Adaptive Habitat Management
for Florida Scrub-Jays
at Merritt Island National Wildlife Refuge

Project Prospectus

Fred A. Johnson[1], David R. Breininger[2], Brean Duncan[2], and Marc Epstein[3]

May 24, 2004 - DRAFT

Abstract.--Florida Scrub-Jays (*Aphelocoma coerulescens*) at Merritt Island National Wildlife Refuge (MINWR) and adjacent government properties constitute a key population of this threatened endemic species. Prescribed burning is the primary management tool for Scrub-Jays at MINWR, but managers face constraints on the timing and location of burns due to the associated fire and smoke hazard to Kennedy Space Center facilities. Within these constraints, managers must decide what frequency and intensity of fire in a collection of management units will best ensure the long-term persistence of the refuge's Scrub-Jay population. These decisions are difficult because of an incomplete understanding of fire dynamics, plant community succession, and the demographic responses of Scrub-Jays to both controlled and uncontrolled environmental factors. We propose to conduct a formal decision analysis for the prescribed burning of Scrub-Jay habitat on MINWR. The product of this decision analysis will be a management strategy, consisting of state and time-specific fire prescriptions, that minimizes the expected quasi-extinction rate of MINWR Scrub-Jays. The management strategy will account for constraints on management actions, for uncontrolled stochastic effects, for key uncertainties in system dynamics, and for imprecision in habitat and population monitoring programs. Moreover, we propose to develop methods that can reduce the uncertainty in predicting management outcomes, so that management performance can be improved over time.

Introduction

The Florida Scrub-Jay is an endemic species that has been designated as threatened under the federal Endangered Species Act. Florida Scrub-Jays are at risk of extinction due to loss and degradation of scrub habitat (Root 1998, Stith et al. 1996). Florida scrub is a rare ecosystem characterized by evergreen, xeromorphic shrubs including oaks (*Quercus* spp.), repent palms (*Serenoa repens*, *Sabal etonia*), and ericaceous shrubs (*Lyonia* spp., *Vaccinium* spp. (Foster and Schmalzer 2003). Scrub is a fire-maintained system, and landscape fragmentation and fire suppression have resulted in many scrub communities that are no longer capable of maintaining Scrub-Jay populations (Breininger and Carter 2003). Consequently, prescribed burning is the primary management tool in reserves where the viability of Scrub-Jays and other scrub species is an important objective.

[1] Division of Migratory Bird Management, U.S. Fish and Wildlife Service, 7920 NW 71st Street, Gainesville, FL 32606
[2] Dyn-2, Dynamac Corporation, Kennedy Space Center, FL 32899
[3] Merritt Island National Wildlife RefugeU.S. Fish and Wildlife Service, , P.O. Box 6504, Titusville, FL 32782

Scrub-Jays at Merritt Island National Wildlife Refuge and adjacent government properties constitute a key population within the species' shrinking range. MINWR contains almost 8800 ha of potential Scrub-Jay habitat, but only about 13% of this was considered in optimal condition in 2000 (Breininger, unpub. data). Little fire management occurred on MINWR prior to 1981, when extensive wildfires prompted managers to accelerate a program of prescribed burning to reduce hazardous fuel loads (Adrian 2003). Since 1993 more emphasis has been placed on restoration and maintenance of wildlife habitat, but refuge managers face constraints on the timing and location of burns due to the associated fire and smoke hazards to Kennedy Space Center, which owns most land associated with the refuge. Neighboring cities, suburbs, and the Cape Canaveral Air Force Station provide additional constraints. Within these constraints, managers must decide what frequency and intensity of fire in a collection of management units will best ensure the long-term persistence of the refuge's Scrub-Jay population. These decisions are difficult because of an incomplete understanding of fire dynamics, plant community succession, and the demographic responses of Scrub-Jays to controlled and uncontrolled environmental factors.

We propose to conduct a formal decision analysis for the prescribed burning of Scrub-Jay habitat on MINWR. The product of this decision analysis will be a management strategy, which will account for constraints on management actions, for uncontrolled stochastic effects, for key uncertainties in system dynamics, and for imprecision in habitat and population monitoring programs. Moreover, we propose to develop methods that can reduce the uncertainty in predicting management outcomes, so that management performance can be improved over time.

A Decision-Theoretic Approach

Formal methods of decision making in natural resource management combine models of the dynamics of an ecological system with an objective function, which values the outcomes of alternative management actions. A common decision-making problem involves a temporal sequence of decisions, each alike in kind, but where the optimal action at each decision point may depend on time and/or system state (Possingham1997). The goal of the manager is to develop a decision rule (or management strategy) that prescribes management actions for each time or system state that are optimal with respect to the objective function. Examples of this kind of decision problem include direct manipulation of plant or animal populations through harvesting, stocking, or transplanting, as well as indirect population management through chemical or mechanical manipulation of habitat features. Often, these problems also have a spatial aspect, wherein management decisions are required simultaneously at different locations.

A formal analysis of such decision problems requires specification of (1) an objective function for evaluating alternative management strategies; (2) predictive models of system dynamics formulated in quantities relevant to the stated management objectives; (3) a finite set of alternative management actions, including any constraints on their use; and (4) a monitoring program to follow the system's evolution and responses to management. The objective function specifies the value of alternative management actions and usually accounts for benefits and costs, as well as conditional constraints. The predictive models must be realistic enough to mimic the relevant behaviors of ecological systems, which often are complex (i.e., include many interacting components), nonlinear, and characterized by spatial, temporal, and organizational heterogeneity. Thus, specification of an objective function and of useful system models can be a demanding and difficult task in applications of decision theory to resource-management problems.

