiloh and Haulover Canal

This landscape (Figure 2) had been subject to greater soils disturbance for longer periods than most landscapes due to earlier agricultural practices. Much scrub in these areas had a history of fire suppression for greater than 35 years. A few fires occurred but they did not burn large areas. Photographic sequences (1943-1979) showed that natural openings disappeared and most of the landscape became a woodland or forest.

The trajectory for Shiloh and Haulover suggested a population decline by 25% within 10 years (Figure 6B). Actual declines in Florida Scrub-Jay population have occurred (R. Schaub unpublished data). The Shiloh area has potential to support a large Florida Scrub-Jay population on KSC/MINWR (Breininger et al. 1991 a) but the population is less than 1/2 its potential (Section 3.5). Declines have probably occurred for longer periods than have occurred at Tel 4 and Happy Creek. There is a large area of scrub north of KSC/MINWR under CNS jurisdiction. This area has been largely unburned for greater than 35 years.

Figure 6. Population trajectories using reproductive success and survival data from A) Titan launch complexes, B) Shiloh and Haulover areas, and C) Canaveral National Seashore. Mean and standard deviations of 1000 simulations represented. Assumes that epidemics occur with a yearly probability of 0.05. Other catastrophic events are excluded.



2.2.5 Canaveral National Seashore

This landscape (Figure 2) had been subject to greater soils disturbance and habitat fragmentation due to recent construction of NPS facilities (Smith et al. 1994). Florida Scrub-Jays are also subject to road mortality in these habitat fragments. Much scrub in these areas had a history of fire suppression for greater than 35 years. Many fires occurred but they burned large areas under USFWS jurisdiction to the north and south of this study area.

The population trajectory suggested a population decline by 25% within 10 years (Figure 6C). Sensitivity analyses indicated that minor changes in demographic data have little influence on the trajectory. Actual declines in Florida Scrub-Jay population have occurred (Smith et al. 1994, unpublished data).

2.2.6 Estimated Population Declines

Recent studies have identified nearly all of the remaining Florida Scrub-Jays on all nonfederal properties at local (Swain et al. in preparation) and state levels (Fitzpatrick et al. in press). Attempts have never been made to estimate the KSC/MINWR population at such accuracy, and the available estimates are insufficient to document changes in population size (Appendix E). Ecological monitoring has focused on detailed, highly reliable data collection for only a portion of the KSC/MINWR landscape. Numerous, qualitative observations indicate that Florida Scrub-Jays no longer occupy many areas that were occupied in 1978 when Florida Scrub-Jay studies began at KSC/MINWR (D. Breininger pers. obs.)

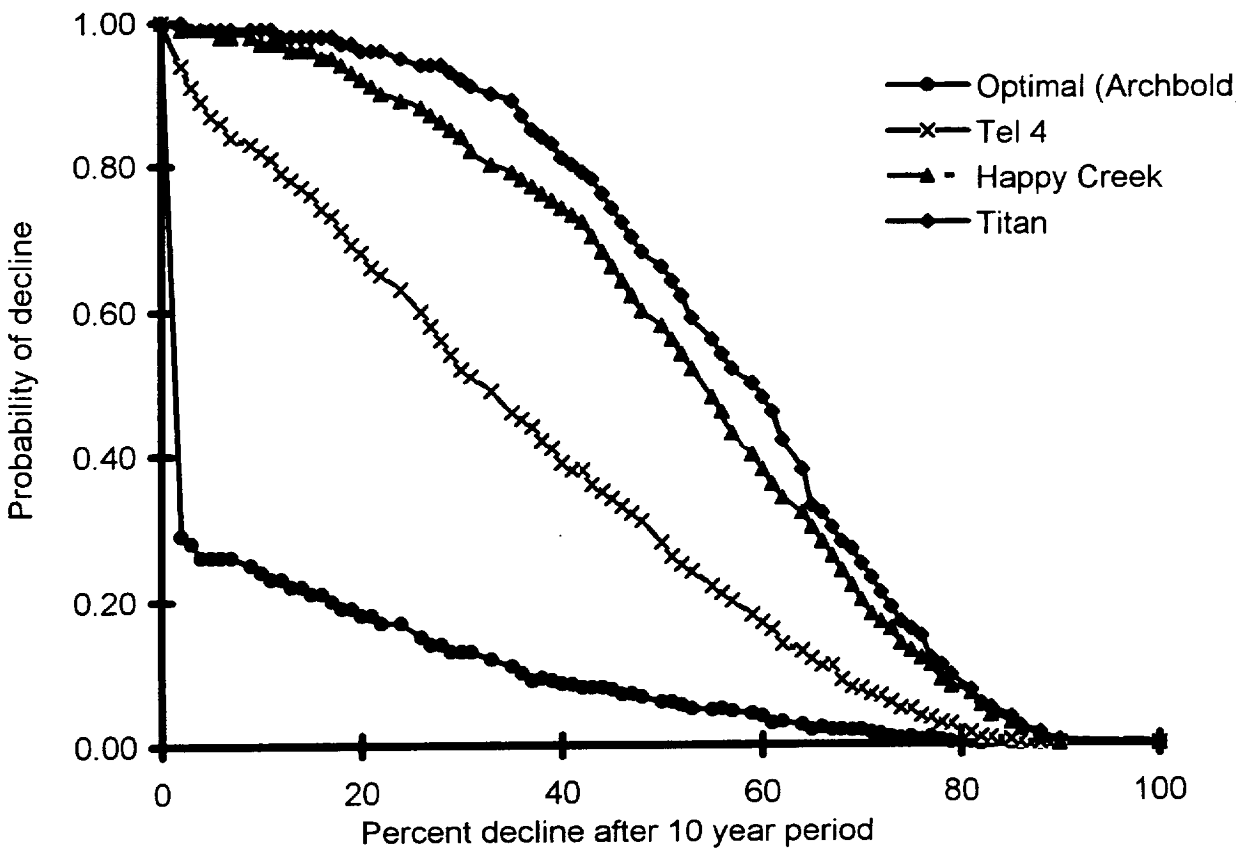
The vital rates from long term study sites can be applied to the KSC/MINWR population to estimate different probabilities of population decline for KSC/MINWR. The same vital rates and model that were used for the above population trajectories were applied to estimate the probabilities of different rates of decline at the end of 10 years, a procedure referred to as terminal percent decline (Ferson 1991). Although the actual decline in the KSC/MINWR population is impossible to determine, one can use the results of such analyses to estimate the probabilities and magnitudes of the decline.

Terminal percent decline results indicated a greater than 70% probability that all KSC/MINWR study areas experienced a decline of greater than 20% in 10 years (Figure 7). The probability of at least a 20% population decline in optimal habitat at Archbold was less than 20%. The probability of a 40% decline in ten years was greater than 70% for Happy Creek and Titan areas. Ongoing historical mapping and habitat data collection (Stout 1980, Breininger 1981, Schmalzer and Hinkle 1987, 1992 a, b; Breininger et al. 1988, 1991 a; Schmalzer et al. 1994) suggest that the habitat conditions responsible for the Florida Scrub-Jay decline have been occurring longer than 10 years. The population has declined by more than 50% from its habitat potential at Shiloh (Section 3.5). It is not possible to estimate the actual decline for the entire KSC/MINWR population; different landscapes probably had different rates of decline. Using a 40% decline as an assumption suggests the current population may only be approximately 400 breeding pairs.

2.2.7 Extinction Risk

Extinction risk is often presented as quasi extinction risk which is the probability that a population will fall below a threshold population size at least once during a specified period of time (Ginzburg et al. 1992). Here, risk curves represent the probability of falling below a threshold population size at least

Figure 7. Comparative probabilities of population declines. The percent decline is the percent of the population that declined at the end of a 10 year period. The curves resulted from 1000 simulations beginning with a population size of 700 breeding pairs. Assumes that epidemics occur with a yearly probability of 0.05. Other catastrophic events are excluded.



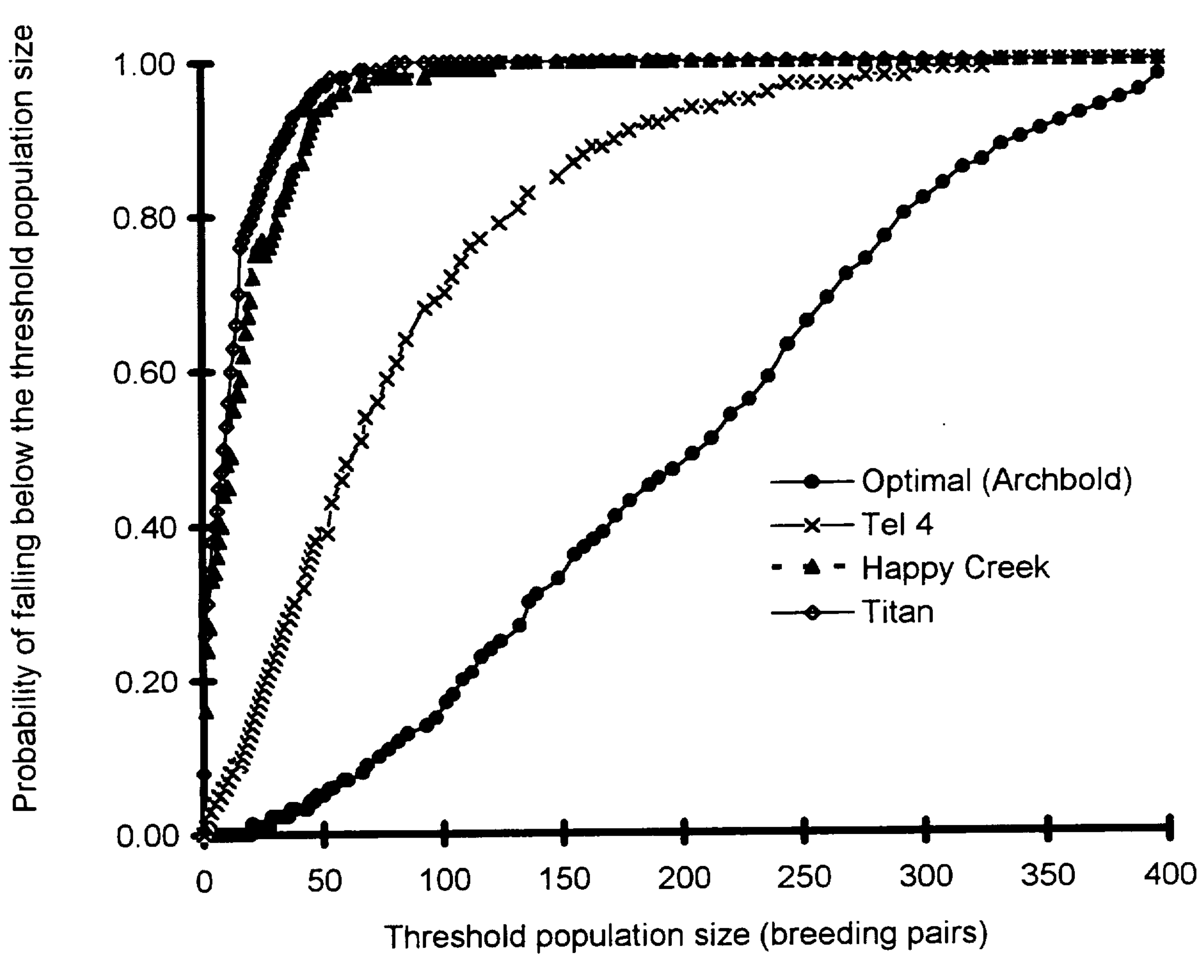
once during a 50 year period, a realistic management time frame. Demography from three study areas was used in three simulations to provide several estimates of risk for the entire KSC/MINWR population. The quasi extinction probabilities for the Happy Creek and Titan areas (Figure 8) suggest that the KSC/MINWR population has a greater than a 95% probability of declining from 400 to 50 breeding pairs within a 50 year period. Florida Scrub-Jay populations below 10 pairs in optimal habitat appear to almost invariably go extinct if isolated from other populations (Fitzpatrick et al. 1991, Woolfenden and Fitzpatrick 1991). The risk of falling below 10 pairs within 50 years is 50% for Happy Creek and Titan areas.

2.3 Landscape Change and Declines in Habitat Suitability

2.3.1 Replacement of Scrub with Urban Areas

Historical photography shows that Florida Scrub-Jay habitat on KSC/MINWR and CCAS population was once contiguous on the outer barrier island to at least as far south as Sebastian Inlet. Most areas south of CCAS are now urban (Larson 1992). Habitat on Merritt Island once was contiguous for many miles south of KSC/MINWR. Now most of this habitat is in agriculture or urban areas. Today, the only potential connection of KSC/MINWR Florida Scrub-Jay populations to the Florida mainland occurs at Oak Hill but the habitat within that area is extremely fragmented and of poor quality due to infrequent fire and high pine densities (Swain et al. in preparation). There are few Florida Scrub-Jays on the mainland near the KSC/MINWR connection, and little to no areas have been recommended for scrub habitat conservation on that area of the mainland due to low population viability.

Figure 8. Comparative extinction risk estimates. The risk curves represent the probability of falling below different threshold population sizes any time during a 50 year period. These threshold populations range from zero (extinction) to 400 breeding pairs, the beginning population size. Curves represent 1000 simulations and assume enough habitat to support a population of 400 breeding pairs. Assumes that epidemics occur with a yearly probability of 0.05. Other catastrophic events are excluded.



2.3.2 Increased Forestation

Pine densities increased and scrub oaks reached tree size during a 20 year period of fire suppression that occurred prior to 1978. Even after 17 years of prescribed fire management, forest cover continues to increase in many areas within the landscape, due to soil disturbance and habitat fragmentation (Schmalzer et al. 1994). Saw palmetto often does not reestablish itself in areas with severe soils disturbance, and this results in fuels discontinuities so that many disturbed areas become oak forests (Breininger and Schmalzer 1990). Pine woodlands and forests occur within habitat fragments or where the soils have been mechanically disturbed. Hardwoods, especially wax myrtle (*Myrica cerifera*), willow (*Salix caroliniana*), and red maple (*Acer rubrum*), have invaded marshes where there is exclusion of fire or alterations in hydrology (Schmalzer and Hinkle 1985). The woody invasion of swale marshes influences surrounding habitats, particularly scrub and pine flatwoods, by fragmenting a previously open landscape. Woody vegetation replaces flammable marsh vegetation so that fires no longer carry into surrounding areas.

2.3.3 Loss of Natural Openings Among Scrub Oaks

Natural openings disappeared during the 20 year period of fire suppression that occurred prior to 1978. Natural openings in scrub have not returned and do not persist long after fires, except in some pinelands (Breininger 1981; Schmalzer and Hinkle 1987, 1992 a; Schmalzer et al. 1994). Openings are abundant around pines and snags on KSC/MINWR (Breininger 1992). Snags often burn for days, sometimes weeks after fires, creating openings. Much scrub on KSC/MINWR has always lacked pines but historically had many openings.

Natural fire pattern and frequency within the landscape differed from the fire patterns achieved by management techniques. Most natural fires occurred during the growing season, and vegetation is adapted to growing season fires (Robbins and Myers 1992). Many prescribed fires have occurred in winter which may explain why natural openings have not returned. Winter fires do not reduce oak cover as effectively as growing season fires (Glitzenstein et al. 1995). Furthermore, the moisture patterns of fuels differ during winter and summer. Different types of vegetation have different flammability. The palmetto, gallberry holly, and grass matrix within oak scrub probably burned more frequently than wide patches of scrub oak. Accounts of historic fire patterns indicate that fire burned into wide patches of scrub oaks where the fires often stopped due to low flammability (Webber 1935). Historical aerial photography shows frequent openings among scrub oaks on KSC/MINWR especially along the edges of saw palmetto-lyonia. Fire suppression results in continuous fuel loadings making it difficult to reestablish openings in oak scrub without having excessive fires that burn across large areas. Scrub oaks need to be at a sufficient age from the last fire to provide acorns (a major food source), cover from predators, and nest sites for Florida Scrub-Jays.

Extensive, mechanical soil disturbances result in openings that can degrade scrub for long periods (Breininger and Schmalzer 1990). These openings are often located along roadsides where Florida Scrub-Jays are frequently killed by motor vehicles (Dreschel et al. 1990, Fitzpatrick et al. 1991). Although man-made edges may be extensively used by Florida Scrub-Jays (Breininger 1981), these edges could be "mortality traps" because they can be systematically searched by predators (Yosef 1994).

2.3.4 Historic Landscape Change

The Tel 4, Happy Creek and Shiloh study areas were selected for historical landuse/landcover analysis on KSC/MINWR. These areas were selected because they span much of the geographic range of KSC/MINWR, are long-term Scrub-Jay study sites, and represent a wide range of historical landuse on KSC/MINWR. Aerial photographs from 1943, 1951, 1958, 1969, 1979, and 1989 were used to map a time series of landuse/landcover changes. Landuse/landcover categories were mapped and digitized into ARC/INFO. Coverages were registered, overlaid, and acreage's of landcover types were determined. These results will be discussed and presented in the following sections for the Tel 4 and Happy Creek Study sites. Work on the Shiloh study sites is currently underway and is not presented here.

