National Key Deer Refuge— Desired Future Conditions for Fire-maintained Habitats

Results and Synthesis of a Fire Management & Fire Ecology Experts' Workshop
16-17 August 2010

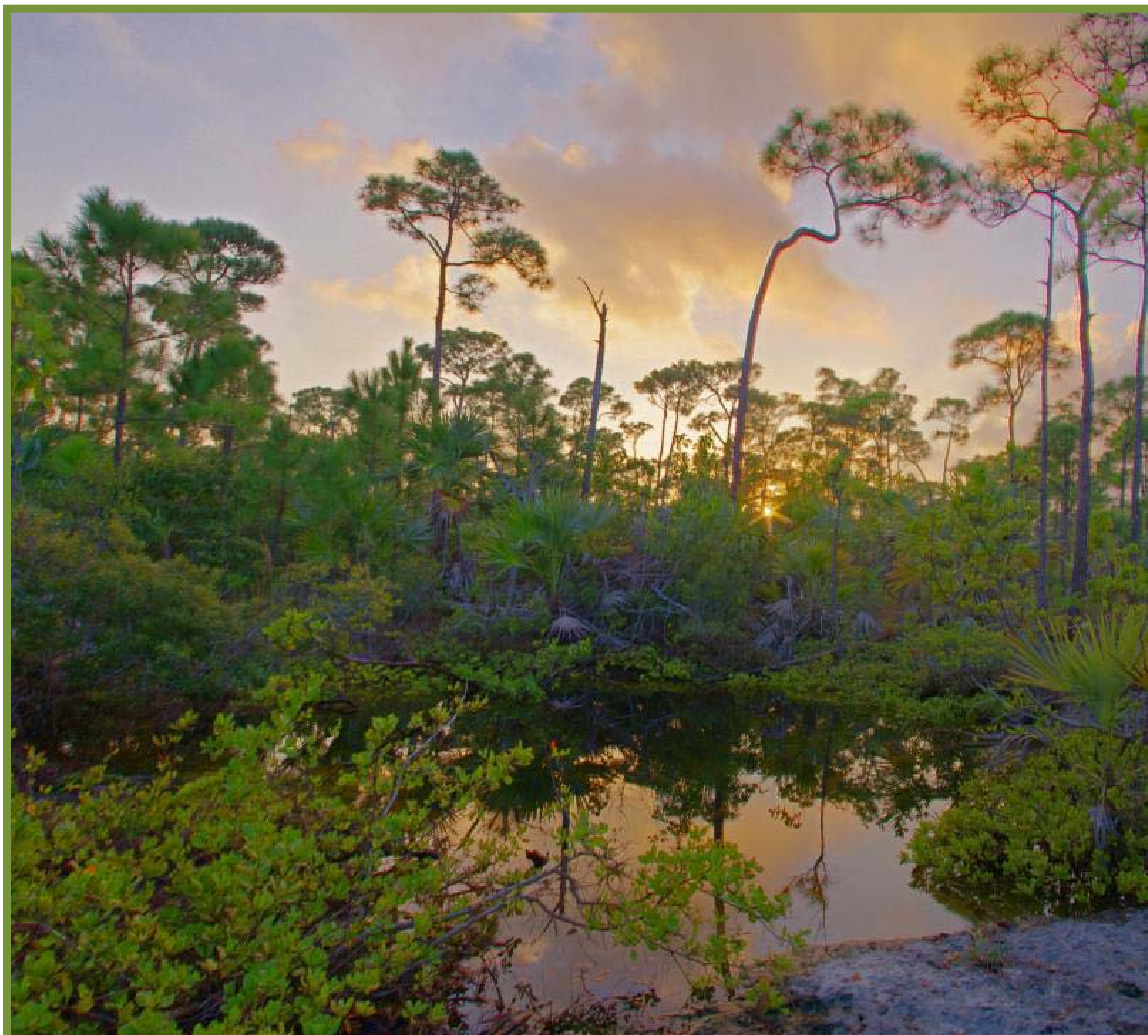

Photo by Chad Anderson

Compiled by: Ronald L. Myers

Executive Summary

Periodic fire plays an important ecological role in two broad vegetation types in the National Key Deer Refuge (NKDR). Those types are pine rockland and marshes (both freshwater and brackish water). Within these two vegetation types, several endangered and threatened animal and plant species, which the US Fish & Wildlife Service has been mandated to protect and manage, depend on habitat conditions that are maintained by burning and other ecological processes. The Key deer, the species for which the Refuge was established, is one of the species where fire maintains important habitat features, such as accessible, favored food plants. Other species that rely to varying degrees on fire-created conditions include the Lower Keys marsh rabbit, the silver rice rat, several species of butterflies, and plant species such as south Florida slash pine, Garber's spurge, Big Pine partridge pea, wedge spurge, and sand flax. Fire also plays a vital role in maintaining the species diversity within the two vegetation types.

Pine Rockland is considered a critically imperiled ecosystem, restricted to a few locations on the south Florida mainland, several of the lower Keys, and four islands in the Bahamas. The Refuge supports a unique example of these pine forests with a higher diversity of tropical species than found on the mainland. A recognized threat to pine rocklands throughout their range is the lack of, or insufficient/inappropriate, burning. Without fire, the pines forests, with their largely herbaceous ground cover, become shrubby and succeed, i.e. change, to subtropical hardwood forest. Similarly, herbaceous marshes, in the absence of fire, become dominated by woody species. In both cases, critical habitats are lost in prolonged absence of fire.