Another challenging task is to explicitly account for uncertainty in the predictions of management outcomes. This uncertainty may stem from incomplete control of management actions, errors in measurement and sampling of ecological systems, environmental variability, or incomplete knowledge of system behavior (Williams et al. 1996). A failure to recognize and account for these sources of uncertainty can severely depress management performance and, in some cases, has led to severe environmental and economic losses (Ludwig et al.1993). Accordingly, there has been a growing interest in the theory of stochastic decision processes, and in practical methods for deriving optimal (or at least, robust) solutions (Walters1978, Hilborn 1987, Williams 1989). Recently, there has been a particular emphasis on methods that can account for uncertainty about the dynamics of ecological systems, and their responses to both controlled and uncontrolled factors (Walters 1986). This uncertainty can be characterized by continuous or discrete probability distributions of model parameters (or by discrete distributions of alternative model forms), which are hypothesized or estimated from historic data (e.g., Walters 1975, Johnson et al.1997). An important conceptual advance has been the recognition that these probability distributions are not static, but evolve over time as new observations of system behaviors are accumulated from the management process (Walters 1986). The popular notion of adaptive resource management involves efforts to account for the dynamics of uncertainty in making management decisions (Walters 1986, Walters and Holling 1990, Williams 1996).

In the following sections, we provide some preliminary thoughts concerning the elements and process necessary for adaptively managing Scrub-Jay habitat on MINWR. However, many of the details of an adaptive-management program will require further development. Ultimately the nature of the adaptive-management program will depend on the needs and capabilities of managers, as well as the fiscal and personnel resources that can be dedicated to the effort.

Management Objectives

Management objectives for Scrub-Jays at MINWR must be formulated within the context of the refuge's habitat-management program, although they should be congruent with recovery criteria established in the Scrub-Jay Recovery Plan (U.S. Fish and Wildlife Service 1990). We believe the ultimate goal of refuge management to be the long-term persistence of the Scrub-Jay population, which can be accomplished by preventing declines in abundance and by enhancing the potential for population growth. For purposes of the refuge decision analysis, we suggest an objective to minimize the probability of extinction (or equivalently, maximize the probability of persistence) of the Scrub-Jay population over some appropriate timeframe. The selection of a timeframe is somewhat arbitrary, but should be sufficiently long to account for both the transient and long-term dynamics of the habitat, as a function of both management actions and uncontrolled environmental factors. We also suggest consideration of an additional objective to maintain population size above some threshold during each step in the time frame to guard against unrecognized Allee effects, demographic stochasticity, and other extinction risks associated with small populations. The probability of population size declining below the threshold is referred to as the quasi-extinction risk (Ginzburg et al. 1982). We note for our purposes that the interest is not in estimating quasi-extinction risk per se, but in comparing the relative risks associated with different burning strategies (while accounting explicitly for important sources of uncertainty).

In addition to management benefits to Scrub-Jays, management costs must be considered. One possibility is to assume a fixed fire-management budget and then constrain the available management options accordingly. A more complicated approach would involve maximizing the benefit to Scrub-Jays per management dollar spent. In this case, management costs would have to be expressed in units comparable to those used to describe benefits (Clemen 1996). The relative value of management costs and benefits involves a subjective choice that can be informed by decision analysis, but the final assignment of those values must ultimately be made by managers (and the stakeholders they represent).

Potential Management Actions

Managers must specify a finite (i.e., manageable) number of possible actions to evaluate. All potential actions must be under some reasonable level of control by the manager. At a minimum we want to determine at each decision point whether a management unit should be burned or not, depending on the unit's extant habitat characteristics, Scrub-Jay population status, and perhaps habitat conditions at neighboring sites. We also would like to evaluate the conditions under which "mosaic" fires are preferred over hot, extensive fires. Mosaic fires depend on differences in flammability among vegetation types, and typically burn only a portion of the scrub oak in a management unit. Hot, extensive fires burn nearly all plant communities and are only feasible during relatively high ambient temperatures, high winds, low humidity, high fuel loads, and low fuel moisture. Fire extent and intensity can also be controlled somewhat by ignition technique, and this relationship should be evaluated as well. The season of prescribed burning appears to have little influence on vegetation dynamics in scrub communities (Foster and Schmalzer 2003) and so will not be explicitly considered.

Refuge managers will have to decide which management units (Fig. 1) are to be devoted to the program (N) and the number of units that could be potentially burned in a given year (n). If n<N, then N should be adjusted so that the average "return time" for each unit (N/n) is not significantly longer than might be needed given the dynamics of the habitat and the response by Scrub-Jays. A fire-return interval of more than about 8 years may be insufficient for maintaining good quality jay habitat at MINWR.

Planning (including budgeting) for burning management units typically is conducted as much as two years in advance. However, there is flexibility in exactly which units are burned each year, and units can be added or deleted from the burn prescription as environmental conditions warrant (assuming adequate time is available for the Section 7 consultation necessary under the Endangered Species Act). Also, the current practice of not burning units devoted to Scrub-Jay habitat during the peak nesting season (mid-March to mid-June) should be examined. Scrub-Jays evolved in a system in which wildfire occurred regularly during the nesting season, and the removal of the constraint on spring burning would provide a greater probability of achieving burn prescriptions.

Dynamic Models of Scrub-Jay Populations and Habitats

Development of an effective management strategy depends on making probabilistic predictions about the outcomes of alternative management actions. These predictions, in turn, depend on dynamic models of vegetation and Scrub-Jay dynamics. This project involves the development of up to three such models (represented by arrows in the following schematic), representing the series of relationships connecting a decision to burn with the ultimate effects on Scrub-Jay population dynamics:

ignition of vegetation → fire extent & intensity → habitat condition → Scrub-Jay demographics

At a minimum, these models must express alternative outcomes and their associated probabilities of occurrence (as estimated from extant data or professional judgment). In some cases, it may be possible to develop more mechanistic models of system dynamics. Regardless of model complexity, however, it will be essential to account for key sources of uncertainty in system behaviors. Explicit recognition of uncertainty in system dynamics is essential for the development of a robust management strategy, and ultimately for validating and refining models using data collected from environmental monitoring programs.