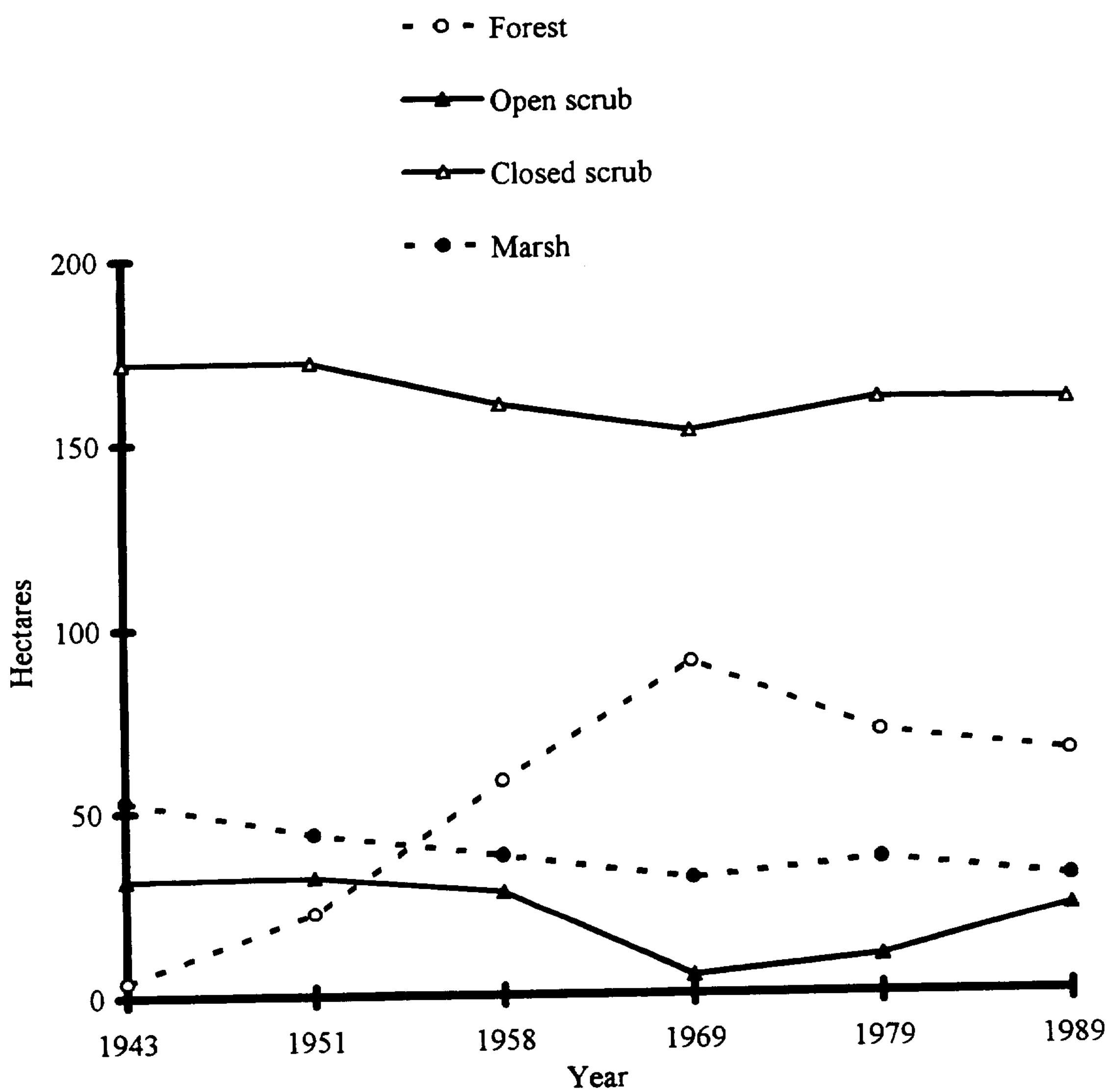
2.3.4.1 Tel 4

Since the 1940's there has been a decrease in the amount of open scrub and an increase in the amount of forest cover in the Tel 4 study area (Figure 9). Forest cover in 1943 was 1.3% of the study area; it increased to 30.7% in 1969, and then decreased to 21.8% in 1989. Open scrub was at its maximum in 1943, representing 10.4% of the study area; it decreased to 1.6% in 1969 and increased to 7.7% in 1989.

The dominant landuse in the Tel 4 area during 1943 was ranching. Other landuse practices such as citrus and a limited amount of crop farming were also present. Ranchers used fire to improve grazing by encouraging herbaceous growth and reducing woody cover. The habitat remained open with range management continuing until NASA purchased the land in the early 1960's (Figure 10). After this point, fire suppression went into effect, and the openings in the scrub began to disappear. In 1977 during this period of fire suppression, a wildfire burned through the Tel 4 area. In the late 1970's, prescribed fire management was implemented on KSC/MINWR. After the implementation of prescribed fire management, openings in the scrub have slowly began to return but have not yet reached the extent before the fire suppression period.

There were large areas of soil disturbance in the form of clearings to support the ranch facilities in the Tel 4 area (Figure 11). These cleared areas

Figure 9. Historical landscape trends mapped using aerial photographs for Tel 4.



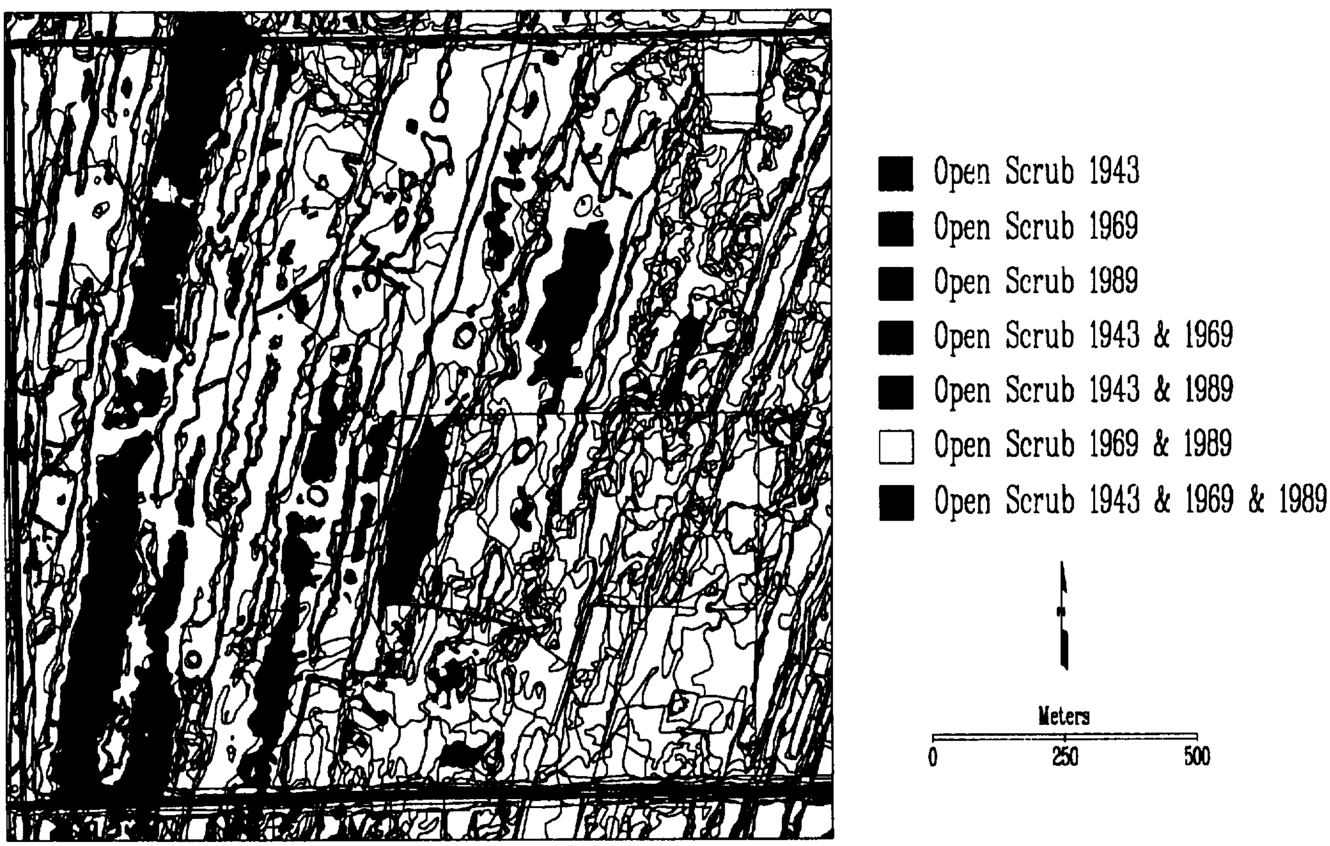


Figure 10. The dynamics of open scrub in the Tel 4 study site on Kennedy Space Center.

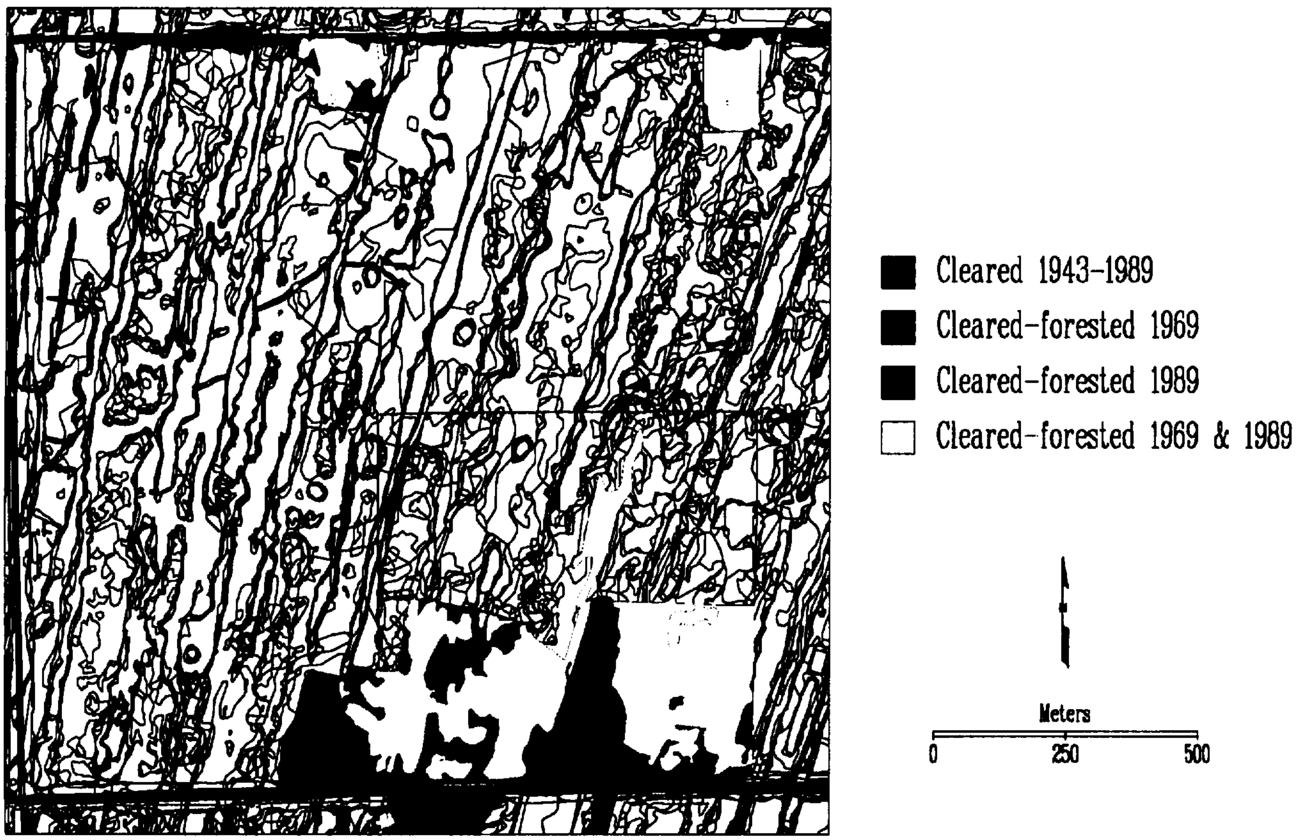


Figure 11. Forest establishment on previously cleared areas in the Tel 4 study site on Kennedy Space Center. Red areas were cleared between 1943 and 1989 but were not forested in 1989. Green areas were cleared between 1943 and 1958 and were forested in 1969. Blue areas were cleared between 1943 and 1979 and were forested in 1989. Yellow areas were cleared between 1943 and 1958 and were forested in 1969 and 1989.

were abandoned gradually until total abandonment after NASA purchased the land. Slash pine (*Pinus elliottii*) densely vegetated the abandoned cleared areas. With fire suppression in effect and the lack of a flammable understory, pines spread rapidly across the Tel 4 landscape (Figure 12). Prescribed fire management has reduced the rate of spread of pine forests but is unlikely to return these areas back to their native type without additional mechanical treatment (Duncan et al. in press).

The Tel 4 study area differs from many other areas on KSC/MINWR because it burned during the fire suppression period, and openings in the scrub oak vegetation were not completely lost. As a result, prescribed burning restored much Tel 4 habitat to optimal. Prescribed fire has also reduced the amount of forest cover over areas with a native understory. Fire is able to carry into these areas, penetrating under the canopy and thinning the overstory. Prescribed fire has not restored many areas that were cleared and recolonized by slash pines. A flammable understory does not extend into the tall pine canopy so that fires are ineffective in thinning (killing) pines to reduce forest cover. Logging and mechanical treatment is required in addition to fire to restore these areas. The Tel 4 study area clearly shows the implications of different land management practices on scrub with a pine overstory and the implications for the Florida Scrub-Jay which inhabits this dynamic habitat type.

2.3.4.2 Happy Creek

Happy Creek gained forest cover and lost openings in scrub (Figure 13). In 1943, 5.2% of the Happy Creek study site was forest cover. Forest cover increased to a maximum of 18.2% in 1989. Open scrub in 1943 comprised 7.7% of the Happy Creek study site, increased to 14.0% in 1951, decreased to a low of 2.7% in 1969 and increased slightly to 3.3% in 1989.

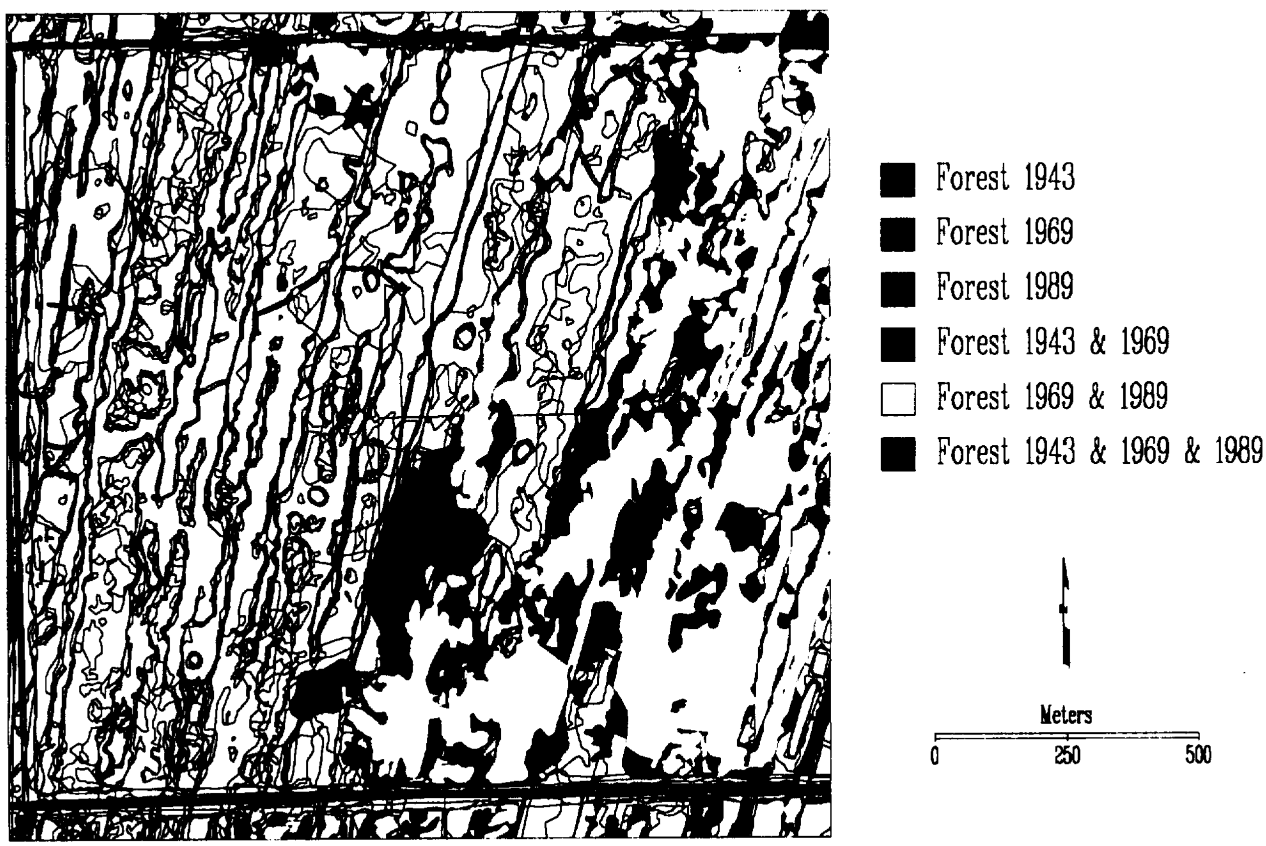
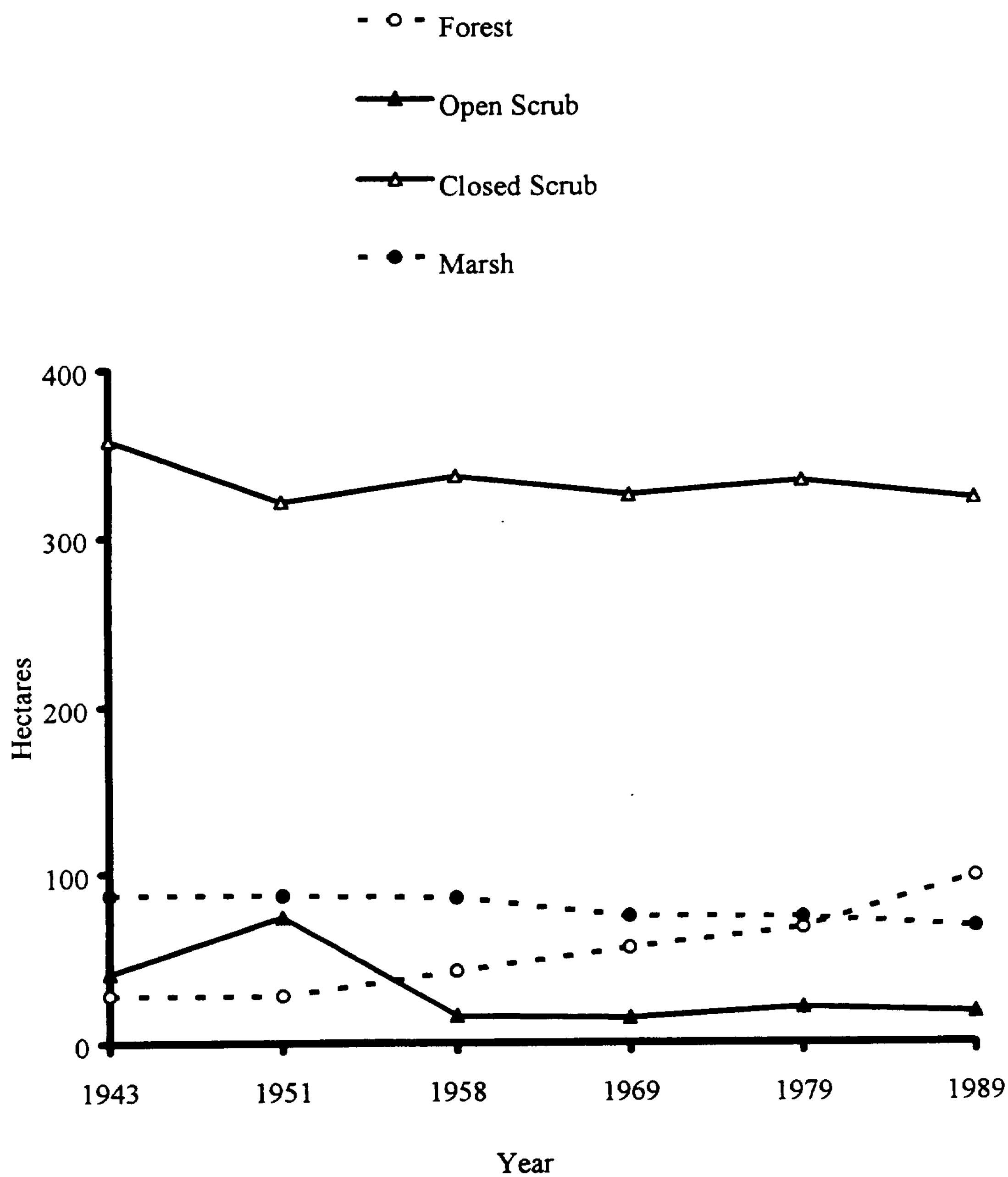