Recent and on-going research at both the NKDR and in pine rocklands and marshes in southern Florida, particularly Everglades National Park, has established the overall importance of fire to the persistence and maintenance of these habitats in the landscape. Studies have also documented changes that have occurred in the absence of fire, identified fire-adapted traits of some of the species, and have pointed to the need to use managed fires, i.e. prescribed burns, at the NKDR in a planned and consistent manner.

Pine rockland and herbaceous marshes are not only fire-maintained, they are also fire-prone, i.e. they are ignitable and readily burn. Wildfires, both human and lightning-caused, have had a long documented history in them and are likely to recur. Because in today's landscape, i.e. natural lands intermixed with people and cultural features, wildfires can rarely be tolerated. Fire has to be managed through the planned integration of fire prevention programs to avoid unwanted fires, fire suppression actions to protect people and resources when fires occur, and fire use to reduce hazardous fuels and maintained natural habitats. The latter involves the judicious application of prescribed fire in those habitats that require burning.

Where habitats are to be managed with planned burns, specific goals or desired conditions need to be defined, that address the question: *what are we trying to accomplish through the long-term management of fire in the NKDR?* Fire management goals, described as *desired future conditions (DFC)*, represent the acceptable range of habitat and species population conditions that are to be reached and maintained through appropriate management actions. The nature of those conditions determine the managed fire regimes that will be designed and implemented, i.e. how often, how intensely, at what times during the year, and where and in what pattern fire will be applied.

Desired future conditions for fire-maintained habitats at the Refuge presented in this document were established through synthesizing research results conducted at the Refuge and elsewhere, as well as the product of a *Fire Ecology and Fire Management Experts' Workshop* held on Big Pine Key, 16-17 August 2010. The synthesis of research and management experience is detailed in this document. The desired future conditions listed in Table 2 on pages 36-47.

The desired future conditions are presented largely as ranges of vegetation structure, primarily percent cover, of key components of the vegetation, such as overstory pines, understory shrubs, hardwood trees, palms, and herbaceous vegetation, but it also includes other criteria such as pine regeneration and age distribution, ground cover diversity, soil organic matter accumulation, and amount of exposed bare rock that combined represent dynamic examples of the Refuge's vegetation types. Another key feature of the DFC is the percentages of several successional stages (i.e. seral stages) to be maintained on the Refuge at any one time within the landscape. In the case of both pine rockland and marshes, the earlier successional stages will be favored, i.e. approximately 70 percent each of high-elevation pine rockland, low-elevation pine rockland, freshwater marshes, and cord grass marsh will be maintained in the more open, early successional state where herbaceous ground cover is dominant. Within those early-seral stages, a wide range of density, percent cover, and vegetation stature are acceptable as long as, habitat variability, species diversity, and habitats of critical species are maintained.

Because the details of the effects of fire on the many species are not fully understood and in many cases can only be determined by documenting species responses to fire over an extended period of time, the Refuge's fire management activities require careful planning and monitoring, along with continued detailed research that address specific scientific questions. The outcome of continuing monitoring and research may suggest modification of management approaches (i.e. changes to the fire management plan), shifts in the fire regime components being applied (e.g. frequency, season, intensity, etc.), and actual changes to the desired conditions presented in this document. This continual reassessment represents an adaptive management approach that allows management changes to be made in response to monitoring data, research results, management experience, and other changing circumstances.

Table of Contents

Contributors……….…………………………………………………………………………6

Introduction…………………………………………………………………………………..7

Role of fire……………………………………………………………………………8

Why manage fires?..12

Purpose of Fire Management Experts' Workshop…………………………………………13

What is desired future condition?……………………………………………………………14

Development process for desired future condition………………………………………...16

Guiding criteria for desired future condition………………………………………………...16

Focal conservation targets……………………………………………………………………18

Focal targets & the role of fire………………………………………………………………..19

Pine rocklands…………………………………………………………………………...19

Freshwater & saltmarsh……………………….……………………………………….26

South Florida slash pine………………………………………………………………..28

Key deer habitat…………………………………………………………………………28

Lower Keys marsh rabbit……………………………………………………………….29

Garber's spurge populations…………………………………………………………...29

Big Pine partridge pea populations…………………………………………………....29

Bartram's hairstreak butterfly habitat………………………………………………….30

Florida leafwing butterfly habitat……………………………………………………….30

Pinelands croton populations…………………………………………………………..30

Fire regimes for pine rockland and freshwater marsh………………………………………..31

Conceptual ecological models…………………………………………………………………32

General assumptions regarding NKDR desired future conditions…………………………34

Table of Contents, continued:

Time-frame of NKDR desired future conditions……………………………………………35

Desired Future Conditions—Pine Rocklands…………………………………………...36

Desired Future Conditions---Marshes……………………………………………………46

Glossary…………………………………………………………………………………..48

Biographical sketches—contributing experts……………………………………………53

Literature cited……………………………………………………………………………56

Contributors

Chad Anderson
USDI Fish & Wildlife Service
National Key Deer Refuge
Big Pine Key, FL

Chris Bergh
The Nature Conservancy
Sugarloaf Key, FL

Keith Bradley
Institute for Regional Conservation
Miami, FL

Dana Cohen
USDI Fish & Wildlife Service
National Key Deer Refuge
Big Pine Key, FL

David Crane
Florida Division of Forestry
Davie, FL

Alison Higgins
The Nature Conservancy
Sugarloaf Key, FL

Philip Hughes
USDI Fish & Wildlife Service
National Key Deer Refuge
Big Pine Key, FL

Stephen Laine
Eglin Air Force Base
Niceville, FL

Anne Morkill
USDI Fish & Wildlife Service
National Key Deer Refuge
Big Pine Key, FL