Fire dynamics.— The size, spatial configuration, and intensity of a fire is a result of many interacting physical and biotic factors. At MINWR, it often is difficult to predict the dynamics of fire once the vegetation has been ignited because vegetation composition and structure is so heterogeneous and because weather conditions can change rapidly. There have been some recent advances in modeling fire behavior as a function of environmental covariates (Finney 1998), and there is some experience in applying these models at MINWR ((Duncan and Schmalzer 2004). We propose to evaluate these models for application to the prescribed burning of Scrub-Jay habitat. In particular, we are interested in calibrating and testing the predictions of these models by using appropriate remote-sensing techniques, in combination with ground-based sampling.

Habitat dynamics.—Optimal habitat for Scrub-Jays has been described as oak-dominated scrub, approximately 1-2 meters in height, interspersed with patches of bare sand used for caching acorns (Woolfenden and Fitzpatrick 1984, 1996). Florida Scrub-Jays avoid areas with too many trees, presumably because they make jays vulnerable to accipiters (Breininger et al. 1995). A fire frequency averaging once every 8-20 years is considered optimal in oak-scrub habitat (Woolfenden and Fitzpatrick 1991). However, oak-dominated scrub at MINWR typically occurs in relatively small patches, which are interspersed among stands of palmetto scrub, pine flatwoods, and emergent or shrub wetlands (Breininger et al. 1991). A critical need for this project then is to determine how mosaics of these habitat types respond to various frequencies and intensities of fire, and how those responses ultimately effect changes in Scrub-Jay abundance (Breininger et al. 2002).

There are both fixed and dynamic features of habitat-management units that affect Scrub-Jay population dynamics. Fixed features include the amount of oak scrub (determined primarily by soil types), as well as boundary conditions that may influence the movement of jays to or from neighboring management units. Important dynamic features of the habitat include the height of the oak scrub, the amount of bare sand, and the occurrence of trees. A key need for this project is to identify the most important dynamic habitat features and to posit models that describe how these features change over time in response to the presence or absence of fire (and to other uncontrolled environmental factors). A major challenge in the construction of these dynamic models will be in determining the spatial resolution of these features necessary to make reasonable predictions of jay population dynamics. We suspect that it will be necessary to characterize habitat attributes of management units at a relatively fine spatial scale given the heterogeneity of habitat types within management units and the sedentary nature of jays. Breininger and Carter (2003) and Breininger and Oddy (2004) suggested that population dynamics of jays could best be understood by considering the habitat features of individual Scrub-Jay territories (approximately 10 ha).

Dynamic models of habitat features can be continuous or discrete. Breininger and Carter (2003) employed a discrete model of scrub height and estimated the probabilities of each height category making a one-year transition to all other types. A Markovian model of this nature could be parameterized initially using information provided by Duncan et al. (1999), Breininger and Carter (2003), Breininger and Oddy (2004), Schmalzer (2003), Schmalzer et al. (2003).

Population models.—There have been several efforts to model the dynamics of Scrub-Jay populations for the purpose of estimating the probability of extinction (or quasi-extinction) under various environmental scenarios (Woolfenden and Fitzpatrick 1991, McDonald and Caswell 1993, Root 1998, Breininger et al. 1999, and Stith 1999). These population models serve as useful starting points for the development of models needed to inform a prescribed-burning program at MINWR. The challenge for this project will be to imbed a properly structured population model (or set of alternative models) in a decision-making context, where management actions are taken on an annual basis, where optimal decisions depend on both the state of the resource and the state of knowledge about system dynamics, and where uncertainty in model predictions can be reduced over time using a resource monitoring program.

A challenging aspect of this project will be to determine the organizational, spatial, and temporal scales of population models needed to support effective decision-making. From an organizational perspective, we propose to develop a stage-structured population model for female Scrub-Jays that at a minimum distinguishes breeders from non-breeders. Although existing models involve up to six demographic stages (Fig. 2, Breininger et al. 1999), the appropriate number of stages depends on a balance between bias and precision in model predictions that is appropriate for the management context at hand. The population model must have enough structure to make reasonably accurate predictions about changes in population size, but not so much structure that stage-specific abundance and transition probabilities among stages cannot be estimated (observed) with acceptable precision. Long-term operational capabilities for monitoring Scrub-Jay dynamics will play a critical role in determining model complexity on an organizational scale.

The spatial and temporal scales of Scrub-Jay models will be designed to accommodate the scales at which management actions are implemented. Because decisions about which management units are to be burned are made annually, we expect model structure to incorporate an annual cycle of population dynamics, using an anniversary date either just prior to or immediately after the peak nesting season (March – April). Decisions concerning the appropriate spatial scale(s) will be more challenging. The spatial extent encompasses the entire refuge population, but it is not yet clear what spatial grain (i.e., the smallest unit of observation) is necessary and practicable. As with organizational scale, selection of the appropriate spatial scale involves a trade-off between bias and precision. Model complexity (structure) could be reduced substantially with a negligible increase in bias if relatively isolated centers of population abundance are treated as independent units. Up to four such spatial units might be feasible at MINWR because of the short-distance dispersal of jays. Within these population centers, however, we expect that model structure may have to accommodate the spatial configuration of management units. In other words, which units are burned in a given year may be as important to Scrub-Jay dynamics as how many units are burned.

Parameterization of Scrub-Jay population models will involve estimation of annual survival, reproductive, and movement rates, as well as the aggregation of these rates into transition probabilities among population stages. Effective management depends on understanding how these quantities vary as a function of habitat-management activities and other uncontrolled environmental conditions. For the purposes of this project, we propose to develop (possibly competing) hypotheses about the effects of extant habitat features on various events in the annual cycle of jay population dynamics. We believe there is sufficient data and understanding of system dynamics available to parameterize an initial set of hypotheses, which then will be refined through the adaptive management process.