Figure 12. The dynamics of forest in the Tel 4 study site on Kennedy Space Center.

Figure 13. Historical landscape trends mapped using aerial photographs for Happy Creek.



Landuse practices at Happy Creek during the 1940's and 1950's were less uniform than at Tel 4. Most land at Happy Creek did not appear to be intensely managed and only contained a few scattered homesteads and farming fields (Duncan et al. in press). The largest disturbance at Happy Creek was extensive land clearing that took place in the northwestern corner just prior to 1958. This clearing, complete with road network, was for a housing subdivision that would have been built if NASA had not purchased the land.

The Happy Creek landscape differs from Tel 4 in other aspects. Another main difference is that Happy Creek's sand ridges are much broader and more extensive than ridges at Tel 4. The dominant vegetation type in Happy Creek is xeric oak scrub with interspersed mesic vegetation while Tel 4 is dominated by mesic vegetation with interspersed xeric oak scrub. Another important difference is that the Tel 4 study site has abundant pines and Happy Creek has few pine trees. Because of these differences, fires carry through the landscapes differently due to the low flammability of scrub oaks and high flammability of pine needles (Webber 1935).

There were many scrub openings mapped from the 1943 imagery, but more openings were mapped from the 1951 imagery (Figure 14). Scrub openings are related to time since fire and there is much evidence for a hot fire prior to 1951. Many openings resulted from a fire that occurred just before the imagery was taken. Historical climate records document 1950 as a year with above average rainfall but, far below average June, July, August and September monthly measurements. An ignition (lightning strike or man induced) probably started the fire under extreme conditions sometime in the above four month period during 1950. Prior to the fire suppression period, fires in xeric scrub probably were most extensive during dry periods (Davidson and Bratton 1986, Robbins and Myers 1992). Slight to moderate increases and decreases in open

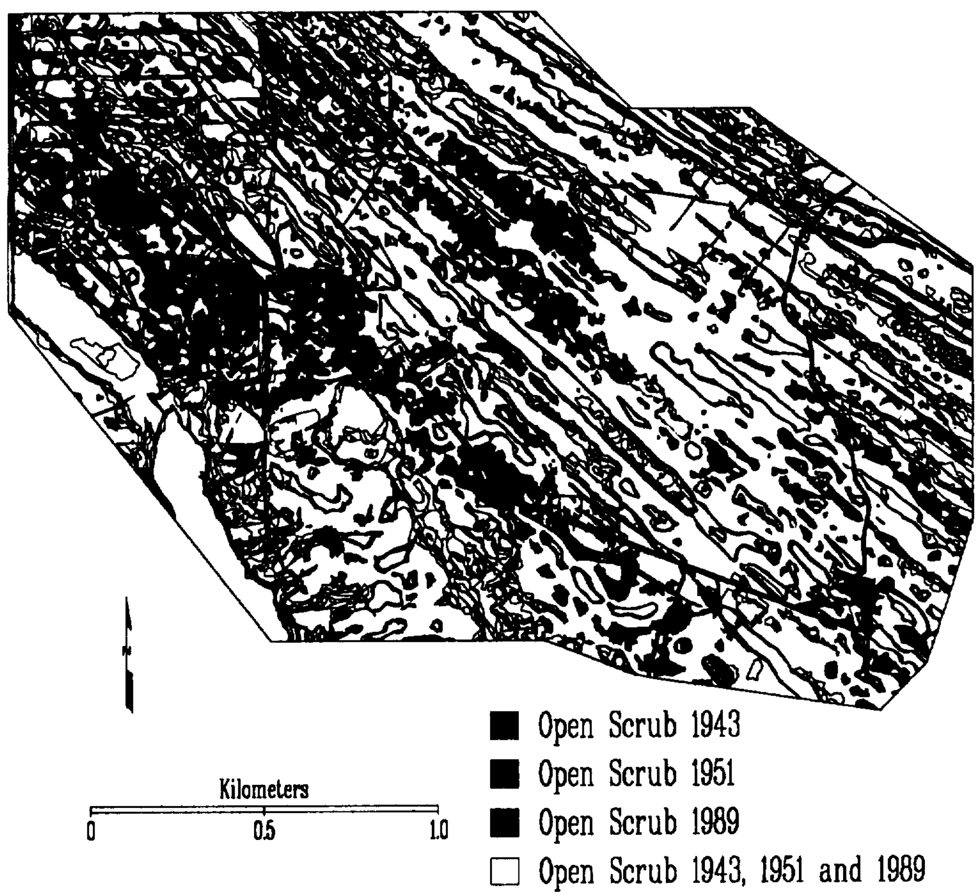


Figure 14. The dynamics of open scrub in the Happy Creek study site on Kennedy Space Center.

space, attributed to time since the last fire, are expected within scrub habitats (Schmalzer and Hinkle 1992 a, b). Openings at Happy Creek before in 1943 and 1958 were a complex mosaic that surrounded scrub oaks.

The imagery for Happy Creek shows that 1958 was the start of a large decline in the amount of openings surrounding scrub oaks. Beginning in the 1960's, fires had little chance to burn across the KSC/MINWR landscape under any conditions, especially after the landscape was fragmented by roads, facilities, and other firebreaks. In the early 1980's, prescribed burning was implemented at Happy Creek but few natural openings returned. Prescribed fires have not reversed trends initiated by fire suppression. Today's natural openings are far below the extent found in 1943 and 1951, when fires swept through the landscape, often during the growing season and occasionally under extreme conditions. Openings at Happy Creek are now associated with simple edges between closed scrub and mowed grass or open sandy trails.

Forest cover increased from 1943 to 1989 (Figure 15). Naturally occurring hardwoods found on poorly drained soils spread into surrounding swales. Without frequent fire, the swale grasses and sedges were unable to compete with hardwoods. Once hardwoods became established, fires carry poorly through these areas. Occasional fire under extreme conditions can burn through the established hardwoods but they simply resprout with little alteration of the hardwood composition. Most prescribed fires around these forests has not slowed the process of forest spread into swales. A 1993 restoration fire burned with high intensity in a few forested areas and significantly reduced tree cover in these areas.

Disturbed sites have often been vegetated by forests (Figure 16). Well drained sites have generally returned to scrub or an oak scrub woodland with slightly altered composition. Saw palmetto, which carries fires through oak scrub, revegetates disturbed areas poorly (Breininger and Schmalzer 1990).

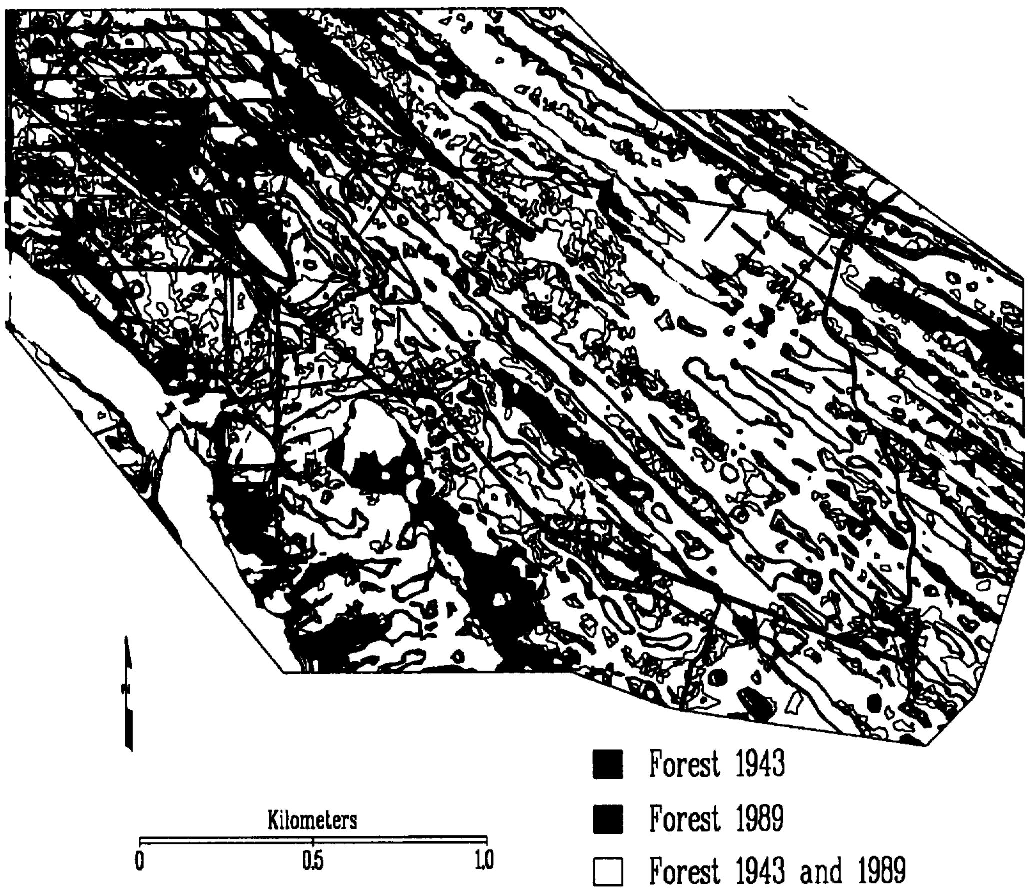


Figure 15. The dynamics of forest in the Happy Creek study site on Kennedy Space Center.

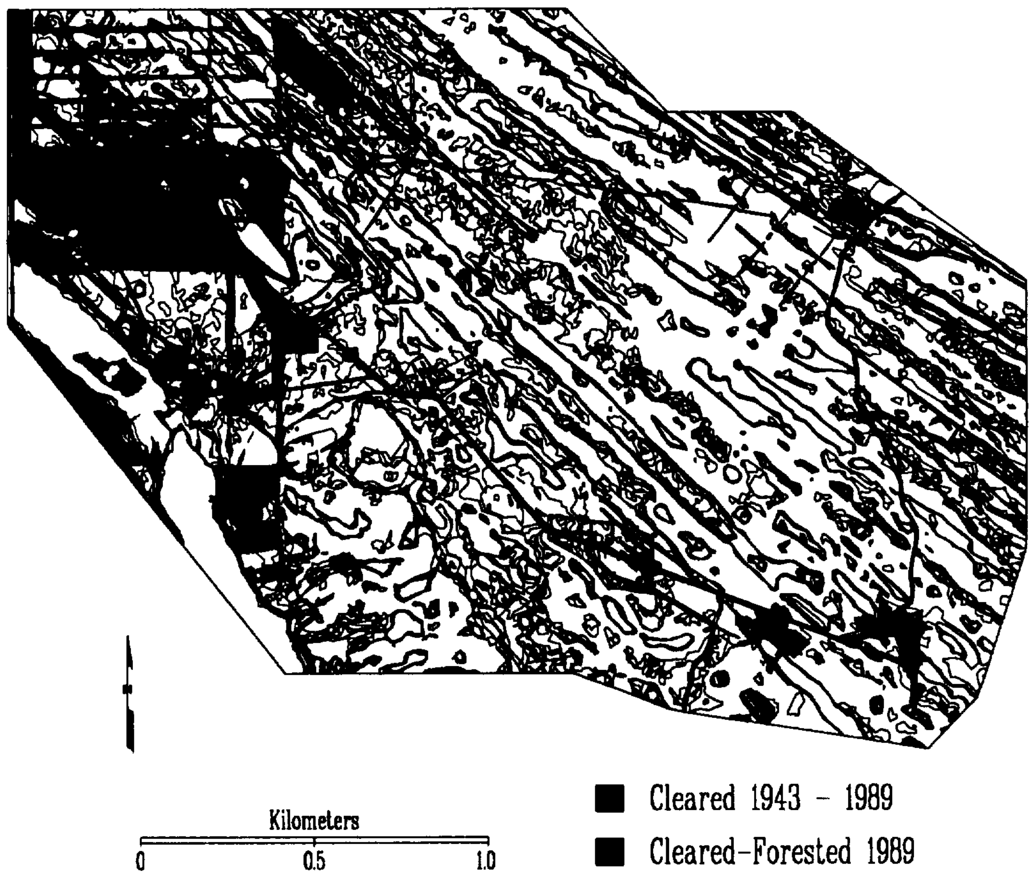


Figure 16. Forest establishment on previously cleared areas in the Happy Creek study site on Kennedy Space Center. Red areas were cleared between 1943 and 1989 but were not forested in 1989. Green areas were cleared between 1943 and 1989 and were forested in 1989.

The relative abundance of scrub oaks also differs in disturbed areas (Breininger and Schmalzer 1990). The Tel 4 vegetation responded differently to clearings, perhaps because there was an abundant nearby source of pine seeds. At Happy Creek, hydric and mesic disturbed areas were colonized by many types of hardwood trees, especially by those characteristic of forests and swamps. These hardwoods burned poorly in comparison to swale marshes.

_Unlike Tel 4, Happy Creek went through a longer period of fire suppression, which had additional habitat degradation effects. Combined with fuels discontinuities resulting from landscape and vegetation patterns, a longer fire suppression period resulted in a greater reduction in habitat suitability than Tel 4. Winter prescribed fires have not reestablished an abundance of natural openings and have not prevented further forestation at Happy Creek.

2.4 Habitat Restoration and Population Recovery

The length of time for population recovery depends upon stochastic events (e.g., epidemics, hurricanes) and habitat suitability, which must be optimal for recovery to occur. It is unlikely that population numbers will rebound rapidly even after a large scale restoration effort (Figure 17). The population recovery period will be longer and have less chance for successful recovery, if aggressive restoration is not implemented quickly. Continued population decline will reduce the number of breeding pairs, as well as the number of helpers. Helpers are important to the population because they are potential breeders for restored areas, and they enhance the demographic success of breeders by helping breeders (Woolfenden and Fitzpatrick 1991).

Restoration of the habitat will decrease extinction risk even if the population does not rapidly increase, providing that most habitat begins to approach optimal conditions (Figure 18). Simulations using empirical

Figure 17. Influence of habitat, helpers, and epidemics on population trajectories in habitat capable of supporting 700 breeding pairs after restoration. Assumes that habitat is restored to optimal or moderate suitability. Reproductive success and survival rates for optimal habitat derived from Woolfenden and Fitzpatrick (1984). Moderately suitable habitat vital rates were approximately midway between optimal and unburned habitat.