Dr. Ronald Myers
Ecological Consultant
Tallahassee, FL

Dr.Joseph O'Brien
USDA Forest Service
Athens, GA

Dr. Mike Ross
Florida International University
Miami, FL

Dr. James R. Snyder
USDI Geological Survey
Ochopee, FL

Sue Wilder
USDI Fish & Wildlife Service
Lacombe, LA

Thomas Wilmers
USDI Fish & Wildlife Service
National Key Deer Refuge
Big Pine Key, FL

Steve Zavalney
Monroe County Fire Rescue & Fire Prevention
Big Pine Key, FL

Introduction

The mission of the National Key Deer Refuge (NKDR) is to enhance populations of, and provide habitat for, *Federally-listed Threatened and Endangered Species*[1] found within the Lower Florida Keys, and to maintain the biodiversity of the pine rockland ecosystem and related habitats through appropriate management and conservation strategies. Fire management, both the control of unwanted wildfires and the use of fire through prescribed burning, is an important management action used by the Refuge to meet its mission criteria.

The NKDR contains two important *fire-maintained* ecosystems or habitats (also called *fire-dependent* ecosystems): 1) pine rocklands and 2) marshlands (fresh & some brackish water). The federally-listed key deer (*Odocoileus virginianus clavium*), the lower keys marsh rabbit (*Sylvilagus palustris paludicola*), the silver rice rat (*Oryzomys argentatus*), rare butterflies (Bartram's hairstreak--*Strymon acis bartrami*, Florida leafwing-- *Anaea troglodyta floridalis*), their sole larval host plant (*Croton linearis*), and the rare herbaceous plants, Garber's spurge (*Chamaesyce garberi*) Big Pine partridge pea (*Chamaecrista keyensis*), wedge spurge (*Chamaesyce deltoides* subspecies *serpyllum*), sand flax (*Linum arenciola*), are restricted to, or depend on disturbances such as fire that maintain open habitats .

The purpose of this assessment is to define *Desired Future Conditions* for the Refuge's fire-maintained habitats using 1) the results of recent and on-going studies within the Refuge, 2) current knowledge about these habitats throughout their range that includes southern peninsular Florida, the Florida Keys and the Bahamas, and 3) the expert opinion of scientists and fire managers who have worked in these ecosystems for much of their careers. This report is the outcome of a Fire Management & Fire Ecology Experts' Workshop held on Big Pine Key, 16-17 August 2010 and a synthesis of the results of scientific studies conducted on the Refuge and in similar habitats in southern Florida, both by the participants of the Experts' workshop and by those of other scientists and fire management experts.

Within the NKDR, pine rocklands can be separated into *lower-elevation* and *higher-elevation* types (Ross *et al*. 1992a). The former being more susceptible to storm surge and climate change induced sea-level rise. Although the two types are structurally similar, there are notable differences in species composition and the relative abundance of dominant species in the ground cover and shrub layer--the low-elevation type being dominated by buttonwood (*Conocarpus erectus*); the high-elevation type composed of a higher diversity suite of tropical hardwoods. The ground cover of the former is dominated by sedges, the latter by grasses. In the absence of fire, both types will become dominated by hardwoods and palms, and gradually change to subtropical hardwood forests of varying composition depending on hydroperiod. The low-elevation pine rockland vegetation grades into freshwater marsh forming a mosaic of pine and marsh habitats marked by slight changes in elevation (Ross *et al* 1992a & b). Storm surge from hurricane Wilma in 2005 and earlier storms killed many of the pines in lower-elevation pine rocklands on all of the keys where pine rockland occurs (Ross *et al* 2009). It can also affect higher-elevation pine rocklands, but to a less drastic degree. Storm surge and hurricane damage are a recurring disturbances in the Keys and similar pine die-backs have presumably occurred in the past and caused periodic contractions followed by expansions of pine populations. Fire is a process superimposed on these die-backs and is likely important in creating regeneration conditions for the re-establishment of pines and maintaining hardwoods

[1]*Note:* terms in italics, besides scientific names of plants & animals, are defined in the glossary on pages

as low-statured shrubs. There has also been a documented reduction in pine forests due to a gradual sea level rise which is likely to continue into the future (Ross *et al.* 1994; Ross *et al.* 2009; The Nature Conservancy 2010).

Marsh vegetation can be separated into freshwater marshes and salt marsh transition—the former dominated by sawgrass (*Cladium* jamaicense); the latter dominated by cordgrass (*Spartina* spp.). Both fresh- and brackish water types are strongly affected by disturbance regimes such as fire, seasonal flooding, storm surge and sea-level rise. Freshwater marsh can become woody in the absence of fire, dominated at least initially by buttonwood. In the absence of fire and/or storm surge, brackish water marshes can support buttonwood and/or mangrove vegetation that does not allow for a diverse herbaceous groundcover.

Although each of these fire-maintained habitat types is a convenient category that aids in habitat description, mapping, and management, in actuality, they represent broad gradients and transitions between and among each of the types, which result in a wide range of structural, species, and habitat diversity.