Monitoring Programs

Kennedy Space Center (KSC) operates a multidisciplinary, long-term ecological monitoring program that includes studies of Florida Scrub-Jays and vegetation dynamics. These studies encompass >13 years of research at sites where nearly all jays are uniquely color-banded to allow quantification of recruitment, mortality, and dispersal in relation to habitat features (e.g., Breininger and Carter 2003, Breininger and Oddy 2004). However, these studies are conducted in <1/5 of the potential habitat at MINWR. Extrapolation from these sites is uncertain because population dynamics can vary greatly across landscapes (Breininger et al. 1996), and because remote sensing studies indicate that these study sites do not represent all habitat conditions found on Merritt Island. There are also many uncertainties from these studies concerning the relationships between habitat conditions and demographic responses by jays (Burgman et al 2001). Finally, studies of vegetation dynamics and application of fire models on Merritt Island indicate that restoring habitat quality degraded by soil disturbance and fire suppression may be especially difficult. Thus, field experiments may be useful for developing more effective habitat restoration and management techniques (Breininger and Schmalzer 1990, Schmalzer and Boyle 1998, Duncan et al. 1999, Schmalzer and Adrian 2001, Duncan and Schmalzer 2004).

A cost-effective monitoring program for Scrub-Jays and their habitats is needed to support effective decision-making across the breadth of Scrub-Jay habitats at Merritt Island. MINWR has conducted an annual Scrub-Jay abundance survey since 1999, with the nominal objectives of determining population trends within and across management units, and of understanding relationships between Scrub-Jay abundance and fire history. However, it is not clear whether this monitoring program is sufficient to support the proposed adaptive management process. In particular, we have concerns about possible bias due to the lack of a statistical design to direct the spatial placement of sample units. In addition, it is not clear how the abundance index derived from the survey routes (jays/100m) relates to jay abundance within the management unit. Finally, it is unknown whether there is an adequate number and distribution of survey routes to estimate jay abundance at the necessary spatial scales and with acceptable precision. A thorough review of this monitoring program is therefore warranted within the context of the proposed habitat-management program. Re-design of the existing survey or design of a supplemental survey likely will be necessary.

We propose to evaluate a simple and inexpensive habitat classification scheme to determine the potential of each management unit to support breeding pairs of Scrub-Jays and to provide a basis for management prescriptions. First, the number of potential Scrub-Jay territories has been approximated by over-laying a 10-ha square grid on recent digital orthophoto quads. A grid-cell size of 10 ha was used because it approximates the size of a typical Scrub-Jay territory (Woolfenden and Fitzpatrick 1984, Breininger et al. 1995). Each grid cell was classified (Fig. 3) as either:

1) Primary – those containing oak scrub ridges ≥0.4 ha on well-drained soils;
2) Secondary – those containing oak scrub ridges ≥0.4 ha on poorly drained soils;
3) Tertiary – those containing oak scrub ridges <0.4 ha on poorly drained soils; or
4) Unsuitable – those unlikely to provide the life requisites of Scrub-Jays (although jays may occasionally use them).

Primary and secondary territories can function as sources (i.e., net exporters of jays because recruitment exceeds mortality) if shrub structure is optimal, whereas tertiary territories are usually sinks (i.e., net importers because mortality exceeds recruitment) (Breininger and Oddy 2004).

The above territory classifications are essentially fixed by soils, topography, and vegetation relationships (Breininger et al. 1991), but a dynamic habitat feature is shrub height, which is a useful measure for evaluating habitat quality and fire management needs (Breininger and Carter 2003, Breininger and Oddy 2004). Shrub height will be classified as either:

1) Short – grid cells dominated by scrub <1.2 m tall and <0.13 of scrub 1.2-1.7 m;
2) Optimal – a mix of short scrub and ≥0.13 ha of scrub 1.2-1.7 m;
3) Tall mix – a mix of tall scrub and short and/or optimal scrub; or
4) Tall – grid cells dominated by scrub >1.7 m.

Habitat structure must be assessed prior to the annual decision concerning prescribed burning. Scrub height and the occurrence of bare sand can be determined through a combination of remote sensing and sample-based ground verification (Duncan et al. 1995; Breininger et al. 1998, 2002). When such monitoring is not feasible (e.g., due to the unavailability of aerial images), scrub height might be approximated based on the correlation of scrub height and time since the last fire (Duncan et al. 1995, Breininger and Oddy 2004).

Optimization and Adaptation

Calculating an optimal strategy for prescribed burning of Scrub-Jay habitat at MINWR involves determining the state and time-specific management actions that minimize the expected quasi-extinction rate over the specified time horizon. Stochastic dynamic programming (SDP) is a very efficient algorithm for solving sequential decision-making problems and it has seen wide use in natural resource management (e.g., Richards et al. 1999). SDP can be applied in problems where system dynamics are uncertain, and optimal management strategies can "evolve" based on a comparison of predicted and observed system responses (e.g., Johnson et al. 1997). A major shortcoming of SDP, however, is its inability to handle high-dimension problems (i.e., those with many state and decision variables, accompanied by high levels of uncertainty).

An alternative to SDP is the application of Bayesian inference and decision theory by (Dorazio and Johnson 2003). This approach provides a sound theoretical framework for identifying optimal actions under uncertainty, as well as a probabilistic basis for sequentially updating beliefs about system dynamics as new information is acquired through monitoring. And unlike SDP, the Bayesian approach can deal with continuous as well as discrete variables, highly complex system dynamics, and system dynamics that are non-Markovian. A disadvantage of this approach compared with SDP is the current inability to calculate "closed –loop" management strategies. Closed-loop strategies provide an optimal sequence of actions, conditioned on the observed system state at each decision point. Current applications of Bayesian decision theory are restricted in practice to the calculation of "open-loop" strategies in which the sequence of decisions is based only on the initial system state. While the performance of a closed-loop strategy is demonstrably better than an open-loop strategy, we believe the difference may be negligible in practice. Strict adherence to a Bayesian philosophy produces a new management strategy at each decision point based on an updating of model parameters and the predicted consequences of current and future actions, given the observed state of the system.