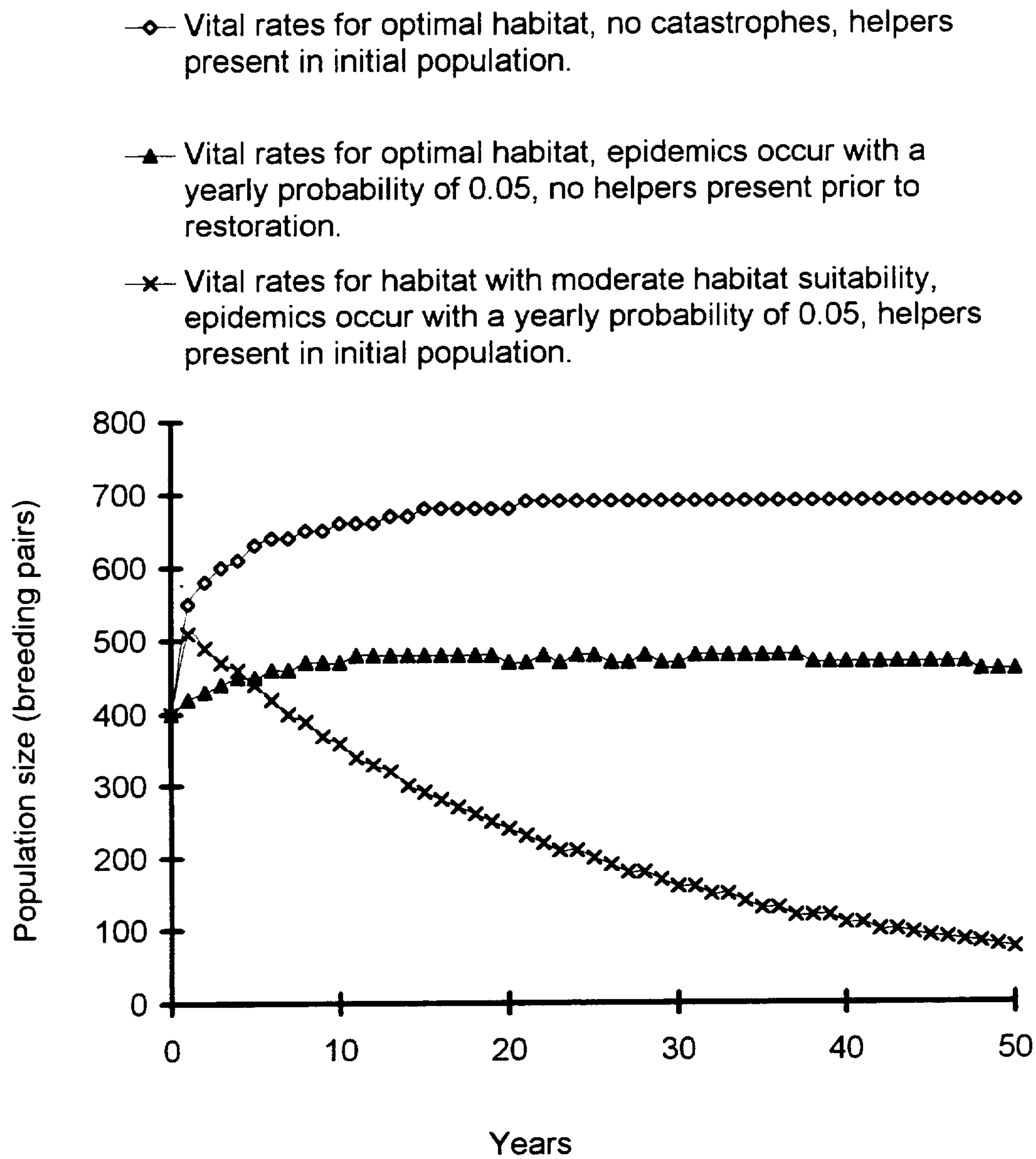
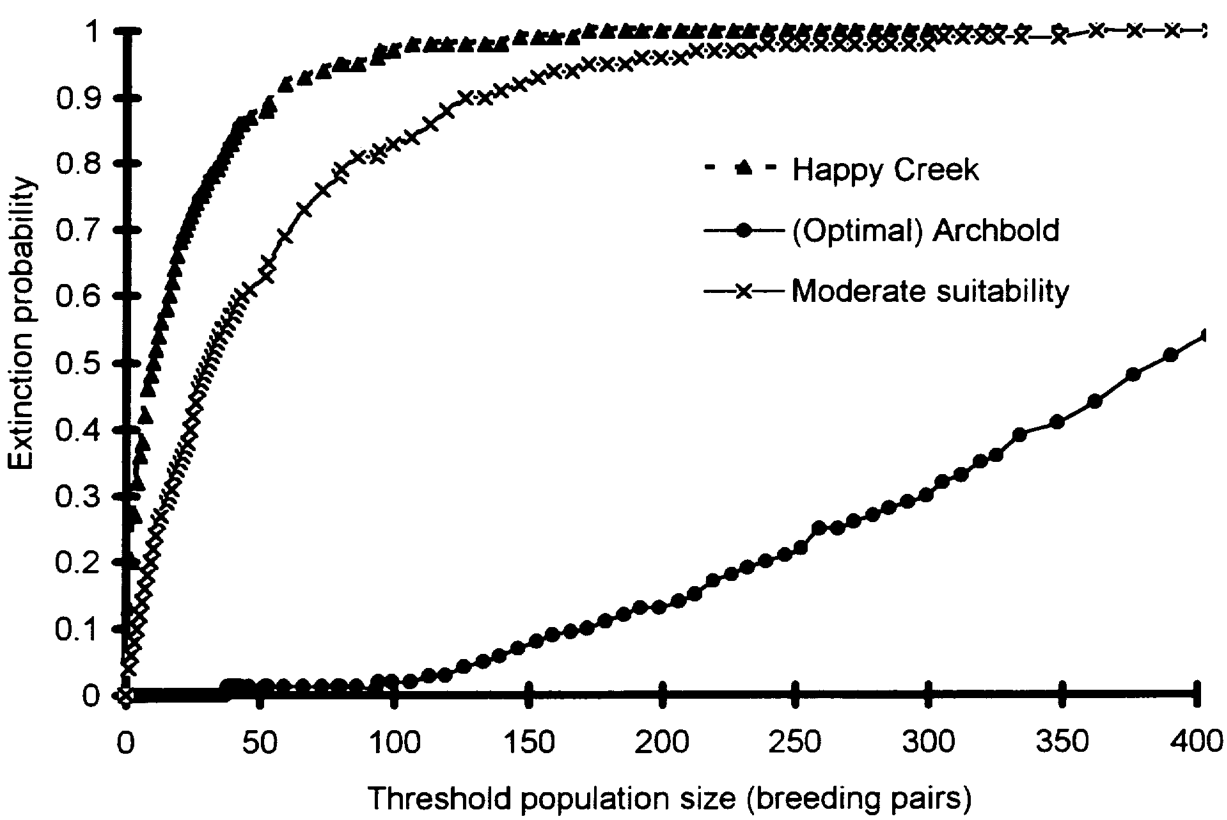


Figure 18. Reduction of extinction risk associated with restoration. Curves represent 1000 simulations beginning with a population size of 400 breeding pairs and assuming enough habitat to support a population of 700 breeding pairs. The risk curves represent the probability of falling below threshold population sizes any time during a 50 year period. The Happy Creek trajectory assumes that reproductive success and survival remain the same as those that currently occur at Happy Creek. The moderately suitable habitat trajectory assumes improvements in habitat quality but that reproductive success and survival rates remain 5% below optimal. The optimal habitat trajectory assumes that optimal habitat conditions follow a restoration program. Assumes that epidemics occur with a yearly probability 0.05. Other catastrophic events are excluded.



data showed that habitat must be optimal for population persistence and that population extinction is inevitable if poor habitat suitability remains characteristic of KSC/MINWR scrub.

Even large Florida Scrub-Jay populations are likely to become extinct within 50 years in poor quality habitat (Figure 19). Extinction probabilities in moderately suitable habitat are relatively low only for large populations. A population size of 400 breeding pairs is essential to have an extinction risk of 1% in optimal habitat (without hurricanes and other large catastrophes). Achieving optimal habitat conditions quickly by extensive restoration is unlikely. Therefore, it is important to manage for a large population size in order to attain low extinction risk.

The hurricane risk attributed to the coastal proximity of KSC/MINWR is a second reason to manage for a population size that approaches the maximum potential population size (Breininger et al. unpublished ms.). A population size of nearly 800 breeding pairs is needed to have an extinction risk of 1% in optimal habitat, when hurricanes are considered (Figure 20). Total storm surge inundation could result in greater mortality than simulated. Half of the scrub on barrier islands could be inundated by category 3 storms and all could be inundated by category 5 storms (Post, Buckley, Schuh, & Jernigan, Inc., 1990). A direct hit by a category 5 storm might be needed to inundate all of KSC/MINWR given that scrub is nearly contiguous for 47 km. No catastrophic hurricanes hit near Merritt Island/Cape Canaveral during the last 100 years (Breininger et al. unpublished ms.).

Figure 19. Influence of initial population size and habitat suitability on extinction risk. Quasi extinction probability refers to the chance that a population will decline below 10 pairs, a population size that usually involves extinction. Assumes that epidemics occur with a yearly probability of 0.05. Other catastrophic events are excluded.

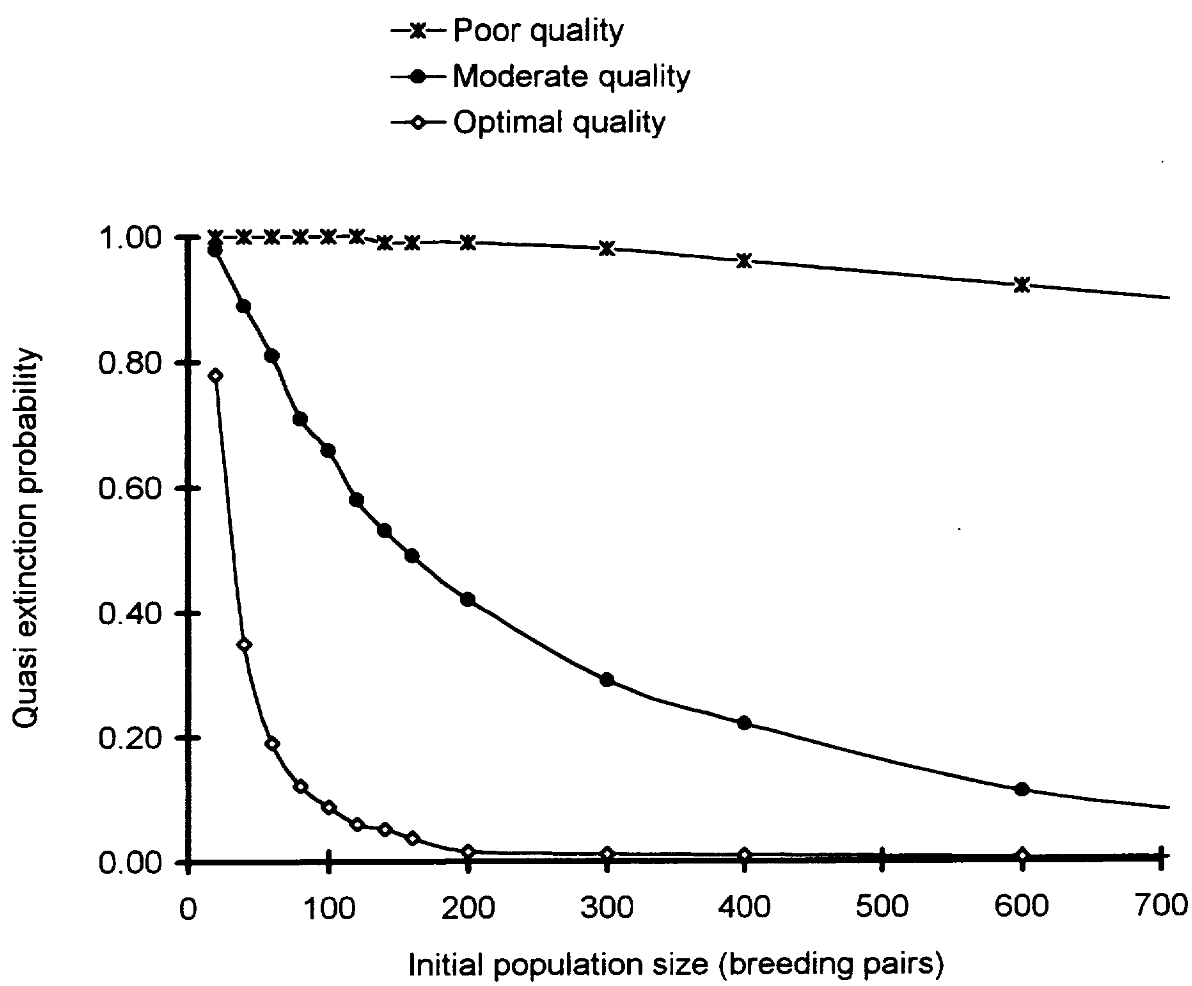
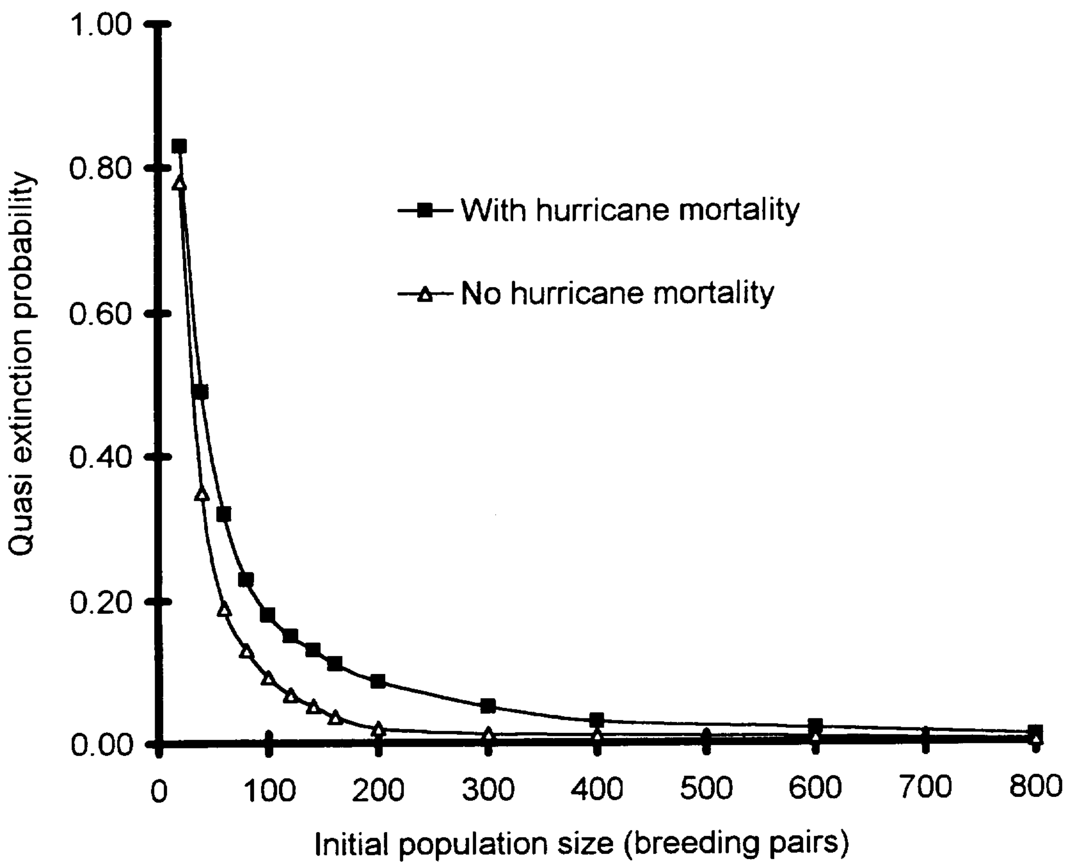


Figure 20. Influence of initial population size and hurricanes on extinction risk in optimal habitat. Quasi extinction probability refers to the chance that a population will decline below 10 pairs, a population size that usually involves extinction. The frequency of epidemics is assumed to be 0.05 per year. The yearly probablity of a catastrophic hurricane is assumed to be 0.01 resulting in a 63% mortality rate of all Florida Scrub Jays.



3.0 Strategic Recovery Plan

One overall objective of this recovery plan is to achieve a core population of 400-800 Florida Scrub-Jays in optimal habitat. Another objective is to maintain the biological integrity and diversity of the scrub ecosystem that is characteristic of KSC/MINWR. The habitat needs of species of conservation concern coincide with the goals of fuels management. The use of prescribed fire as a primary management tool will manage scrub habitat for species of conservation concern (Appendix C) and eliminate fire safety hazards that result from high fuel loadings. Knowledge and resources require that this effort be phased and involve successive refinement following adaptive management principles. Recovery will require numerous parallel activities undertaken during an interim period of extensive restoration.

3.1 Criteria of Reserve Design

Most Florida Scrub-Jay habitat must be in optimal condition for population persistence, and this is not readily achieved using only prescribed fires, once habitat is degraded (see Sections 2.4 and 3.3). An adaptive, detailed reserve implementation process will need to be established to prioritize fine scale habitat restoration, prescribed burning, and ecological monitoring. Landscapes need to be subdivided based on current habitat suitability, potential habitat suitability, and the potential for habitat management with and without mechanical restoration. Alternative, detailed reserve designs can then be formulated based on economic estimates for mechanical restoration, fire management, and proximity to urban and industrial areas. Expected population sizes can be estimated based on average territory size and available habitat.

A coarse reserve and conservation strategy can be developed with existing information. Maps have been prepared of existing landscapes and potential reserves using existing vegetation, soils, habitat and land use maps

(Huckle et al. 1974, Breininger et al. 1991 a, Larson 1992). Several principles for reserve designs can be immediately adapted using basic conservation science (Thomas et al. 1990, Noss 1991, Murphy 1992, Brussard and Murphy 1992, Murphy and Noon 1992, Noss and Cooperider 1994). Many of these principles apply to Florida Scrub-Jay conservation planning at state (Fitzpatrick et al. in press) and local (Brevard County) planning levels (R. Bowman, Archbold, unpublished, Swain et al. in preparation).

3.1.1 Provide for a Large Population

A large population reduces the probability of extinction. Efforts should be focused on meeting state guidelines for core populations (Fitzpatrick et al. in press). Reproductive success and mortality rates of Florida Scrub-Jays are precariously balanced with habitat quality so that most habitat occupied by Florida Scrub-Jays must be optimal for population persistence. Uncertainty exists concerning the existing population size and the ability to return all habitat to optimal conditions. Even with immediate management changes, much of the population may temporarily decline given the population trajectories resulting from landscape change within the last half-century. Consequently, restoration should include all major scrub landscapes.