Role of fire:

Fire-maintained ecosystems require periodic fire to maintain their structural characteristic, species composition, and ecosystem processes. If fire is removed, or if the *fire regime* is altered in terms of frequency, intensity, and/or season, the ecosystem gradually changes to something else, and species and habitats are lost (Myers 2006). Many, if not most, species in fire-maintained ecosystems have adaptations to survive fire; in many cases they respond positively to it, and dominant species promote the spread of fire. Plants may have adaptations to survive certain types of fires or may need the heat of the fire or post-burn conditions to facilitate reproduction. For example, south Florida slash pine (*Pinus elliottii* var. *densa*) has a thick, heat resistant bark that protects living inner bark and cambium from heat, and long needles that shield vulnerable apical buds from heat, along with a growth form and stand structure that facilitate the dispersion of heat limiting damage to the tree crowns from low-intensity fires burning in *surface fuels*. It also has a seedling morphology, i.e. a thickened stem and fascicles tightly crowded around the bud, that may afford the seedling some protection from the heat of low-intensity fire, at least when compared to the morphology of the more northerly variety of slash pine (*Pinus elliottii* var. *elliottii*). South Florida slash pine also requires open, sun-exposed soil, free of heavy leaf litter accumulation, for successful regeneration. Frequent burning also prevents the accumulation of fuels, both in the form of dead organic matter (pine needles, palm fronds and grasses), and as live fuels in the form of dense pine stands, and shrub and palm thickets that can produce higher intensity fires, lethal to even the largest pines. Accumulation of needle and leaf litter around the base of pines can lead to smoldering fires that can damage the cambium in pine trunks and kill roots near the soil surface (O'Brien *et al.* 2010).

Fire stimulates flowering and seed germination in many herbaceous species in both the pine rockland and marsh. Most herbaceous species are perennial, and both perennial herbs and shrubs, have the ability to re-sprout following fire. Successful reproduction and maintenance of some of the rare herb populations may depend on fires of varying intensity (Liu *et al.* 2005).

Palms are resistant to low-intensity fires due to their growth form. They do not have an inner bark and cambium near the stem surface that could be heat damaged, and they have an apical bud that is protected to some extent from heat damage, even when the fronds are consumed (Snyder *et al*. 2005; Cooley 2004).

The nutrients released from burning increase productivity, improve forage quality for animals, and increase fruit and seed production that may enhance plant regeneration capacity and provide wildlife food, including the key deer (Carlson, *et al*. 1993; Main & Tanner 2009).

Dominant plant species in fire-maintained ecosystems tend to be flammable (Mutch 1970; Gagnon *et al.* 2010). These are the species that are responsible for carrying the fire across the landscape In pine rocklands, these flammable components include pine needles, palm fronds and bunch grasses. In the marshes, flammable components include bunch grasses and other graminoids like sawgrass. These pyrogenic characteristics of the vegetation provide a feedback that controls the fire regime. The heat produced by these flammable species and their capacity to burn at frequent intervals tend to limit the establishment and reproduction of competing species arresting the successional trajectory toward woody shrubs and trees that would occur in the absence of fire, or infrequent fire.

Fire-maintained ecosystems have been called *fire climaxes*, i.e. vegetation that contains species with adaptations to fire and whose fuel characteristics allow them to persist in an environment under an appropriate climate, weather conditions, and fire regime, and where there is a high likelihood of ignition sources, both natural and human derived. Fire-climaxes are unique ecosystems or assemblages of species that persist under a specific fire regime, not a successional stage in the traditional sense that the vegetation would go through following a disturbance without fire (Platt 1999). There are also multiple stable states the ecosystem could be in depending on the fire regime, for example pine rockland with a primarily herbaceous ground cover maintained by relatively frequent fire versus pine rockland with a predominately shrubby and palm understory maintained by somewhat less frequent fire.

Animals in fire-maintained habitats tend to have behavioral adaptations to avoid fire and to take advantage of increased forage quality, and flowering and seed production that follow a fire. Some individuals may be killed by fire, but the populations as a whole benefit from fire as their habitat and food sources are maintained. Without fire, their habitats and food sources would disappear or become less productive. Wildfires tend to be more lethal to animals than prescribed burning because in the latter ignition techniques, fire behavior, and timing can be planned and manipulated to prevent or limit direct impacts on fauna (Main & Tanner 2006).

When a particular species or habitat is described as *fire-adapted* or *fire-dependent*, it does not mean that the species or habitats are adapted to, nor dependent upon just any fire, but rather to a specific *fire regime* defined as the *recurring conditions of fire that characterize a given ecosystem* (Myers 2006). Those conditions include *fire frequency* (how often on average a fire returns to a particular spot), *intensity* (fire behavior = heat release characteristics such as flame intensity and heat *residence time* from both flaming and smoldering combustion), *severity* (impact of the heat regime on biota & soils), *seasonality* (time of year and in relation to phenological and meteorological events), and *patch size & pattern* (how and where fires move across and impact the landscape).

The variability of each fire regime condition or component is likely more important ecologically than its average property, i.e. there is a *range* of each of the recurring conditions of fire that maintain a given ecosystem or habitat type and support the diverse array of characteristic species. Some of the species may be favored by one set of criteria of the fire regime, for example, fires that recur very frequently, while another set of species in the same ecosystem may be favored when there are some longer fire-free intervals. Similarly, different species may be favored by different burn intensities or different season of burn; thus, it seems to be the variability within the fire regime that allows the full suite of species to persist in the landscape. These variability effects have been documented in the NKDR with some of the rare species in the NKDR (Liu *et al.* 2005), with pine stand dynamics and regeneration (Snyder *et al.* 2005), with shrub and palm survival and density (Sah, *et al.* 2006; Cooley 2004; Snyder *et al.* 2005). Similar fire regime variability responses have been studied in Everglades National Park and Big Cypress National Preserve (Snyder *et al* 1986; Snyder & Ward 1987; Spier & Snyder 1998).

In very general terms, the *historic* or *ecologically-appropriate fire regime* that has maintained both pine rockland and marshes in the NKDR can be described by its:

- *Frequency:* relatively frequent (3-10 years, give or take a few years).