Application of Bayesian inference and decision theory will nonetheless be limited in problems where the decision space is very large. For example, consider a problem in which three alternative management actions are being considered for each of 15 management units. In this case, $3^{15} = 14,348,907$ possible management scenarios would need to be evaluated. A possible alternative to an exhaustive search of this decision space is application of a heuristic optimization algorithm. These algorithms are not guaranteed to produce the optimal strategy, but can produce good sub-optimal strategies in an acceptable amount of computer time. A heuristic approach that shows great promise is simulated annealing, which is based on an analogy with the cooling of heated metals (Kirkpatrick et al. 1983). Simulated annealing readily accommodates a Bayesian statistical framework, can provide solutions for problems with extremely large decision spaces in a matter of hours on personal computers, and can produce bona fide optima for at least some problems (R. M. Dorazio, U.S. Geological Survey, pers. comm.).

Funding and Personnel Needs

Development of an adaptive-management program for Scrub-Jay habitat at MINWR will depend on an efficient and focused use of existing resources. These resources include the current fire-management program at MINWR, the monitoring and research programs of Dynamac

Corporation, and the time and expertise of refuge biological staff. We also anticipate the need for additional resources over at least a 2-year period as a necessary "front-end investment." The goal, however, is to develop an operational adaptive-management program that can be funded over the long-term at a lower and more reasonable cost.

We foresee a need for dedication of new resources in at least four key areas:

1) Project Coordination. – Successful execution of this project will require extensive communication and coordination among relevant government agencies and contractors, and between managers and researchers. We believe an individual with an adequate understanding of the problem (as well as the path to its solution) is needed to provide project oversight and coordination. This individual will need both exceptional technical and communication skills, and preferably would be an employee or contractor of the U.S. Fish & Wildlife Service (USFWS). We suspect that at least one person-year over a 2-year period will be necessary to act in this role.

2) System Modeling. – Development of an adaptive burning program will require the construction of habitat and population models designed specifically for this purpose. Construction of these models should be a joint effort between managers in the USFWS and researchers with Dynamac Corporation. There will be a need to rely heavily on the expertise at Dynamac, as their research findings concerning Scrub-Jay demography and fire-habitat relationships will be essential for constructing and parameterizing an initial set of models. USFWS managers will be responsible for ensuring that these models are structured to serve the management needs and capabilities at MINWR. A one-year post-doctoral student or other contractor jointly funded (but working under the direct supervision of the USFWS) should be considered. We anticipate the need for approximately $75,000 to fund this contract.

3) Development of Suitable Optimization Techniques. – We believe the most effective approach for developing optimization techniques would be to fund a Research Work Order (RWO) with the U.S.G.S. Florida Integrated Science Center. The Center is currently is working on application of Bayesian decision analysis and advanced optimization techniques to problems in natural resource management. We estimate the cost of this RWO at $50,000.

4) Design and Conduct of Monitoring Programs. – We propose to approach the development and operation of monitoring programs adaptively. Initially, we propose to test various protocols with the intent of finding those that are most effective for the least cost. Obviously, population and habitat monitoring programs must be affordable if they are to be maintained over the long term. In the short term, however, we expect that a fairly substantial investment will be required to design and test various methodologies, including remote-sensing techniques for habitat assessment and mark-resight protocols for estimating abundance and vital rates of jays. We believe the effort would be best served by developing a jay monitoring program that compliments (rather than replaces) the existing monitoring at selected research sites by KSC. The idea would be to expand the scope and intensity of jay monitoring throughout the refuge to better support management, while using the KSC long-term research sites to help compare the efficacy of monitoring protocols at different spatial

and demographic scales (and to help parameterize initial models of system dynamics). We suggest that Dynamac Corporation take the lead for design of habitat monitoring protocols, and the USFWS (possibly through the Southeastern Adaptive Management Group: http://cars.er.usgs.gov/SEAMG/seamg.html) assume responsibility for design of the mark-resight program that will occur outside existing KSC research sites. Field data-collection should be a shared responsibility of the USFWS and NASA. We believe additional funding of $100,000 for each of two years would be adequate to develop specific recommendations for effective and affordable operational monitoring programs.

Literature Cited

Breininger, D. R. and G. M. Carter. 2003. Territory quality transitions and source-sink dynamics in a Florida Scrub-Jay population. Ecological Applications 13:516-529.

Breininger, D. R. and D. M. Oddy. 2004. Do habitat potential, population density, and fires influence Florida Scrub-Jay source-sink dynamics? Ecological Applications 14:000-000.

Breininger, D. R., and P. A. Schmalzer. 1990. Effects of fire and disturbance on plants and animals in a Florida oak/palmetto scrub. American Midland Naturalist 123:64–74.

Breininger D. R., B. W. Duncan, and N. J. Dominy. 2002. Relationships between fire frequency and vegetation type in pine flatwoods of east-central Florida, USA. Natural Areas Journal 22:186-193.

Breininger, D. R., M. A. Burgman, and B. M. Stith. 1999. Influence of habitat, catastrophes, and population size on extinction risk on Florida Scrub-Jay populations. Wildlife Society Bulletin 27: 810-822.

Breininger, D. R., M. J. Provancha, and R. B. Smith. 1991. Mapping Florida scrub jay habitat for purposes of land-use management. Photogrammetric Engineering and Remote Sensing 57: 1467-1474.