3.1.2 Maintain the Northern and Southern Extent of the Population

The proximity of habitat to the Atlantic coast makes the population vulnerable to hurricanes (Breininger et al. unpublished ms.). The topography (i.e., very low elevation and shallow water table) makes this region potentially vulnerable to climatic events (Weiss and Murphy 1993). The location and nature of operations for the space program and national defense makes the population vulnerable to catastrophes. Maintaining and enhancing the geographical distribution of Florida Scrub-Jays decreases the risk of single devastating impacts on the population. The combination of KSC/MINWR, CNS, and CCAS populations provides for a larger population overall. Evidence suggests that demography varies among landscapes (Breininger et al. 1995); thus, some landscapes may be particularly important as population sources in comparison to other landscapes. This may relate to landscape configurations, predator populations, or other environmental factors. For these reasons, it is imperative to maintain the maximum north-south distribution of the population and the links to the Cape Canaveral population.

3.1.3 Maintain the Population in Large, Contiguous Landscapes

Large habitat patches are likely to maintain the largest numbers of Florida Scrub-Jays, if all other factors are equal. Small, fragmented patches are often adjacent to forests that have a negative influence on Florida Scrub-Jay habitat suitability (Breininger et al. 1995). Florida Scrub-Jays have a keenly developed sentinel system for detecting predators such as hawks (McGowan and Woolfenden 1989). Families surrounded by other families, not forests, have early warnings when woodland hawks are nearby. Large, open landscapes allow Florida Scrub-Jays to detect predators from long distances (Woolfenden and Fitzpatrick 1984, 1991; Fitzpatrick et al. 1991). Nonbreeders have greater opportunity to detect breeding vacancies in their surroundings with less risky dispersal then when surrounded by poor quality habitat, forests, or development (B. Stith, unpublished data). Populations in large, contiguous landscapes thus have the best chance for long term survival.

3.1.4 Minimize Edge by Keeping Reserve Areas Wide

The geology of Merritt Island and Cape Canaveral has resulted in the formation of longitudinal ridges of habitat mostly parallel to the coastline. Geological formations have also influenced the position of other landscape features including forests and roads. In order to maximize total area and minimize the amount of edge, population areas should be elliptical (Sisk and Margules 1993). Orientation of the long axes of the patches should be generally north to south, making each patch as wide as possible east to west.

Minimizing edge will reduce the number of territories along busy roads that are likely to have high mortality and will often be population sinks (Fitzpatrick et al. 1991, Dreschel et al. 1990). The proximity of scrub patches to forests should also be minimized, because populations near forests are subject to nest and adult predation. A long north-south axis maintains continuity across the KSC/MINWR population, and a wide east-west axis minimizes edge effects.

3.1.5 Maximize Well Drained Scrub but Maintain the Necessary Matrix

Most high quality Florida Scrub-Jay habitat consists of scrub on well drained soils with adjacent scrub on poorly drained soils areas (Woolfenden and Fitzpatrick 1984). Nearly 80% of the Florida Scrub-Jay population in the mid-1980s occurred within 300 m of well drained areas on KSC/MINWR (Breininger et al. 1991 a).

Reserve design and habitat management should minimize the interspersion of woodlands, forests, and industrial areas within landscapes important to Florida Scrub-Jays. Poorly drained scrub and swale marshes are native landscape components that should surround well drained scrub and serve as buffers between forests and other edges of negative influence. Native matrix habitats are important because they provide prey species for Florida Scrub-Jays and habitat for other species of conservation concern (Moler and Franz 1987; Breininger et al. 1994 a, b). Fires that burn into wide patches of scrub oaks often stop due to low flammability (Webber 1935). Saw palmetto, gallberry holly, and grasses, which dominate palmetto-lyonia and marshes, are more flammable and accumulate fuel more rapidly than scrub oaks (Abrahamson 1984 a, b Abrahamson and Hartnett 1990, Myers 1990, Schmalzer et al. 1991, Schmalzer and Hinkle 1992 a, b). Thus, the flammability of native matrix habitats is important for spreading fires into oak dominated areas that often burn poorly.

3.1.6 Keep Patches in Close Proximity

Contiguity is important because it minimizes dispersal risk. Mortality of Florida Scrub-Jays moving through mostly non-scrub habitats is very high (B. Stith unpublished data). Scrub within the reserve should be as contiguous as possible without gaps, such as forests, development, or large bodies of water. Small woodlands, agriculture, and urban areas increase the risk of mortality for dispersing jays. Dispersal across large bodies of water or forests is improbable and poses extreme risks. Gaps in suitable habitat should be as narrow as possible. Some narrow and less optimal corridors of habitat will be required to maintain linkages among all patches.

3.1.7 Maximize Habitat Quality and Minimize Restoration Costs

Populations within regions of the highest habitat quality will have the greatest probability of persistence (Breininger et al. unpublished ms). High habitat quality will maximize population size and its associated survival and reproductive success. Restoration costs and risks of successful restoration efforts increase as habitat quality decreases.

Early objectives of restoration should focus on reversing the decline in demographic success of the Florida Scrub-Jay in all major landscapes and establishing stable populations in the selected landscapes by managing for optimal habitat (Woolfenden and Fitzpatrick 1991, Breininger 1992 b). Monitoring during this process will be needed to identify finer scale habitat requirements for long term population persistence. Recovery efforts will need continual evaluation and modification as data on vegetation and populations accumulate. The process will need to continually evaluate the importance of habitat management strategies to other species of conservation concern and ecosystem processes. Much overlap occurs between conditions optimal for Florida Scrub-Jays and conditions required for other species of conservation concern (Appendix C). Management of Bald Eagle (*Haliaeetus leucocephalus*) nesting habitat requires additional considerations and priorities that need to be incorporated into alternative reserve designs.

3.2 Biogeographical Considerations

3.2.1 Population Centers

Recent habitat mapping (Larson 1992) identified four landscapes dominated by scrub (Table 1, Figures 21, Figure 22) which may serve as scrub reserve units (SRUs). These areas have the highest habitat potential for the population (Breininger et al. 1991 a). These areas could provide a population of approximately 700 territories, assuming 10 ha of scrub is needed for each territory. Historical aerial photographs and edaphic conditions show that these landscapes were dominated by scrub with many openings, marshes, and few forests. Much of the Shiloh landscape is dominated by well drained soils, while most other KSC/MINWR landscapes include patches of well drained soils in a matrix of poorly drained soils (Huckle et al. 1974, Breininger et al. 1991 a).

Cape Canaveral was dominated by coastal scrub on mostly well drained soils, but it has been subject to 40 years of fire suppression. Historical aerial photography shows that Cape Canaveral scrub had many openings and few trees.

The adjacent Florida mainland originally supported much more extensive well drained scrub than present, but this scrub was decimated by habitat destruction. Scrub on the Florida mainland now occurs as patches of mostly long unburned habitat (Snodgrass et al. 1991, Larson 1992, Bergen 1994). There is no realistic potential to link mainland Florida Scrub-Jay populations with those on KSC/MINWR due to wide expanses of open water that separate the mainland from Merritt Island and the extent of scrub destruction and degradation on the Florida mainland (Swain et al. in preparation).

Table 1. Current land cover composition (hectares) of the Scrub Reserve Units (SRUs) and corridors between SRUs.

Land cover type	Description	SRUs				Corridors				Totals
		I	II	III	IV	a	b	c	d	
Scrub	Oak scrub, coastal strand, scrubby flatwoods, pine flatwoods, and palmetto prairie	860	2406	1387	1854	101	97	91	384	7181
Marsh/swale	Fresh water marsh and ephemeral swales	66	375	527	132	0	4	1	10	1116
Mixed shrub/exotics	Wax myrtle, baccharis, disturbed cabbage palm, Brazilian pepper, and Australian pine	148	122	199	49	69	35	20	29	672
Barren land/sand	Fire breaks, impoundment dikes, cleared areas, beach sand and other open sand areas	33	60	68	14	18	3	36	21	253
Wet shrubs	Willow or wax myrtle wetlands	57	148	181	12	3	8	9	19	436
Salt marsh/mangrove	Salt tolerant grass marshes, Spartina, black rush and mangrove	25	303	1	0	17	64	153	14	577
Hammock	Oak, pine, cabbage palm and deciduous forests	343	760	506	290	181	19	104	237	2440
Urban/agriculture	Developed	49	218	288	112	105	74	79	333	1258
Water	Estuarine and fresh open water	24	57	61	34	28	74	42	81	401
Totals		1605	4450	3219	2497	521	378	535	1129	14332

SRU I = Shiloh, II = Happy Creek, III = Schwartz Road, IV = Southern Pinelands; a = Haulover, b = Banana Creek, c = Cape Canaveral, d = Industrial Area.

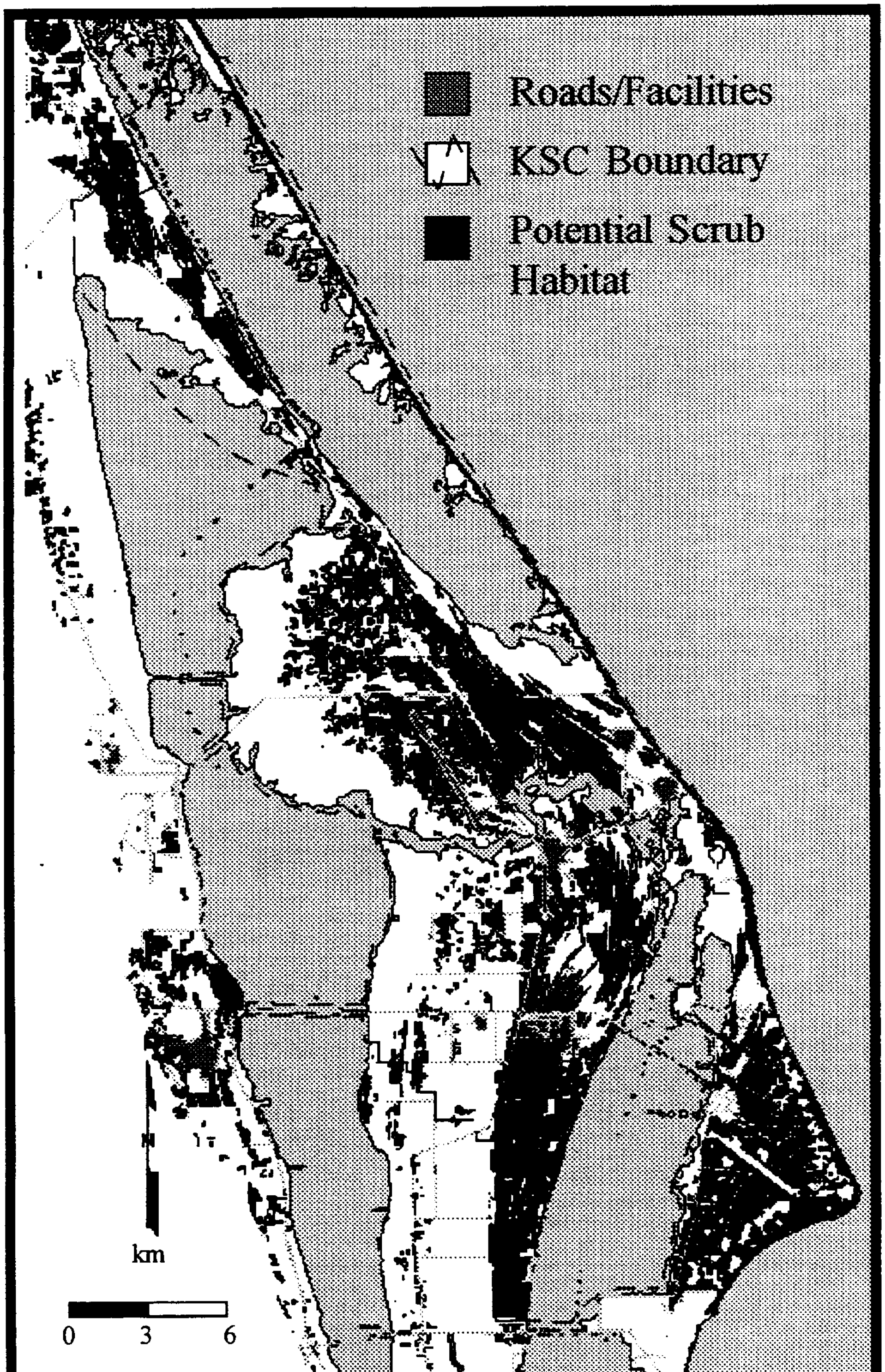


Figure 21. Potential scrub habitat on John F. Kennedy Space Center/Merritt Island National Wildlife Refuge, Cape Canaveral Air Station and adjacent lands.

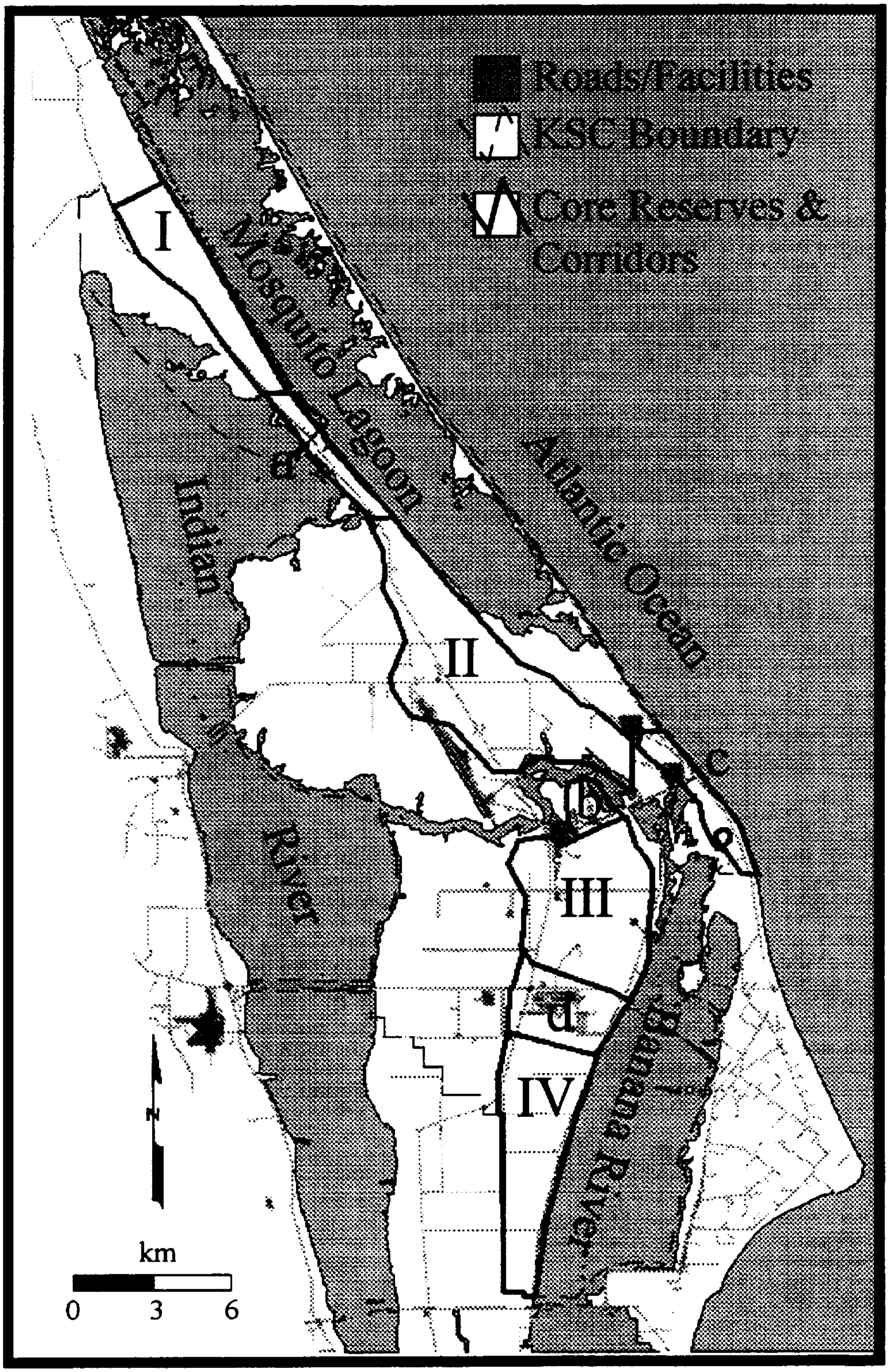


Figure 22. Scrub reserve units (SRUs) and corridors. Roman numerals indicate cores. SRU: I-Shiloh, II- Happy Creek, III-Schwartz Road, and IV-Southern pinelands. Corridors: a-Haulover, b-Banana Creek, c-Cape Canaveral, and d-Industrial Area.

3.2.2 Linkages

A narrow corridor of occupied Florida Scrub-Jay habitat surrounding the Space Shuttle (i.e., LC39A and LC39B) and Titan (i.e., LC40 and LC41) Complexes exists between KSC/MINWR and CCAS (Larson et al. 1993). This is a vital link between SRUs on KSC/MINWR and CCAS (Figure 22); this corridor is also important for other scrub species of conservation concern.

Several linkages between scrub reserve units on KSC/MINWR require restoration. The most northern of these is the Haulover corridor which connects the Happy Creek area with the Shiloh landscape (Figure 22). Movement through this area requires crossing Haulover Canal which is a 90 m wide expanse of open water, crossed by a drawbridge. Florida Scrub-Jays occupying the area immediately south of Haulover Canal have been seen crossing the canal on several occasions (R. Schaub personal observation). These crossings were not made for territorial defense or as a dispersal attempt and were likely the wanderings of young birds. Also, three long distance dispersals are known to have crossed the canal (R. Schaub unpublished data).