- *Intensity:* generally low-intensity surface fires (burning primarily in surface fuels = pine needle litter, grasses, and lower palm fronds) although higher intensity flare-ups are common in localized areas of fuel accumulation, where *ladder fuels* have developed, and where dense pine and palm stands occur. Intensity can also be high under extreme burn conditions even where *fuel loads* are relatively low.

- *Severity:* low to moderate impact on canopy pines and palms except in localized areas of fuel accumulations and dense stands; shrubs and perennial herbaceous species are generally top-killed but re-sprout. During droughts surficial organic matter and organic accumulations in cracks, crevices and solution holes may be consumed resulting in root damage.

- *Season:* fuel can be flammable during any month of the year. Winter and spring dry-season fires have been historically human-caused. During the summer season, lightning-ignited fires have had a greater importance in southern peninsular Florida (see research in the Everglades, e.g. Gunderson & Snyder 1994; Snyder 1991) although this has not been the documented case for the Lower Keys (Bergh & Wisby 1996). Because of lower ambient and fuel temperatures, winter fires tend to have less impact on pines, but they are less effective in reducing hardwoods (Sah *et al.* 2006).

- *Patch size & pattern:* variable depending on season, weather and fuel continuity. Under a regime of frequent fire, seed germination and survival relies on patches that escape burning or have burned with very low intensity. Historically, some fires likely burned entire areas of contiguous pine rockland leaving some unburned patches. This is particularly true for dry season human-caused fires that burned across much of Big Pine Key (Chad Anderson, FWS, Personal Communication based on on-going fire scar studies). On the other hand many fires, particularly in the summer, would also have been small, limited by vegetation changes, fuel moisture, rainfall, and humidity recovery at night.

The frequency range of 2-10 years does not imply that pine rockland could be maintained with fires recurring every 2 years or at the other extreme of every 10 years. If a pine rockland burned repeatedly every 2 years, without an intervening longer fire-free period, pine seedlings may have trouble becoming established and pines might eventually be eliminated. A very short fire-return interval may also limit palm regeneration (Snyder *et al.* 2005). Although very frequent fires would likely be patchy because fuels would not be continuous and pine regeneration could occur in patches that escape fires for 3 or more years. An individual pine seedling generally needs 3 to 5 fire free years before it is likely to survive a fire (Klukas 1973). Older pines, on the other hand, can readily survive burns every 1-2 years, and having short cycles of high fire frequency may be important for the establishment of some herbaceous species and prevent an over-abundance of shrub species. Frequent burning (every 2-3 years) may also be needed to reduce shrub density in those areas that have not burned enough in the past and have become overgrown. At the other end of the range, burning every 10 years over a long period of time could create a mid-story dominated by shrubs rather than grasses and forbs, with the eventual loss of the latter. In contrast, a pineland that has experienced very frequent burning over a long period of time and the shrubs are thus widely scattered and of low stature could readily experience a 10-12 year fire free period without degradation. In short, it is the variation in the frequency and other fire regime components that maintains species diversity and habitat conditions across the landscape.

Intensity and severity can occasionally be high even in frequently burned areas when weather and fuel conditions are extreme, i.e. low humidity, low fuel moistures, high winds, and many days since the last rainfall. In these instances, some stands of pines and palms may be killed, either by heat from the flames or by root damage when soil organic matter burns.

Dead pines (*snags*) are an important part of the pine rockland ecosystem, providing habitats for some species, particularly birds and arthropods. Clumps of dead pines are also important as regeneration sites for the pines themselves, as the soil surface in the gap that is formed by dead trees receives more direct sunlight than under pine canopies and they experience lower fuel accumulation for future burns due to the lack of further pine needle litter input. Lower intensity, patchy fires in these gaps permit a greater survival probability for young pines (O'Brien *et al*. 2008) and perhaps other species. Fire is not the only factor that produces gaps in the pine canopy. Hurricane winds, storm surge, and insect infestations play important roles in creating canopy gaps, that are suitable for pine regeneration once a fire as eliminated the extant fuels (O'Brien *et al.* 2008).

The historic or ecologically-appropriate fire regime in herbaceous marshes, both freshwater and cordgrass salt marsh is very similar to that of the pine rockland, i.e. frequent, relatively low-intensity surface fires that can burn during any month of the year, however in marshes there is the interaction between fire and water level (Kushlan 1990). Post-fire effects and responses are highly dependent on the presence, absence or level of standing water when a burn occurs and what happens to that level immediately post-burn (i.e. a few days to weeks) (Forthman 1973). Under appropriate fuel and weather conditions fires can burn across standing water. The vegetation response will depend on whether the water recedes or rises faster than plant growth in the days following the burn. The interaction of fire with water level controls the species composition and diversity of habitats in marsh ecosystems. It may also have some constraint on the rate of re-growth following fire.

Sawgrass, the dominant fuel in freshwater marshes at NKDR, is known to respond well to fire. In the absence of fire, sawgrass litter builds up and plant vigor declines (Wade *et al.* 1980). The fire frequency range for sawgrass marsh has been described as 2-25 years (Forthman 1973) and it seems to respond well with burning every 3-5 years (Wade *et al.* 1980). Sawgrass-dominated vegetation can shift to other herbaceous types if fires occur when there is not standing water and organic soils are dry enough to burn allowing consumption of sawgrass rhizomes (Lowe 1986). Such high-severity burns are an important aspect of marsh vegetation dynamics, but in prescribed burning they are generally avoided because of problems of fire control with burning organic soils and with extended smoke production causing air quality problems.