Breininger, D. R., V. L., Larson, D. M. Oddy, R. B. Smith and M. J. Barkaszi. 1996. Florida Scrub-Jay demography in different landscapes. Auk: 113:617-625.

Breininger D. R., V. L. Larson, B. W. Duncan, R. B. Smith. 1998. Linking habitat suitability to demographic success in Florida Scrub-Jays. Wildlife Society Bulletin 26:118-128.

Breininger, D. R., V. L. Larson, B. A. Duncan, R. B. Smith, D. M. Oddy, and M. Goodchild. 1995. Landscape patterns in Florida Scrub Jay habitat preference and demography. Conservation Biology 9: 1442-1453.

Burgman, M. A., D. R. Breininger, B. W. Duncan, and S. Ferson. 2001. Setting reliability bounds on habitat suitability indices. Ecological Applications 10: 70-78.

Clemen, R. T. 1996. Making hard decisions: an introduction to decision analysis. 2nd edition. Duxbury Press, Pacific Grove, CA. 664pp.

Dorazio, R. M., and F. A. Johnson. 2003. Bayesian inference and decision theory – a framework for decision making in natural resource management. Ecological Applications 13:556-563.

Duncan, B. W. and P. A. Schmalzer. 2004. Anthropogenic influences on potential fire spread in a pyrogenic ecosystem of Florida. Landscape Ecology 19:153-165.

Duncan, B. W., D. R. Breininger, P. A. Schmalzer, and V. L. Larson. 1995. Validating a Florida Scrub Jay habitat suitability model, using demography data on Kennedy Space Center. Photogrammetric Engineering and Remote Sensing 56:1361-1370.

Duncan, B. A., S. Boyle, D. R. Breininger, and P. A. Schmalzer. 1999. Coupling past management practice and historical landscape change on John F. Kennedy Space Center. Landscape Ecology 14:291-309.

Finney, M. A. 1998. FARSITE: Fire area simulator – model development and evaluation. U.S. department of Agriculture Forest Service, Research Paper RMRS-RP-4. 47pp.

Foster, T.E. and P.A. Schmalzer. 2003. The effect of season of fire on the recovery of Florida scrub. In: Proceedings of the Second International Wildland Fire Ecology and Fire Management Congress, American Meteorological Society, Published on CDROM and at http://www.ametsoc.org.

Ginzberg, L. R., Slobodkin, L. B., Johnson, K., and A. G. Bindman. 1982. Quasiextinction probabilities as a measure of impact on population growth. Risk Analysis 2:171-181.

Hilborn, R. 1987. Living with uncertainty in resource management. North American Journal of Fisheries Management 7:1-5.

Johnson, F. A., C. T. Moore, W. L. Kendall, J. A. Dubovsky, D. F. Caithamer, J. R. Kelley, Jr., and B. K. Williams. 1997. Uncertainty and the management of mallard harvests. Journal of Wildlife Management 61:202-216.

Kirkpatrick, S., C. D. Gelatt, Jr., and M. P. Vecchi. 1983. Optimization by simulated annealing. Science 220:671-680.

Ludwig, D., R. Hilborn, and C. Walters. 1993. Uncertainty, resource exploitation, and conservation: lessons from history. Science 260:17, 36.

McDonald, D. B. and H. Caswell. 1993. Matrix methods for avian demography. Current Ornithology 10:139–184.

Possingham, H. P. 1997. State-dependent decision analysis for conservation biology. Pages 298-304 *in* S. T. A. Pickett, R. S. Ostfeld, M. Shachak, and G. E. Likens, eds. The ecological basis for conservation: heterogeneity, ecosystems, and biodiversity. Chapman and Hall, New York, NY.

Richards, S. A., H. P. Possingham, and J. Tizard. 1999. Optimal fire management for maintaining community diversity. Ecological Applications 9:880-892.

Root, K. V. 1998. The effects of habitat quality, connectivity, and catastrophes on a threatened species. Ecological Applications 8:854-865.

Schmalzer, P. A. 2003. Growth and recovery of oak-saw palmetto scrub through ten years after fire. Natural Areas Journal 23:5–13.

Schmalzer, P. A. and F. W Adrian. 2001. Scrub restoration on Kennedy Space Center/Merritt Island National Wildlife Refuge 1992-2000. Pages 17-21 *in* D. P. Zattau, editor. Proceedings of the Florida Scrub Symposium 2001. U.S. Fish and Wildlife Service, Jacksonville, FL.

Schmalzer, P. A. and S. R. Boyle. 1998. Restoring long-unburned oak-saw palmetto scrub requires mechanical cutting and prescribed burning. Restoration and Management Notes 16:96-97.

Schmalzer, P.A. T. E. Foster, and F.W. Adrian. 2003. Responses of long-unburned scrub on the Merritt Island/Cape Canaveral barrier island complex to cutting and burning. In: Proceedings of the Second International Wildland Fire Ecology and Fire Management Congress, American Meteorological Society, Published on CDROM and at http://www.ametsoc.org.

Stith, B. M., J. W. Fitzpatrick, G. E. Woolfenden, and B. Pranty. 1996. Classification and conservation of metapopulations: a case study of the Florida scrub jay. Pages 187-216 *in* D.R. McCullough, editor. Metapopulations and Wildlife Conservation. Island Press, CA.

Stith, B. M. 1999. Metapopulation dynamics and landscape ecology of the Florida Scrub-Jay (*Aphelocoma coerulescens*). Ph.D. Dissertation, University of Florida, Gainesville, FL.

U. S. Fish and Wildlife Service. 1990. Florida Scrub-Jay recovery plan. Southeast Region, Atlanta, GA. 23pp.

Walters, C. J. 1975. Optimal harvest strategies for salmon in relation to environmental variability and uncertain production parameters. Journal of the Fisheries research Board of Canada 32:1777-1784.