Much of the Haulover corridor has been fragmented by citrus groves and land cleared for urban development (Section 3.5). These occurred before NASA acquired the land. Although urban development ceased after NASA's purchase, soil disturbance associated with land clearing has resulted in expanses of severely degraded scrub habitat and shrub and brush land. Most of the citrus groves continue to be farmed. Several groves, abandoned after hard freezes, have become dominated by native and introduced grasses and forbs, grape vines (*Vitis* spp.), and cabbage palms (*Sabal palmetto*) (Schmalzer et al. 1994), not native scrub plants.

The most difficult corridor to establish involves the connection of the Happy Creek area to the Schwartz Road landscape. Movement between these areas involves crossing about 3.5 km of peripheral impoundments, open water of Banana Creek, and industry associated with the LC39 area (Figure 22). The landscape to the west of SR 3 includes Banana Creek that is hundreds of meters wide and is bordered by wide marshes on either side. The only possible connections occur along the crawlerway, barge canal, islands, and peninsulas that extend into Banana Creek.

The best connection between Schwartz Road and the Southern Pinelands occurs near the western shore of the Banana River through an area of scrub that has been unburned for greater than 20 years and is outside BUs (Figure 22). The only unavoidable discontinuity is the busy, two lane NASA Parkway (SR 405) and its grassy edges. The connection between these two major landscapes could be widened readily by pine thinning and burning in areas outside BUs north and south of NASA Parkway. Although risky, dispersal can occur across four lane roadways (i.e., SR 405) and industrial areas dominated by buildings, landscaped trees and shrubs, parking lots, and large grassy areas.

Potential for a permanent connection between KSC/MINWR/CCAS/CNS and Florida Scrub-Jay populations outside the federal boundaries is unlikely. There are less than 20 territories remaining on Merritt Island near the south boundary of KSC/MINWR (Swain et al. in preparation). These territories occur in small patches of habitat with no hope of population persistence except for those adjacent to the Southern Pineland area. Some scrub adjacent to the Southern Pinelands has been purchased by the Brevard County Environmentally Endangered Lands Program as the Kabboord Sanctuary, and it could support several territories. The other scattered territories on Merritt Island have been excluded from the reserve design for the Brevard County Habitat Conservation Plan (Swain et al. in preparation).

3.3 Restoration Activities

Small scale habitat restoration efforts have been planned and implemented (Schmalzer et al. 1994). Experimental efforts include planting scrub vegetation in abandoned citrus groves. The success of these efforts will not be known for decades, but it is clear that scrub will not reestablish in abandoned groves without intensive efforts. Other restoration efforts include mechanical treatment and burning to convert xeric woodlands into an open scrub landscape suitable to support territories of Florida Scrub-Jays.

The application of prescribed fire needs to be greatly increased. Restoration techniques should rely mostly on fire with cautious use of mechanical techniques which may result in soil disturbance and a discontinuity of fuels (Breininger and Schmalzer 1990). Although mechanical techniques are required in many areas, much can be accomplished using prescribed fire. Pine trees should be thinned by fire within BUs or other burn areas. Mechanical techniques will be useful along edges and in areas that have had extensive soil disturbance.

3.3.1 Mechanical and Burning Techniques

Mechanical techniques have been used in several landscapes to cut oaks and other vegetation that have grown too tall to be restored by burning alone (Schmalzer et al. 1994). Experimental cutting techniques have involved the Brown tree cutter, rollerchopper, K-G blade, and V blade. Burning has followed cutting at these sites. Vegetation responses have been promising (P. Schmalzer unpublished). Oaks, saw palmettos, and other shrubs resprouted in areas treated with the Brown tree cutter and prescribed fire. Some techniques produced more soil disturbance resulting in an increase in herbaceous weeds, but the oaks, saw palmettos, and other shrubs are recovering.

Florida Scrub-Jays have actively used restored areas for foraging, caching acorns, and even nesting within 18 months postfire. However, most restored areas have been too small relative to the overall landscape and the period after restoration too short to judge demographic success. Given the large size of Florida Scrub-Jay territories, it is clear that restoration activities must occur across entire landscapes.

3.3.2 Restoration Burning

Many areas can be restored by using fire at an increased frequency and with spatially explicit objectives. A standard for Lake Wales ridge scrub is burning every 8-20 years with a 15 year mean cycle (Fitzpatrick et al. 1991, Menges et al. in prep.). Prescribed fire for scrub habitat restoration on KSC/MINWR will require burning more frequently than considered standard for the maintenance of excessively drained scrub on the Florida mainland. Initial prescribed fires for restoration should be used to thin pine trees and reduce shrub height. These prescriptions may require intense fire and may need to be conducted within management areas smaller than existing BUs to achieve desired results.

"Hard" fire lines are needed to control fire spread in some areas. Efforts should be made to minimize soil disturbance that has been associated with undesirable fuel discontinuities and subsequent forestation. A natural mosaic of openings is preferable to artificial edges, such as fire breaks and roadsides, that can be searched systematically by predators of Florida Scrub-Jay nests and adults.

Seasonal variation in prescribed fire involving the increased use of summer fires to mimic historical fire patterns will also be needed (Robbins and Myers 1992). The recovery of open space can be performed more easily in pinelands by allowing snags and downed trees to burn. However, allowing these to burn creates potential smoke problems for roadways, urban areas, NASA, and CCAS operations.

The recovery of openings in scrub without pine trees is more difficult. It may be difficult to establish openings quickly without mechanical techniques or herbicides. A long term experimental approach will be needed to reestablish openings. Initial frequent fires (every 2-4 years) for 10-15 years are needed to reduce the accumulation of underground carbohydrate reserves in enough patches for openings to return. The ratio of dead to live fuels is important in being able to get areas to burn. It appears that 25% of the above ground biomass needs to be dead for effective fire (F. Adrian pers. obs.) Thus, at least two years between burns in areas with abundant palmetto and at least three to four years for oak scrub with sparse palmetto are required. This minimum time between burns limits the speed to create openings using burning.

Extremely specific, usually small (less than 200 ha), burns should be conducted each year in a few experimental landscapes (e.g., Happy Creek). These can expedite restoration towards optimal conditions and investigate fine scale habitat restoration needs essential for reproductive success to exceed mortality. Yearly burns are not intended to burn the same exact patches each time. Florida Scrub-Jays need oaks at sufficient stature and age for acorns, nesting, and cover. Many areas burn poorly so that repeated fires are needed to get them to burn, especially when considering the operational complexities of smoke management.

A variety of ignition techniques and prescriptions should be used in early restoration fires. Ignition strips of mechanically chopped fine fuels to produce intense head fires that can penetrate tall, long unburned oak patches have been implemented. Narrow stripped, flank fires can produce the fire intensity required to restore overgrown scrub. Aerial ignition, using delayed aerial incendiary devices (DAIDs) or a heli-torch may be necessary for burning patches that are not easily accessible or pose a safety threat due to fuel loads or burning conditions. A heli-torch would be more effective than DAIDs at igniting areas that do not carry fire because of fuel discontinuity (Adrian and Farinetti 1995).

3.4 Habitat Quality

Detailed mapping of Florida Scrub-Jay habitat quality has been performed only in long term study areas (Breininger et al. 1995, in preparation; Duncan et al. 1995 a), although several maps of potential habitat have been developed for the entire KSC/MINWR landscape (Provancha et al. 1986, Breininger et al. 1991 a, Larson 1992). Long term demographic data on color banded Florida Scrub-Jays are being used to evaluate how Florida Scrub-Jay demographic success varies with landscape conditions (Breininger et al. 1995, in preparation; Duncan et al. 1995 a). These local scale efforts require intensive effort that is not feasible throughout KSC/MINWR. Habitat suitability modeling is approaching a phase in which it can be applied over large areas (Duncan et al. 1995 a, Breininger et al. in preparation).

3.4.1 Degraded Habitat and Restoration Costs

Preliminary habitat quality inventories have been conducted at coarse resolution to identify areas of disturbance and severe habitat degradation using soils, fire history, the presence of woodlands and forests, and the proximity of development. These and more detailed studies can be coupled with population inventories (Section 3.5) to assess the metapopulation structure present today. Initial analyses of habitat quality indicate that 57% of the scrub is degraded (Table 2, Figure 23). Degradation is widespread in areas excluded from BUs and along edges of BUs, facilities, and forests. Edges of BUs, facilities, and forests often do not burn effectively because of their fuels structure or

Table 2. Disturbed and degraded habitat [a] (hectares) within Scrub Reserve Units (SRUs) and corridors between SRUs.

Land cover type	Description	SRUs				Corridors				Totals
		I	II	III	IV	a	b	c	d	
Scrub	Oak scrub, coastal strand, scrubby flatwoods, pine flatwoods, and palmetto prairie	426	1090	911	1049	91	97	91	355	4111
Marsh/swale	Fresh water marsh and ephemeral swales	16	139	286	106	0	4	1	10	562
Mixed shrub/exotics	Wax myrtle, baccharis, disturbed cabbage palm, Brazilian pepper, and Australian pine	106	96	175	45	64	35	20	29	571
Barren land/sand	Fire breaks, impoundment dikes, cleared areas, beach sand and other open sand areas	11	57	67	12	18	3	36	20	225
Wet shrubs	Willow or wax myrtle wetlands	47	81	131	9	3	8	9	19	306
Salt marsh/mangrove	Salt tolerant grass marshes, Spartina, black rush and mangrove	25	71	1	0	16	64	153	14	343
Hammock	Oak, pine, cabbage palm and deciduous forests	330	535	464	152	179	19	104	237	2020
Urban/agriculture	Developed	49	218	289	112	105	74	79	333	1258
Water	Estuarine and fresh open water	24	43	56	30	24	74	42	80	373
Totals		1034	2331	2380	1516	499	378	535	1097	9770

[a] Defined as habitat: (1) outside of burn units (BU), (2) within 300 meters of facilities, (3) within 100 meters of urban land or forested land, or (4) within regions of scrub having dense Florida slash pine. SRU I = Shiloh, II = Happy Creek, III = Schwartz Road, IV = Southern Pinelands; a = Haulover, b = Banana Creek, c = Cape Canaveral, d = Industrial Area.

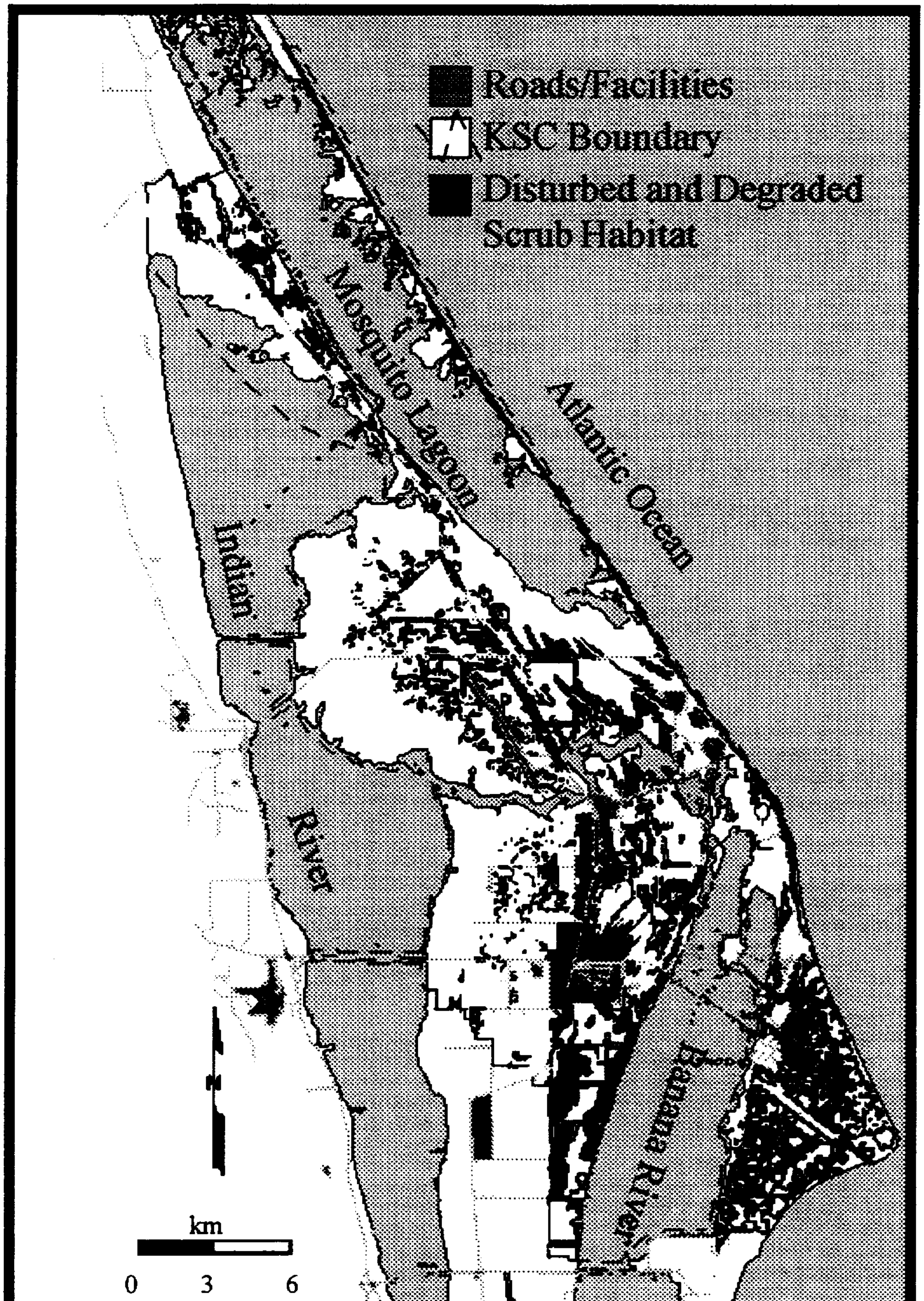


Figure 23. Disturbed and degraded scrub. Defined as scrub: (1) outside of burn units, (2) within 300 meters of facilities, (3) within 100 meters of urban land or forested land, or (4) within regions of scrub having a dense Florida slash pine canopy.

deliberate fire suppression near facilities where fire or smoke may be considered hazardous. These inventories of disturbed and degraded habitat can be used to estimate restoration costs within SRUs and corridors critical to the population.

There is at least 4100 ha of degraded scrub that need frequent fire with or without mechanical treatment. The initial fires in most of these areas will be difficult to initiate and/or control without prior mechanical treatment of the trees. Areas dominated by pines can be thinned by logging activities using timber sales. However, costs are also incurred for planning, implementing, and monitoring of commercial thinning operations. The mechanical cutting of oaks will incur many costs associated with time and equipment. The exact number of hectares associated with specific restoration actions are difficult to determine without further habitat inventories.

Most scrub within the proposed reserve that is not severely degraded will require increased fire frequency fires to produce openings and decrease tree cover. This scrub is approximately 3080 ha.

There are 571 ha of disturbed habitat and 306 ha of marshes occupied by willows and wax myrtle that need frequent fire and other restoration activities. Many historical marsh/swale habitats have become hammocks. Some hammocks, not present in the native landscape, need extensive fire and cutting because they have fragmented potential population centers with too much forest edge habitat for Florida Scrub-Jay populations to be successful.

3.5 Population Inventory

Approximately 150 families of Florida Scrub-Jays are under investigation within KSC/MINWR. The study areas include territories monitored for short-term impact assessments, restoration activities, and long-term (e.g., 3-8 years) investigation (Figure 2). Because of the extent and variation in scrub habitat quality, center wide territory censusing has not previously conducted. As habitat quality and population estimates continue to decline, center wide surveys of jay territories are needed. Territory censuses should first target areas within SRUs. Secondary efforts will focus on territories that exist within linkage regions and in areas of poor quality habitat.

The overall approach used to survey the KSC/MINWR population more accurately should have accuracy comparable to the statewide Florida Scrub-Jay mapping project (Fitzpatrick et al. in press). One difference to be considered is that that Florida Scrub-Jays occupy poorly drained soils on KSC/MINWR, requiring that all habitat be surveyed. Visual searches and the playback of Florida Scrub-Jay territorial calls provide methods for determining occupancy. The number of Florida Scrub-Jay territories need to be estimated based on the initiation of territorial disputes, and other behaviors that imply habitat occupation and ownership (Woolfenden and Fitzpatrick 1984).

3.5.1 Shiloh and Haulover Population Inventory

A complete Florida Scrub-Jay inventory was conducted for the Shiloh SRU and Haulover corridor in 1995 (R. Schaub unpublished data). Because overgrown scrub was a visual barrier, it was often necessary to have two biologists surveying together. Florida Scrub-Jays occupying territories within tall, unburned scrub were often slow to respond to a playbacks of territorial calls (R. Schaub personal observation). Inventory protocols required that one biologist remain with a resident group while the second searched for the adjacent group. During the inventory, the second biologist began playing the territorial calls at 50-70 m from the position of the resident group, and continued playing territorial calls while moving away from the group under observation. After finding the adjacent group, both groups were kept under observation until both biologists were satisfied that they had separate groups. Two-way radios allowed biologists to be aware of group activities (e.g., direction and distance of travel). Repeated visits were made at sites where no Florida Scrub-Jays were detected.

Estimates of the potential population size (breeding pairs) were made from inventories of potential habitat, which includes available scrub, disturbed shrub and brush, abandoned citrus groves, and conifer plantations that are contiguous with scrub cover types. These later cover types are considered potential habitat because they have the potential to be restored. An additional estimate was made of the historical population size based on potential habitat and active citrus groves that are contiguous with potential habitat.

Comparisons of field inventories and estimates based on habitat indicate that the population has declined severely throughout the Shiloh SRU. The number of breeding pairs in the Shiloh SRU is at 40% carrying capacity (total number of breeding pairs based on potential habitat), with some burn units at less than 25% capacity (Table 3). Much of the available habitat (at 46% capacity) is also unoccupied because of fire suppression and forestation. There is little active citrus in this area. Restoration of available scrub, without the more difficult restoration of disturbed areas (disturbed shrub and brush, abandoned citrus and pine plantations), could provide habitat for 87 territories.