The density and stature of shrubs in marshes and their potential encroachment from adjacent habitats is limited by the frequent fires. There are a number of areas in the NKDR where former herbaceous marsh has become dominated by buttonwood and other hardwoods due to the lack of fire.

Two broad terrestrial vegetation types within the Refuge are *fire-sensitive:* mangroves and tropical hardwood hammock. In other words, these two types are not dependent on fire and most of the species do not have obvious adaptations to fire. Fire appears to be very damaging and it can have dramatic effects on vegetation structure and species composition. These vegetation types, however, are periodically *influenced* or affected by fires. The fires usually originate in the fire-maintained types, i.e. pine rockland or marsh, and burn into the hammock or mangrove. As long as these fires do not recur too frequently, the vegetation recovers. Fire in these vegetation types is an ecological succession initiating event. In other words, they have a history of fire, i.e. a regime of fire that allows them to persist in the landscape expressing a variety of habitats related to the successional stage or post-fire recovery. A frequent fire return interval forces hammocks toward pine rockland, savanna or marsh. Conversely, the absence of fire in pine rockland forces it toward hardwood hammock; freshwater marshes toward buttonwood thickets, and salt marsh toward buttonwood and mangrove.

Fire is not only important in determining the relative importance and distribution of both fire-dependent and fire-sensitive vegetation types and habitats in the Refuge landscape but they are also important in maintaining dynamic transition zones between fire-maintained and fire-sensitive vegetation. These transition zones have unique structures and species composition that provide cover and important habitat characteristics for certain species. The transition may be abrupt if fire has been common in the fire-maintained vegetation. This is because fires in the pinelands and marshes go out as fuel and environmental conditions change with the change in vegetation. During droughts, and under extreme burning conditions, fires will enter more deeply into fire-sensitive vegetation causing a change in structure. Likewise, fire-free periods will allow hardwood species to encroach into the pineland, and buttonwood into freshwater marsh.

The important role of fire in maintaining pine rockland, and southern Florida freshwater and brackish water marsh ecosystems, and in influencing tropical hammocks and mangroves is well documented and unequivocally supported in the scientific literature (see reviews in Wade *et al.* 1980, Snyder *et al.* 1990, Kushlan 1990, Frost 1993, Ross *et al.* 1996, Myers 2000, Snyder *et al.* 2005). Recent studies in the NKDR provide similar support for the important role of fire under the island influences and with the focal species found in the pine rocklands and marshes of the Florida Keys (Ross *et al.* 1992a, Carlson *et al.* 1993, Cooley 2004, Snyder *et al.* 2005, Lui *et al.* 2005a & 2005b, Sah *et al.* 2006, Bradley & Saha 2009, Albritton 2009, Horn & Grissino-Mayer 2010).

Why manage fires?

In spite of the facts that the fire-maintained ecosystems within the NKDR are flammable and have a long history of burning at relatively frequent intervals, fire is no longer operating as it once did in the Florida Keys. The fire regimes that once maintained pine forest and herbaceous marsh have been altered to a degree that significant habitat changes have taken place and are continuing to occur. These ongoing vegetation and habitat changes will increasingly have a negative impact on key deer, marsh rabbit, rare butterflies, and rare plant species populations along with the pine rockland and freshwater marsh landscape as a whole if *ecologically appropriate fire regimes* are not restored and maintained. The fire regimes have been altered because:

1. Free-ranging wildfires can no longer be tolerated given existing conditions on all of the Refuge keys with the exception of Little Pine Key and possibly Sugarloaf Key. Fire suppression actions and fire prevention programs have been, and will continue to be, essential to protecting human life and property in and around the Refuge and protecting key habitats that are much reduced in area due to landscape fragmentation.

2. Past Refuge management approaches have, until recently, not consistently incorporated the role of fire in Refuge management.

3. Urban development on the keys has fragmented the landscape and reduced habitat area i.e. there is both less of each habitat that could burn, and roads and developed properties form barriers to the spread of fires that once burned unimpeded across the landscape. These barriers serve as loci for the development and expansion of less flammable vegetation.

.

4. Lack of clear desired future conditions and appropriate fire management strategies to reach habitat and species goals.

In short, the fire-maintained pine rockland and marshes will have to be burned with managed fires if the Refuge is to meet its legally-obligated goals and mission, and to reach the desired future conditions described in this document. Fires that once burned largely unimpeded and then were suppressed now have to be managed, i.e. prevented, suppressed and ignited as prescribed burns. Fire managers will have to make decisions about each of the fire regime components, i.e. frequency, intensity, severity, season and distribution of burning across the landscape. In other words, fire managers, with input of scientists, administrators, and stakeholders, will be designing the fire regimes that will occur on the Refuge into the future. This is an unavoidable consequence of the human context in which the Refuge is now embedded and is a part, and the Refuge's mission.

Purpose of Fire Experts' Workshop

Because fire plays such an vital role in ecosystem dynamics and the maintenance of important NKDR habitats, and because fire as a process is no longer operating under an ecologically appropriate fire regime, explicit goals, or *desired future conditions*, need to be developed for the entire NKDR landscape, and for specific habitats and key species. These goals are particularly important for habitats that require direct management intervention, such as prescribed fire, to reach them. The goals or desired conditions form the basis for selecting specific management actions and treatments; in the case of pine rocklands and marshes, where, when and how to burn, and where and when to limit burning.

The objectives of the Fire Management Experts' Workshop were to utilize expert knowledge and opinion to 1) define desired future conditions for the Refuge's fire-maintained habitats, and 2) develop a process to identify key factors and assign values and weights to prioritize burn treatment areas that the Refuge staff can use to guide future fire management decisions and actions.