Walters, C. J. 1986. Adaptive management of renewable resources. Macmillian Publishing Company, New York, NY. 374pp.

Walters, C. J., and R. Hilborn. 1978. Ecological optimization and adaptive management. Annual Review of Ecology and Systematics 9:157-188.

Walters, C. J. and C. S. Holling. 1990. Large-scale management experiments and learning by doing. Ecology 71:2060-2068.

Williams, B. K. 1989. Review of dynamic optimization methods in renewable natural resource management. Natural Resource Modeling 3:137-216.

Williams, B. K., F. A. Johnson, and K. Wilkins. 1996. Uncertainty and the adaptive management of waterfowl harvests. Journal of Wildlife Management 60:223-232.

Woolfenden, G. E., and J. W. Fitzpatrick. 1984. The Florida Scrub Jay: demography of a cooperative-breeding bird. Princeton Univ. Press, Princeton, New Jersey.

Woolfenden, G. E., and J. W. Fitzpatrick. 1991. Florida Scrub Jay ecology and conservation. Pages 542-565 in Bird population studies. C. M. Perrins, J. D. Lebreton, and G. J. M. Hirons, editors. Oxford University Press, NY.

Woolfenden, G. E., and J. W. Fitzpatrick. 1996. Florida Scrub-Jay (*Aphelocoma coerulescens*). Pages 1-28 in A. Poole and F. Gill, editors. The Birds of North America, No. 228. The Academy of Natural Sciences, Philadelphia and The American Ornithologists' Union, Washington D.C.

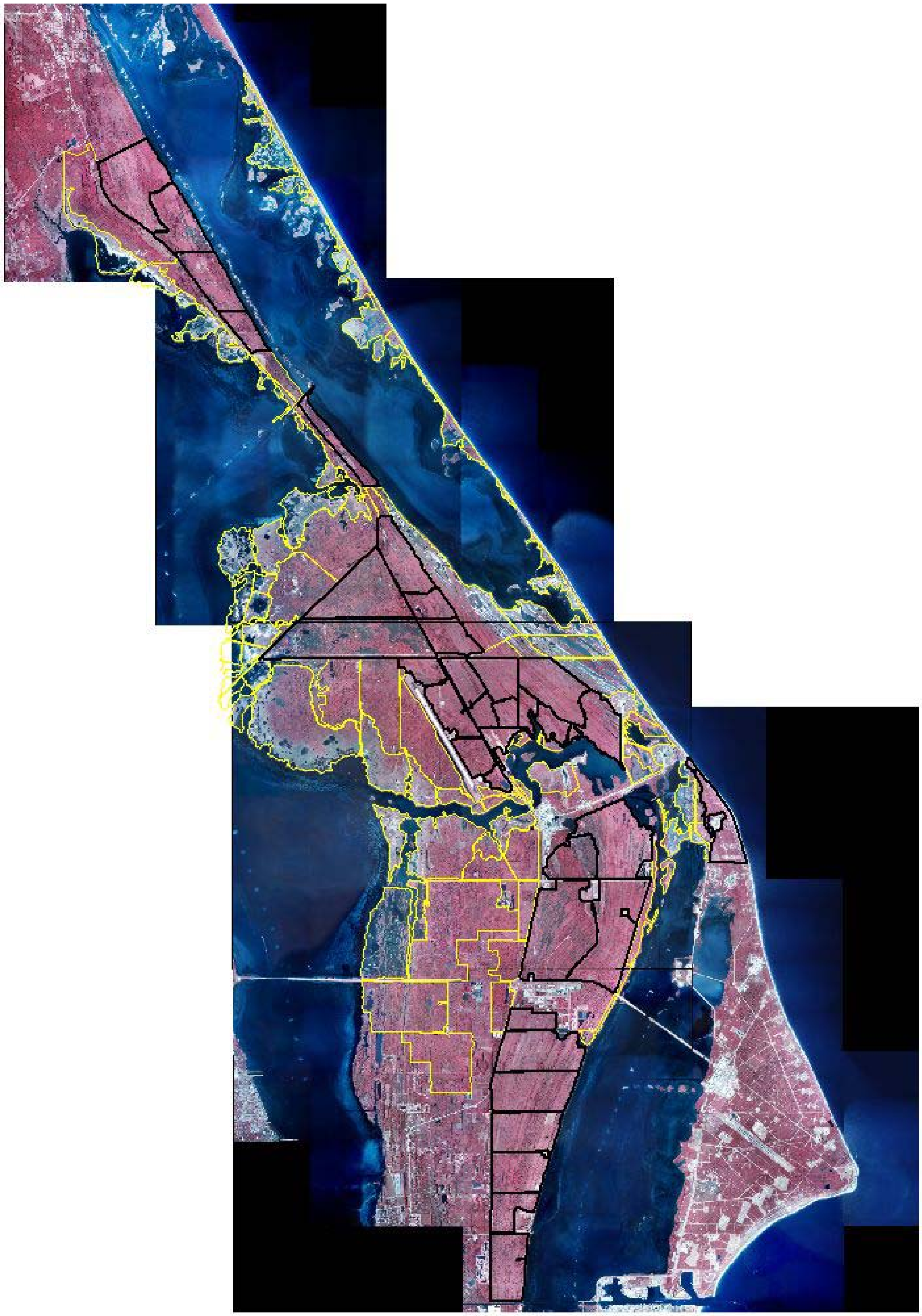

Figure 1. Management units for prescribed burning at MINWR, with those that might be used in an adaptive management program for Scrub-Jay habitat outlined in black.