Analysis of data from the Haulover corridor suggested a high density of Florida Scrub-Jay groups relative to the amount of available scrub (Table 3). However, many of the Florida Scrub-Jay groups in this region occupied disturbed shrub and brush (where the dominant vegetation includes cabbage palms, wax myrtle, and Brazilian pepper). These disturbed areas resulted from land clearing associated with residential development prior to NASA acquisition. Much of the current scrub is excessively overgrown and not occupied by Scrub-Jays. Although the disturbed areas have low suitability, they contain some scrub oaks, patches of low growing vegetation, and open sandy areas. These later

Table 3. Florida Scrub Jay groups and habitat by burn unit in the Shiloh Scrub Reserve Unit and Haulover Corridor.

Area	Burn Unit	Active Groups[d]	Available scrub[a]			Historical habitat[b]			Potential habitat[c]		
			Ha	Potential Groups[e]	Percent Capacity[f]	Ha	Potential Groups[e]	Percent Capacity[f]	Ha	Potential Groups[e]	Percent Capacity[f]
Shiloh	1.2A	17	288	29	59%	321	32	53%	321	32	53%
	1.2B	6	268	27	22%	288	29	21%	287	29	21%
	1.4A	16	201	20	80%	263	26	62%	263	26	62%
	1.4B	1	109	11	9%	124	12	8%	121	12	8%
	Total	40	866	87	46%	997	100	40%	992	99	40%
Haulover	1.5	2	26	3	67%	82	8	25%	36	4	50%
	2.1	2	9	1	200%	41	4	50%	25	3	67%
	3.1	6	64	6	100%	112	11	55%	98	10	60%
	Total	10	99	10	100%	234	23	44%	160	16	63%

[a] Available scrub includes palmetto prairie, pine flatwoods, scrubby flatwoods, and oak scrub cover types.
[b] Historical habitat includes currently available habitat, active citrus groves, disturbed areas, and conifer plantations.
[c] Potential habitat includes historically available habitat minus active citrus groves.
[d] Groups active during 1995 inventory.
[e] Potential groups assumes a territory size of ten hectares per group.
[f] Percent capacity = active groups / potential groups.

features make some disturbed areas more suitable than overgrown scrub, explaining why some disturbed areas are occupied while overgrown scrub is not occupied. Based on potential habitat the number of breeding pairs in the Haulover corridor is at 63% carrying capacity (Table 3).

Citrus farming has had an additional impact on Florida Scrub-Jays. The Florida citrus industry became established during the post-Civil War expansion (late 1800s). By 1950 orange groves replaced much of the upland scrub between Mosquito Lagoon and the Indian River from Oak Hill to Haulover Canal (Davidson and Bratton 1986). Within the Shiloh region, citrus farming occurred primarily west of SR 3. These areas are currently so degraded that they are of no current value to Florida Scrub-Jays and were not included within the Shiloh SRU.

Relative to the amount of habitat that was historically available (prior to citrus farming and disturbance), the number of territories in the Haulover corridor is at only 44% carrying capacity. The Haulover corridor represents a geographical bottleneck for Florida Scrub-Jays dispersing to or from the Shiloh SRU. Within the Haulover Corridor, there are 74 ha of active citrus groves. The implications of these groves for maintaining connected Florida Scrub-Jay populations needs further evaluation.

3.6 Habitat Management

Prescribed fire frequency for management after restoration may follow more closely the standard for maintenance of excessively drained scrub on the Florida mainland, but future work will be needed to determine this. Some patches of oak scrub may not need to burn more frequently than 8-20 years once restoration is completed, but the surrounding matrix of flatwoods and marsh will still require frequent fire to prevent an excessive accumulation of fuels. Maintenance fires should occur every few (2-8) years in scrub landscapes, but burns should result as mosaics leaving most (2/3) patches of scrub oaks unburned in any one fire. Habitat management considerations have been updated in the MINWR Fire Management Plan (Adrian 1990, Adrian and Farinetti 1995). Fire prescriptions for each unit are under continuous revision based on changes in habitat conditions.

There is a need for the NPS to develop and implement fire management in two large scrub landscapes: 1) between the new Playalinda Beach Access Road and the railroad tracts, and 2) north of the Gomez Grant Line.

3.7 Ecosystem Management

Restoration of scrub communities, for the persistence of the Florida Scrub-Jay, should be conducted in consideration of the objectives for management of the entire KSC/MINWR and Indian River Lagoon ecosystem. These objectives must consider both the structure and function of all the communities within the region. Complimentary habitat conservation planning and endangered lands acquisition efforts have occurred at county, regional, and state levels.

The proposed reserve design has been presented in direct response to Florida Scrub-Jay population decline but will also need to be evaluated for other selected target species based on available data and published literature. For example, Bald Eagle nest site management will remain a priority for pine stands that have been identified as potential nest sites (Figure 24). However, these stands are relatively small (Hardesty and Collopy 1981). Of 39 Bald Eagle nests that have been used in the recent past, 20 are within SRUs and 19 of these are within scrub. Habitat management for native landscape conditions will be beneficial for most species of conservation concern, and harmful for none (Appendix C).

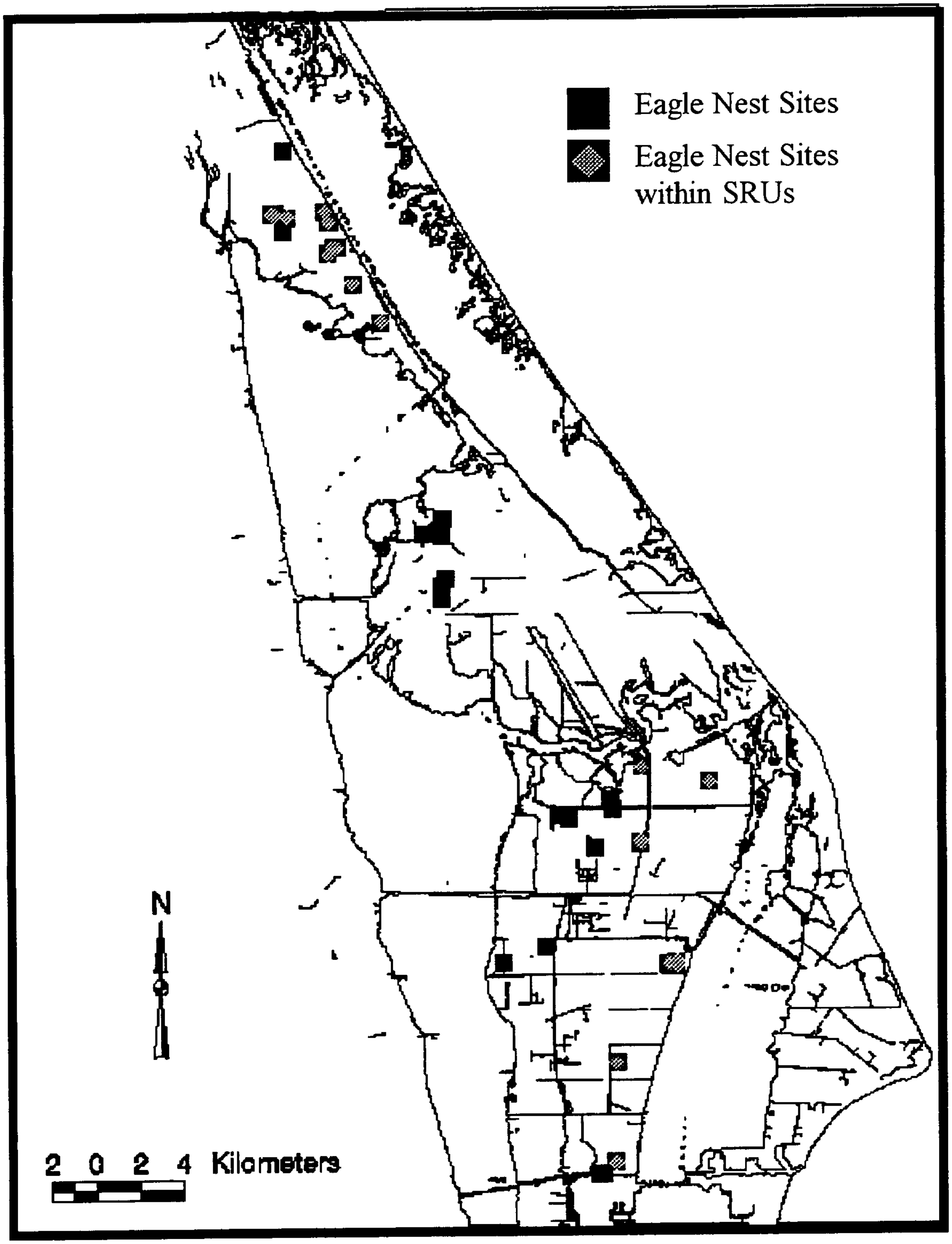


Figure 24. Eagle nest sites on John F. Kennedy Space Center/Merritt Island National Wildlife Refuge. SRUs = Scrub Reserve Units.

The role of fire, identified as a driving force in the structure of scrub habitat (Abrahamson 1984 , b; Myers 1990, Breininger and Smith 1992, Schmalzer and Hinkle 1992 a, b), is just beginning to be understood. Understanding the complex interactions of fire, plant physiology, hydrology, and edaphic conditions (i.e., including disturbances), as well as the temporal variations of these factors, will greatly improve the success of restoration efforts. A broader approach to ecosystem management planning must be undertaken in the future. Researchers and managers must work closely to implement adaptive management strategies for all aspects of the ecosystem.

3.8 Long-term Monitoring

The combination of habitat management, restoration, remote sensing, spatial analyses, vegetation, and Florida Scrub-Jay demography studies continue to be integrated into a program that is peer reviewed through the process of scientific publication. The KSC/MINWR long-term monitoring program continues to investigate reproductive success and survival of Florida Scrub-Jays distributed among major regions and significant corridors. These studies include monthly censuses of color banded Florida Scrub-Jays, nest monitoring, territory mapping, survival measurements, dispersal measurements, habitat and fire mapping.

Uncertainty exists about specific habitat conditions needed for Florida Scrub-Jay population persistence. Long term monitoring studies, coupled with landscape management are essential for population recovery over the restoration period. Additional population modeling will be needed to evaluate changes in population trajectories based on habitat and demographic data. Given the potential influence of helpers on reproductive success and survival, some feedback loops and nonlinear relationships may occur, depending on mean family sizes. Spatially explicit comparisons of demographic success to KSC/MINWR habitat and landscape characteristics are revealing population sources (where reproduction exceeds mortality) and population sinks (where mortality exceeds reproductive success) (e.g., Breininger et al. 1995). Demographic success varies with habitat arrangements (Breininger et al. 1995, in preparation; Duncan et al. 1995 a) so that the optimization of restoration needs to consider spatial structure. Identifying and managing sources is essential for population persistence (Pulliam 1988, Pulliam and Danielson 1991, Howe et al. 1991, Dunning et al. 1992, Pulliam et al. 1992).

Individual-based territory models may be useful for evaluating alternative reserve designs and restoration activities. Examples of these approaches have been adapted to recovery of other taxa (Noon and McKelvey 1992, Pulliam et al. 1992, Possingham et al. 1993, McCarthy in press).

Long-term responses of scrub communities to fire and to combinations of mechanical treatment and burning will continue. Remote sensing methods to determine vegetation height and to map fire distribution are being evaluated. Historical mapping of land use and natural communities is also being conducted for the Indian River Lagoon National Estuary Program which will include two eras of historical maps for KSC/MINWR, 1900-1920 and 1940-1960. These maps will also be helpful in evaluating existing habitat quality and modifying management objectives based on measurable changes in the quality and extent of scrub found on KSC/MINWR.

Detailed fire mapping has experimentally been initiated to document fire patterns and intensities within BUs throughout KSC/MINWR. These data can identify burn patches and improve the understanding of habitat change associated with burn intensity and frequency. Fire maps can also be used to improve fire prescriptions within BUs and to target habitat that requires special ignition techniques or alternative management. Analyses of habitat changes within the reserve, after implementation of the interim management activities, can be used with other available data to modify design strategies.

In addition to mapping fires and historical landscapes, other projects are underway or proposed to explore remote sensing technologies to map elements of habitat quality at a finer resolution. These include studies of spectral signatures of openings, scrub oaks, and saw palmettos (Bostater et al. 1992), spectral signatures of oak scrub canopy structure and biomass (C. Hall and C. Bostater, unpublished), and vegetation height profiles (e.g., Ritchie et al. 1994). Studies have been proposed to use a variety of remote sensing tools to develop a comprehensive approach to mapping habitat suitability. Application of these technologies will allow greater automation of fine resolution mapping of habitat quality in a dynamic landscape

Other species of conservation concern that use scrub landscapes need investigation. Many recent and ongoing scrub herpetological studies include Gopher Tortoises (Breininger et al. 1988, 1991b, 1994 b; Smith et al. in prep.), Eastern Indigo Snakes (Kehl et al. 1991), Florida Gopher Frogs and other anurans (R. Schaub in progress) and herpetofaunal community studies (R. Seigel and others). Mammal studies include Ehrhart (1976), Stout (1980), Extine and Stout (1987), D. Oddy and others (unpublished).

Several areas needing further study remain unfunded. Data on the effects of fire season on vegetation and species of conservation concern has long been desired. Studies on management techniques that create a mosaic of openings among scrub oaks have long been desired. Topics that have attracted recent funding interests include smoke management and fuels modeling.

Appendix A: Description of the John F. Kennedy Space Center

A.1 Landscape

Lands and lagoons of KSC/MINWR comprise 57,000 ha. KSC/MINWR occurs within a biogeographical transition zone, having faunal and floral assemblages derived from both temperate Carolinian and tropical/subtropical Caribbean biotic provinces. The diversity of wildlife on KSC/MINWR is attributed to the variety of upland and wetland habitats, proximity to the coast, and migratory birds (Breininger et al. 1994 a).

Fluctuating sea levels with alternating glacial-interglacial cycles have shaped the barrier island complex comprising KSC/MINWR. The Merritt Island landscape probably began forming 240,000 years ago, although most sediments are not that old (Metha and Brooks 1973). Cape Canaveral dates from less than 7000 years before present as does the barrier strip separating Mosquito Lagoon and the Atlantic Ocean. The barrier beach along Mosquito Lagoon is gradually regressing landward by seaward erosion and washover, in contrast to Cape Canaveral which is a progradational series of beach deposits (Mehta and Brooks 1973).

Topography on KSC/MINWR is marked by a series of swales and ridges, (which represent relict dunes) ranging from sea level to 3 m. A narrow strip of dune and coastal strand occurs adjacent to the Atlantic Ocean. Surficial deposits are of Pleistocene and recent ages and consist primarily of sand and sandy coquina (Schmalzer and Hinkle 1990). Detailed vegetation maps show scrub and pine flatwoods as the dominant upland communities (Provancha et al. 1986, Larson 1992). Fresh marshes occur in low areas interspersed in scrub and pine flatwoods (Schmalzer and Hinkle 1985, Breininger 1992 b). Forests occur in lower areas among scrub and pine flatwoods.

A.2 Climate

The climate is warm and humid. Mean daily maximum temperatures range from 21C in January to 31C in July. Mean daily minimum temperatures range from 11C in January and 23C in July (Mailander 1990). There is a seven percent chance that hurricane force winds (121 km/hr) will reach the 80 km stretch of KSC/MINWR/CCAFS coastline during hurricane season (August through November) (Mailander 1990). KSC/MINWR has one of the highest frequencies of lightning strikes in the world with 1400 $\pm$ 840 cloud to ground strikes per month during the summer (Eastern Space and Missile Center 1989). Annual normal rainfall ranges from 54 to 56 inches (137-142 cm) depending on location with nearly 70% occurring between June and September (Mailander 1990). Water levels are often lowest in spring due to low rainfall combined with high evapotranspiration (Schmalzer and Hinkle 1990).

A.3 History

Indigenous human occupation in the region occurred from 8000 BC to 1705 AD, and there was some clearing, use of fire in wildlands, and building of shell middens (e.g., Turtle Mound) (Davidson and Bratton 1986). Spanish colonization until 1762 involved free-ranging cattle, burning in the St. Johns watershed, and some citrus planting; however, disturbance was probably minor on KSC/MINWR. English colonization and Spanish retrogression involved some draining and diking, limited live oak and pine logging, and some plantation farming. With early Florida statehood (1845-1861) came extensive live oak logging and some town establishment around citrus groves, followed by abandonment. After the Civil War, railroad establishment led to permanent towns associated with the citrus industry. Logging of virgin pine became prevalent. From 1900-1962 there was repeated logging of pine, burning for free-ranging cattle, and the draining and diking of wetlands for mosquito control

(Davidson and Bratton 1986). Brevard County was predominantly rural prior to 1950.

Prior to NASA acquisition, there were some small towns, fish camps, citrus groves, and other human establishments on KSC/MINWR. Although much of the land was not extensively developed, it was altered by drainage, mosquito control impoundments, grazing, timbering, hunting, and roads (Trost 1968, Davidson and Bratton 1986). In 1962, NASA began acquiring KSC/MINWR property. MINWR was established in 1963 to manage lands and waters not being used directly by the space program. CNS was established in 1975. NASA remains the landowner, and lands are occasionally removed from the refuge or seashore when needed by the space program (NASA 1979, EG&G Florida Inc., 1994). The United States Air Force (USAF) has habitat management responsibility on the adjacent CCAS.