What is *desired future condition*?

Desired future condition is "a clearly articulated, broad to specific expression of ecosystem condition, attainable within the *human context* over a set period of time, used to guide management" (Sutter *et al.* 2001). It is a desired description of the character of a specific ecological unit for a given time and place; "the description reflects *environmental criteria* deemed desirable by resource managers and the public" (Medina *et al.* 1996). For the National Key Deer Refuge, it is the condition that the refuge managers, with input from experts and the public, are attempting to obtain over the Refuge landscape by means of management actions they deem necessary to reach those conditions. In short, the desired future condition is the management goal for the Refuge's ecosystems. A key aspect of reaching the desired conditions is restoring or maintaining the ecological processes that underlie that maintenance. These ecological processes have become known as *desired functional processes* (Medina *et al.* 1996). A critical process in the pine rockland and marsh habitats at the NKDR is fire, or more specifically, an ecologically-appropriate fire regime designed to mimic the conditions under which those habitats developed and species evolved.

Desired future conditions do not represent a static structural condition of the target habitat, but rather represent a range of conditions that allow for the dynamic character of ecosystems to persist that involve natural disturbances, successional processes, and habitat diversity. Desired future conditions are based on the best current state of ecological knowledge, and are flexible enough to accommodate new data through *adaptive management*, i.e. making decisions based on current knowledge to meet immediate needs while gaining knowledge, through monitoring, research and experience, to adjust and improve management in the future (Stankey & Allan 2009). Adaptive management is an essential part of fire management as the outcome of a chosen fire regime, which needs to be applied over decades before results are obvious, cannot be fully known at the beginning of the process. Furthermore, the habitats on the Refuge have been changing in the absence of an appropriate fire regime. In order to get ahead of the curve with respect to vegetation changes, the process of burning needs to be increased before detrimental changes proceed too far and restoration and burning becomes too difficult and expensive. Adaptive management allows for continuous evaluation and adjustment of both the management process and the goal as more is learned about the system being managed and the response of its component parts.

Establishing desired future conditions for fire-maintained ecosystems at the NKDR will:

- Provide a vision of future conditions of that can be communicated to Refuge staff, colleagues, stakeholders and the general public;

- Provide an agreed upon sense of purpose and focused management activity for Refuge staff;

- Guide management actions within the existing and future human and environmental contexts and constraints;
- Provide a scientific framework for identifying short-term management objectives and benchmarks;
- Identify spatial and temporal priorities for management actions that will allow for the effective use of time, tools, staff and resources;
- Integrate existing monitoring activities into adaptive management to guide course corrections to more effectively reach appropriate desired conditions;
- Highlight additional areas of monitoring focus;
- Aid in identifying future research needs and adjustment of desired conditions.

There are four components of desired future condition:

- **Condition**—based on ecological criteria, the range of acceptable structure (vertical & horizontal), species composition, relative abundance of species, function and heterogeneity of the ecosystem or habitat being restored or maintained. The condition can also be applied to a species population. For example, south Florida slash pine is a key component of pine rockland because it provides fuel and provides important structural features to the ecosystem. We would want to consider not only pine density, but also stand age structure and *regeneration niche* (i.e. the conditions needed for successful pine regeneration). The population structure, abundance, habitat and regeneration niche of rare species should also be considered.

  Crucial is ensuring that the chosen condition is viable and attainable within the present and future human and environmental context at the Refuge. These contexts include land use around and imbedded within the Refuge—primarily private residences and businesses; policy constraints; the legal context that defines the mission and purpose of the Refuge; limits of funding; periodic storm surge and hurricane winds that can drastically and rapidly change ecosystem structure and composition; climate change induced sea-level rise; and unwanted wildfires.

- **Spatial setting**—defines where on the ground the various desired conditions will be maintained, restored or managed for, including various percentages of different states within the acceptable ranges. Aspects of the human context, such as wildland urban interface or aspects of environmental context, such as areas most susceptible to sea-level rise and storm surge, may strongly influence some of the decisions regarding spatial setting for specific conditions.

- **Realistic time frame**—the time frame to reach desired conditions should be based on ecological or life history criteria, e.g. the time it might take for some pine stands to reach maturity or old growth, and possess multiple ages. Alternatively, the time it would take an unburned pineland to lose its characteristic pineland features, in essence, to be beyond the point of realistically restoring those features.

- **Specificity**—desire future condition encompasses the range of variability that is appropriate for the conservation target, be it a species or habitat. In the case of pine rockland and marsh habitats, this would be the range of structural conditions and species compositions that characterize the habitats and that can be maintained by re-introducing, maintaining and managing ecological processes, such as fire, that are needed to reach the management goal. For a species like the Lower Keys marsh rabbit it might be the percentage of marshland in dense graminoid ground cover.

Development process for desired future conditions

Step 1. Identify and select key or focal conservation targets that will be used to determine desired conditions. There is the assumption that these key targets would *ecologically capture* the full range of species and their habitats.