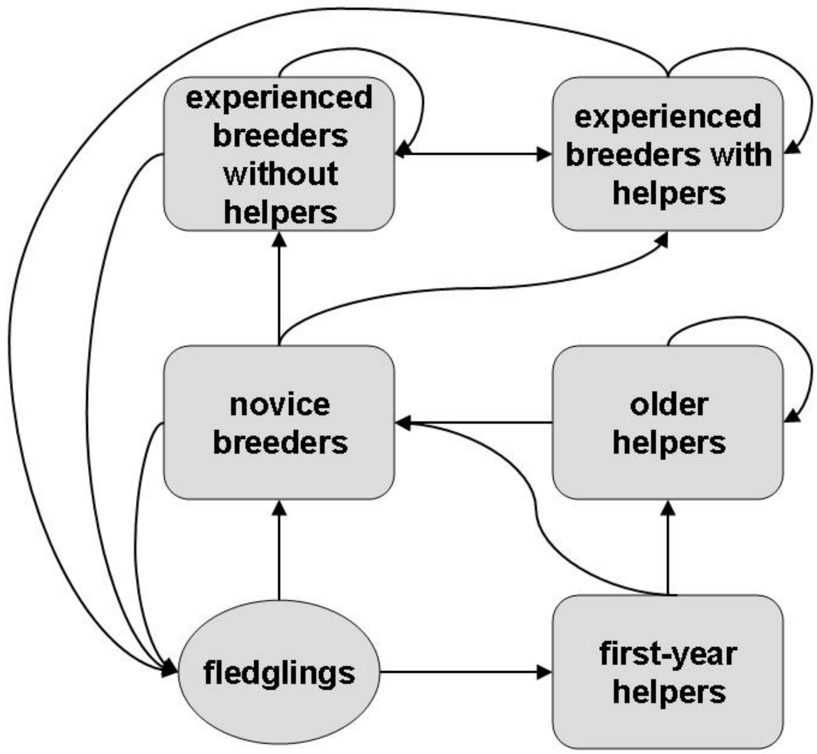

Figure 2. A stage structured model for Scrub-Jays as described by Breininger et al. (1999).

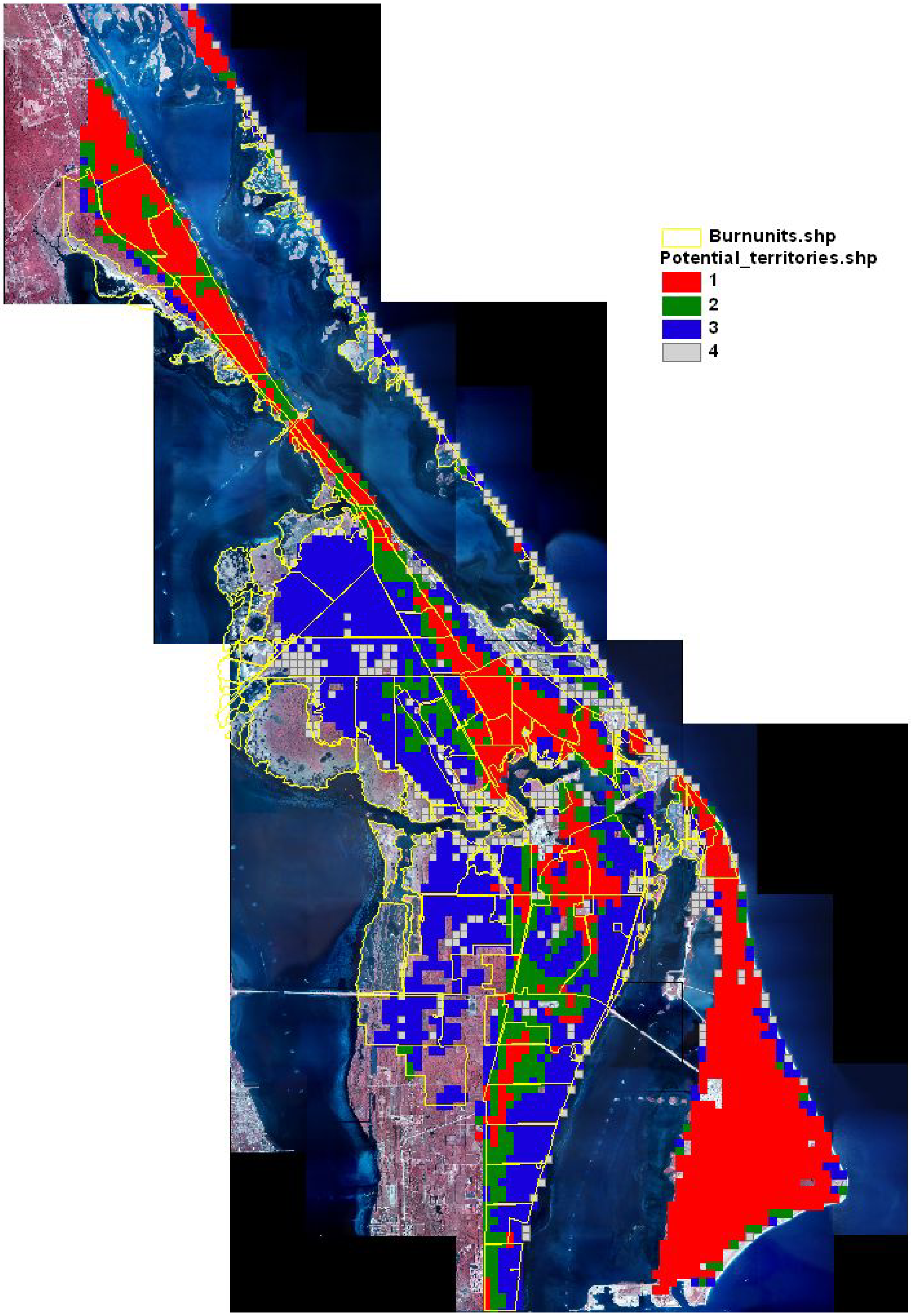

Figure 3. Classification of potential Scrub-Jay territories at MINWR. See text for descriptions of primary (1), secondary (2), tertiary (3), and unsuitable (4) territories.