Environmental monitoring on KSC/MINWR, administered by the NASA Biomedical Operations Office, include operation and construction monitoring, long-term ambient monitoring, and ecological studies (Ecological Program Plan 1995). Environmental management and permitting are the responsibility of the Environmental Management Office within the NASA Engineering Development Directorate. One of eight overall goals of KSC is to enhance and protect KSC/MINWR's unique environment (KSC Strategic Plan 1991). The KSC Strategic Plan identifies the need to apply new and existing techniques, processes, and materials to preserve the environment. Initiatives related to wildlife include minimizing effects attributed to new facilities, enhancing workforce awareness, minimizing environmental risks, and enhancing prediction and analysis capability to enhance environmental management.

A.4 Habitat Descriptions

The KSC/MINWR, CNS, and CCAS coastline is the longest stretch of protected coastal dune and coastal strand along the east coast of Florida

(Johnson et al. 1990). Most of the coastal habitats from Brevard to Dade County have been developed or are in a highly fragmented condition except on KSC/MINWR and CCAS (Johnson et al. 1990). Coastal strand occurs immediately behind the coastal dunes. It is often dominated by saw palmetto although other shrubs occur such as rapanea (*Rapanea punctata*), nakedwood (*Myrcianthes fragrans*), tough buckthorn (*Bumelia tenax*), Hercules-club (*Zanthoxylum clava-herculis*), red bay (*Persea borbonia*), and snowberry (*Chiococca alba*). Proceeding westward, a dwarf variety of live oak (*Quercus virginana* undescribed variety) is found that forms a coastal scrub or coastal woodlands community. This coastal scrub includes many of the same hardwoods and occurs on alkaline soils with greater abundance of many soil nutrients in contrast to more interior scrub (Kurz 1942; A. Johnson, pers. comm.). The outer coastal strip is often narrow, and salt marsh vegetation or mangroves border the coastal strand with few or no oaks.

Coastal strand is used by Florida Scrub-Jays when adjacent to scrub oaks (Breininger 1981) or coastal live oak woodlands (Simon 1986). Coastal dune and coastal strand on KSC/MINWR and CCAS provide most of the protected habitat for the largest population of the Southeastern Beach Mouse (*Peromyscus polionotus nivieventris*) (Extine and Stout 1987). Records suggest that lightning fires were common historically in this habitat (Davidson and Bratton 1986). Coastal scrub species sprout rapidly after fire and grow quickly.

Scrub and scrubby (pine) flatwoods on KSC/MINWR have similar shrub layers, but pine flatwoods differ by having an open overstory of slash pine and occasionally pond pine (*P. serotina*). Scrub *oaks (Quercus myrtiflolia, Q. geminata, Q. chapmanii*) dominate drier sites, while saw palmetto dominates the wetter end of the scrub gradient (Schmalzer and Hinkle 1987, 1992 b). On most sites, a mixed oak/palmetto shrub layer occurs. Scrub is often used to describe an excessively drained, desert-like habitat (Woolfenden and Fitzpatrick 1984). Most scrub and pine flatwoods on KSC/MINWR differs from this by having a water table that is relatively close to the surface for much of the year (Schmalzer and Hinkle 1987, 1992 b; Breininger et al. 1988). Well drained ridges occur as a series of long narrow strips formed on relict dunes oriented north-to-south. These comprise only 14% of the scrub and slash pine flatwoods; however, scrub oaks are abundant within patches in at least half of the remaining scrub and pine flatwoods (Breininger et al. 1991 a).

There are no records of longleaf pine (*Pinus palustris*)/wiregrass (*Aristida strictus*) or longleaf pine/turkey oak (*Quercus laevis*) ("sandhill") occurring on KSC/MINWR in the recent past. The few scattered stands of sand pine scrub on KSC/MINWR are small and have a very open tree canopy. A few small stands of scrub hickory (*Carya floridana*) occur on KSC/MINWR; this is probably the most limited plant association on KSC/MINWR.

Appendix B Fire Management

Fires occurred frequently in the KSC/MINWR landscape prior to NASA acquisition (Davidson and Bratton 1986). In 1773, Bartram noted that central Florida pine habitats had Florida Scrub-Jays, Loggerhead Shrikes, and many Rufous-sided Towhees (*Pipilo erythrothalmus*) (Jackson 1988). The presence of Loggerhead Shrikes suggests open habitat conditions that could be maintained only by periodic fires. The presence of Florida Scrub-Jays and an abundance of Rufous-sided Towhees also suggests a significant shrub layer (Breininger 1981, Breininger and Schmalzer 1990, Breininger and Smith 1992). In 1837, Merritt Island scrub was noted to be an expanse of two to four feet tall "prairies" of scrub and saw palmetto (Motte 1837). Natural fires most often occurred in spring and summer (Komarek 1965, Robbins and Myers 1992). Fires during the rainy, humid growing season are often patchy and regrowth occurs quickly (Robbins and Meyers 1992). Growing season burns occurred in dry (spring) and wet months (summer), with the transition between them representing the height of the fire season (Robbins and Meyers 1992). Prescribed fires during spring droughts differ greatly from fires during wet seasons when fuel moisture levels are high and the primary fuels available are living volatile vegetation such as wiregrass, saw palmetto, and gallberry holly. Summer fires were probably more patchy than spring drought fires that burned under very dry conditions. Fires caused by humans on KSC/MINWR have occurred throughout the year but were especially common in the winter (Davidson and Bratton 1986). Scrub can burn readily in winter when fuel moisture levels are lowest due to low rainfall and humidity.

Historical aerial photography from the 1940s and 1950s shows numerous fire scars, openings, and only a few hardwood forests present in the landscape. The open structure of scrub and the lack of many forests strongly suggests that fires burned frequently across Merritt Island. Past turpentining, timbering, grazing, and drainage also altered the structure of pinelands (Davidson and Bratton 1986). Many agricultural practices resulted in considerable soil disturbance (Davidson and Bratton 1986).

There was a 20 year period of fire suppression that occurred prior to 1978 when the USFWS initiated a limited prescribed fire program. Twenty years of fire suppression resulted in a buildup of heavy fuel loads. Extensive wildfires in 1981 resulted in two human casualties. Subsequently, a more aggressive fire management program was implemented where many areas were given the opportunity to burn every three years. This prescribed fire program was directed initially towards fuels reduction.

Natural landscapes previously allowed fires to burn through large regions, but fragmentation now prevents such occurrences. Some fragments, particularly those adjacent to roads and facilities, have remained unburned for long periods. Reliance on wildfires is no longer an option due to operational and safety constraints and habitat fragmentation.

Appendix C: Ecosystem Integrity and Biological Diversity

Biological diversity was considered when formulating this recovery strategy. Past analyses reveal that all threatened and endangered vertebrates at KSC/MINWR tolerate a fire frequency that is optimal to Florida Scrub-Jays, or they prefer a more frequent fire cycle (Breininger and Smith 1992, Breininger et al. 1994 a, b). More specific formulations are needed for other species but these are beyond the scope of this strategic plan. Below some specific habitat needs of other scrub taxa are discussed.

Some scrub plants such as sand pine (*Pinus clausa*) and rosemary (*Certiola ericoides*) require a longer fire interval than is optimal for Florida Scrub-Jays, but these plants are characteristic of more excessively drained soils than typical for KSC/MINWR and are naturally rare on KSC/MINWR (Schmalzer and Hinkle 1992 b). Scrub oaks, saw palmetto, and ericaceous shrubs tolerate a wide range of fire intervals. Many scrub herbs require openings which have declined in the absence of fire; these include rare species such as *Lechea cernua* and *L. divaricata*.

Many of the amphibians found in scrub and slash pine flatwoods use swale marshes for reproduction; these marshes are also maintained by periodic fire that eliminates dead vegetation and makes nutrients available for new growth (Vogl 1973). Amphibians are part of the food chain for numerous species inhabiting scrub and slash pine, particularly the Eastern Indigo Snake which uses Gopher Tortoise burrows as den sites and marshes for hunting (Moler 1986). Eastern Indigo Snakes use all habitats within the scrub and pine flatwoods landscape and may occur far from well drained areas (Kehl et al. 1991). Gopher Tortoises also have a wide distribution, using nearly all scrub and pine flatwoods (Breininger et al. 1988, 1991b, 1994; Giovanetto 1988). Telemetry studies have shown that Gopher Tortoises readily use flooded burrows even when unflooded burrows are nearby (Smith et al. unpublished ms.). Gopher Tortoises may prefer more frequent fire than Florida Scrub-Jays (Breininger et al. 1988). However, Gopher Tortoise densities are not significantly lower within preferred Florida Scrub-Jay habitat when compared to other areas. Recruitment of Gopher Tortoises into the population also occurs in preferred Florida Scrub-Jay habitat (Breininger et al. 1994 b).

KSC/MINWR once supported one of the most dense concentrations of Bald Eagles in North America (Howell 1973, Hardesty and Collopy 1991); today less than 10 pairs nest on KSC/MINWR. The population on KSC/MINWR has not recovered as it has elsewhere in Florida for reasons that are unclear. The number of immature Bald Eagle observed in surveys in the past three years has gone from one or two per season to 6-10 per season (H. Hill unpublished data). Poor quality nesting sites are currently being selected for active nesting activities by one or two pairs (H. Hill unpublished data). There is a shortage of preferred Bald Eagle nesting habitat on KSC due to excessive pine densities and a lack of large (old) pines. Bald Eagles appear to select for large supercanopy or codominant trees within stands that have an open canopy of 25-47 trees/ha (Hardesty and Collopy 1991). Individual trees of the stature used as Bald Eagle nest sites are rare on KSC/MINWR due to past logging, a fire suppression policy that allowed heavy levels of fuels to accumulate, and subsequent wild and prescribed fires. Most nest sites for the Bald Eagle are in poorly drained slash pine flatwoods or within the interspersed grassy swales (J. Hardesty, University of Florida, pers. comm.). It is unclear whether these sites provide optimal conditions for pine growth or whether they serve as refugia for pine regeneration and survival in a landscape subject to periodic fires.

Fifty percent of the slash pine flatwoods that is of current or recent historical importance to Bald Eagles (defined as all slash pine flatwoods within 0.8 km of a nest site) overlaps 12% of areas identified as Florida Scrub-Jay population centers (D. Breininger and J. Hardesty unpublished). Bald Eagle stands can be relatively small (Hardesty and Collopy 1991). Some additional areas should be located for Bald Eagle nest site management. Florida Scrub-Jay densities decline with increasing slash pine density between 25-50 trees/ha (Breininger unpublished data) which is the tree density that is common in many Bald Eagle nest sites. Habitat management does not need be performed for either species in a manner that is detrimental to the other. Stands used for nesting by Bald Eagles do not need to be large. There is overlap in suitability with respect to pine density, and pine stands will most likely occur in poorly drained areas, whereas Scrub-Jays prefer well drained areas.

Habitat suitable for Florida Scrub-Jays is suitable for most scrub and pine flatwoods birds on KSC/MINWR except for special requirements for Bald Eagles described above and for the Downy Woodpecker (*Picoides pubescens*). Populations of this woodpecker need snags in recently burned pine flatwoods (Breininger 1992 a, Breininger and Smith 1992).

The Florida Mouse populations may be sustained within well drained areas, but they do at least occasionally occur within some poorly drained areas (Stout 1980). Long term research at Archbold suggests habitat suitable for Florida Scrub-Jays is suitable for small mammal species within well drained scrub and pine flatwoods since small mammals have a broader successional tolerance and are divided into groups that prefer older or more recently burned areas (Layne 1990). Many herpetofauna that occupy scrub also use the early and middle successional phases that are preferred by Florida Scrub-Jays (Campbell and Christman 1982).

Potential management indicator species within KSC/MINWR scrub and pine flatwoods include the Eastern Indigo Snake, Gopher Tortoise, Southern Bald Eagle, Florida Scrub-Jay, Downy Woodpecker, Florida Mouse, and Bobcat (Breininger et al. 1994 a).

Appendix D: Population Risk Model

The population risk models used here are summarized below. Complete descriptions and sensitivity analyses of the primary model are available elsewhere (Breininger et al. unpublished ms.). Both models were developed to incorporate the sociobiology of Florida Scrub-Jay populations using RAMAS/stage (Ferson 1991). The stages of the primary model included juveniles, yearlings, older helpers, novice breeders, experienced breeders without helpers, and experienced breeders with helpers. The second model distinguished one helper class and two breeder classes (breeders with helpers and breeders without helpers). Both models were based only on females, as typical for such models (see Burgman et al. 1993).

Density dependence was implemented by placing a ceiling limit on the number of breeders (territories) (see Woolfenden and Fitzpatrick 1984, 1991). During periods of unusually high reproduction (and/or low mortality) helpers can accumulate until mean family sizes became unusually large (3.6 birds/territory). Continuing sensitivity analyses indicate little influence on population trajectories when helper ceilings are altered. The number of helpers was a function of the juveniles produced and their survival during earlier time steps (years) minus the number of helpers that become novice breeders due to vacancies attributed to breeder deaths. The number of experienced breeders with helpers was a function of the number of helpers and the number of experienced breeders.

The number of breeders was the sum of surviving experienced breeders plus the number becoming novice breeders providing there were nonbreeders (older helpers, first year helpers, or young) available to become breeders. The model assumed that 90% of the available nonbreeders would breed when given a chance. Older helpers followed by first year helpers had the first opportunities to breed. Young from the previous year could become breeders if helpers were unavailable. This was based on data in suburban populations (D. Breininger, R.

Bowman, Archbold; B. Toland, USFWS). Epidemics were assumed to occur every 20 years, resulting in no survival of juveniles and lower survival of other stages (Woolfenden and Fitzpatrick 1991).

Florida Scrub-Jay mortality was assumed to occur in areas hit by the eyewall of catastrophic (winds greater than 180 km/hr) hurricanes (Breininger et al. unpublished ms.). A mortality rate of 0.63 was applied to all stages, based on Hooper et al. (1990). A yearly catastrophic hurricane probability was 0.01 (Breininger et al. unpublished ms).

Previous Florida Scrub-Jay population models include a population risk model described by Fitzpatrick et al. (1991) and Woolfenden and Fitzpatrick (1984) and a matrix model (McDonald and Caswell 1993). The latter model is not a population risk model. Although both models include the presence of nonbreeding helpers, neither distinguishes the effects of breeders with helpers and breeders without helpers. Both models are based on long-term studies in optimal habitat at Archbold where nearly half the territories have helpers (Woolfenden and Fitzpatrick 1984). Many Florida Scrub-Jay territories in marginal habitats on KSC/MINWR no longer have helpers. Breeding pairs without helpers have lower reproductive success and survival than pairs without helpers (Woolfenden and Fitzpatrick 1984). Helpers generally result from years of reproductive success exceeding mortality and a ceiling limit to the number of breeding pairs attributed to saturated habitat (Woolfenden and Fitzpatrick 1984). Declining populations in marginal habitat may be subject to an extinction vortex (see Gilpin and Soule 1986). Consequently, the model used here was a useful tool for exploring population viability in habitat of varying suitability.

Appendix E: Other Florida Scrub-Jay Studies

Early studies by Salata (1978), Cox (1984, 1987) and Breininger (1989) reported the number of Florida Scrub-Jays sighted or believed to be present. Recent studies indicate that the number of breeding pairs (territories) is a more informative measure (Fitzpatrick et al. 1991). The results of earlier studies can be converted crudely to the number of territories by dividing the number of birds by 3 (Woolfenden and Fitzpatrick 1984, Breininger et al. 1995).

Using transect bird counts along roads the KSC/MINWR population was first estimated to be 860-1600 territories (Salata 1978). Florida Scrub-Jays densities were compared with habitat features from 1979-1980 to study habitat preferences and not estimate population size (Breininger 1981). The latter study attempted to sample the across the range of habitat conditions on KSC/MINWR, resulting in high Florida Scrub-Jay densities along several transects. Average densities from Breininger (1981) were later used by Cox (1984, 1987) to produce an estimate of 2,000-3,300 territories on KSC/MINWR. Studies based on bird densities from circular plots in 1985 and 1986 and habitat mapped from 1978 imagery indicated that areas having high Florida Scrub-Jay densities were rare on KSC/MINWR, suggesting the population size was closer to 800 territories (Breininger 1989, Breininger et al. 1991 a). None of these studies were sufficient to evaluate population trends.

Other earlier Florida Scrub-Jay studies on KSC/MINWR focused on the influence of habitat features on Florida Scrub-Jay densities or nest success (Gipe 1987; Wilkinson 1989) or environmental impact assessments (Larson et al. 1993, Smith et al. 1994). Some studies have focused on the overall effects of fire and mechanical disturbance on habitat structure and bird communities (Breininger and Schmalzer 1990, Breininger and Smith 1992) and avian use of other habitats within landscapes dominated by scrub (Breininger 1990, 1992).

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E. Adrian and H. Hill, Jr.

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13. ABSTRACT *(Maximum 200 words)*

The Florida Scrub-Jay (*Aphelocoma coerulescens)* is an indicator of ecosystem integrity of Florida scrub, an endangered ecosystem that requires frequent fire. One of the largest populations of this federally threatened species occurs on John F. Kennedy Space Center/Merritt Island National Wildlife Refuge. Population trends were predicted using population modeling and field data on reproduction and survival of Florida Scrub-Jays collected from 1988 - 1995. Analyses of historical photography indicated that habitat suitability has been declining for 30 years. Field data and computer simulations suggested that the population declined by at least 40% and will decline by another 40% in 10 years, if habitat management is not greatly intensified. Data and computer simulations suggest that habitat suitability cannot deviate greatly from optimal for the jay population to persist. Landscape trajectories of vegetation structure, responsible for declining habitat suitability, are associated with the disruption of natural fire regimes. Prescribed fire alone can not reverse the trajectories. A recovery strategy was developed, based on studies of Florida Scrub-Jays and scrub vegetation. A reserve design was formulated based on conservation science principles for scrub ecosystems. The strategy emphasizes frequent fire to restore habitat, but includes mechanical tree cutting for severely degraded areas. Pine thinning across large areas can produce rapid increases in habitat quality. Site-specific strategies will need to be developed, monitored, and modified to achieve conditions suitable for population persistence.

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