Step 2. Through monitoring, synthesis of research results, and expert opinion, compile appropriate ecological information for key conservation targets;

Step 3. Develop alternative desired future conditions that may differ due to geographical location, i.e. the various Keys that may have unique traits, current conditions and possible future conditions, or management constraints due to the human context of the Refuge, such as the problems and issues of burning in the urban wildland interface and adjacent to people's homes;

Step 4. Identify knowledge gaps and uncertainties that may be needed for adaptive management and refinement of desired future conditions;

Step 5. Adapt as needed. The desired condition selection process is *expert driven* and *adaptive.* In the case of this assessment, sixteen science and fire management experts from universities, state and Federal government land conservation agencies, environmental consulting institutes, and conservation organizations were directly involved in the Experts' Workshop that developed the desired future conditions presented here. The results were also reviewed by experts who could not attend the workshop. Participating experts relied on the results from their own studies and those of a number of other researchers whose studies are listed in the bibliography. The experts also recognize that further research and monitoring will allow for refinement of both the desired conditions and the management actions to reach those conditions.

Guiding Criteria for Desired Future Condition

Measurable habitat and species criteria (structural, life history, ecosystem processes) need to be identified and used to describe current and desired conditions. Frequently, *reference conditions* are used as models for what future conditions should or could be. Reference condition, sometimes called the *historical range of variability* (HRV), is defined as the range of ecosystem structure, function, and composition operating on a landscape if post-Columbian settlement influences had not occurred (Barrett *et al.* 2006). Conceptually, reference conditions are what would be “natural” if post-Columbian human activities and impacts had not interfered with “natural” conditions and processes, and led to the conditions we see today. In reality, determining what was “natural” is not practical, as there can be many different interpretations and a fair degree of speculation as to what those conditions were or should be. Furthermore, going back to some historic time does not take into account natural changes in climate, geomorphologic process, and natural species dynamics and invasions, nor does it recognize that more recent human activities many have had a significant influence on creating the conditions that we now deem desirable (O’Brien *et al.* 2008).

Historic range of variability as a reference condition has been useful in parts of the country where marked post-Columbian influence has been relatively recent, such as in parts of the western United States, and where there exists written and photographic documentation of those conditions. The existence of useful reference or historic conditions does not negate the need to incorporate species life histories and documented current ecosystem dynamics into the determination of desired conditions.

Florida and the Florida Keys have had more than 500 years of post-Columbian influence. Pre-Columbian conditions and influences can only be inferred from limited archeological evidence of human populations and activities, and from fire and vegetation history information gleaned from pollen and charcoal studies which may give indications of general changes in dominant vegetation and the prevalence of fire in the landscape. At best, this information only gives a hint to what conditions may have been in the past and an indication whether fire has been a significant process affecting the landscape in the past.

Pollen and charcoal data can give very general condition trends over a period of thousands of years. Such studies have been conducted on Big Pine Key (Albritton 2009). The results of microscopic charcoal analysis show that fire has had a long history (at least 1700 years—the limit of time accessible to the cited study) on Big Pine Key and pollen analyses demonstrate that pine was dominant during this period.

A more detailed fire history can be determined from fire scars on older pine trees and on stumps. Such studies are underway by the University of Tennessee, and preliminary results on Big Pine Key suggest that the fire return interval between 1890 and 1950 was 3-5 years and may go back to the 1700’s (See Figure 1). After 1950, the return interval lengthened to 5-12 years (Horn & Grissino-Mayer 2010). This latter period coincides with the establishment of the Refuge in 1957, accompanied by a focus on suppressing fires, and when fragmentation of private lands was well underway. Some samples were collected in areas that have been subject to prescribed burning by the Refuge managers. It may be

Figure 1. 1922 photo of pine rocklands on Big Pine Key--a period before organized fire suppression efforts. Note low stature of palms, exposed rock and herbaceous vegetation.

found that other areas not subject to prescribed burning will have an even longer fire return interval after 1950. The 3-5 year return interval suggests that the argument that fires may have been less frequent in the Keys compared to pine rocklands on the mainland because the former are more xeric and have lower productivity than the latter may not be valid, and that some of the extant vegetation structure is more a result of the change in fire frequency that occurred in the 1950's than the result of the more xeric conditions in the Keys.

Some areas on Big Pine Key may be closer to desired conditions because they have had a recent history of relatively frequent prescribed fire and wildfire. These areas support uneven-aged stands of pine, and they contain viable populations of rare plants and rare butterfly food and host plants. These can be used as a reference for areas approaching desirability. In general, however, in places like the NKDR, where there is no definite reference condition, it is primarily the life histories of key species that shed light on appropriate desired conditions. More specifically:

1. What is known about the life histories of dominant species (pines, palms, grasses, shrubs), particularly their stand structure and *regeneration niche*, i.e. what conditions are needed for successful reproduction and growth into an adult reproductive stage,

2. What is known about how focal habitats and species are spatially influenced by elevation, hydrology, soils, fire, and episodic disturbances, and

3. What is known about habitat conditions of priority rare and threatened or endangered species, such as the key deer, marsh rabbit, rare plants, and food plants for rare butterflies, and how they respond to or impacted by fire?

Because different species will have varying responses to different sets of conditions, the full range of possible pine rockland conditions should be managed for by creating and maintaining multiple "pineland recovery states" (Ross *et al* 1992) within the pine rockland landscape which will meet the needs of the full range of species.

There is uncertainty associated with the desired conditions for the NKDR. Although it is recognized that information is incomplete, it is also acknowledge by all experts familiar with the Refuge's ecosystems and the role of fire that fire management actions need to be started soon if further degradation of habitats is to be avoided. There is sufficient understanding of ecological processes like fire, hydroperiod, and succession coupled with recurring disturbances to make well-founded estimates of the desired structure and spatial distributions of focal habitats. It cannot be over-emphasized that identifying desired future condition is an iterative process, with improvements to be made as more information becomes available and management experience suggests course corrections.

In this first iteration of desired future conditions for the fire-maintained ecosystems and habitats, *vegetative canopy cover* and mid-story height will be the primary (though not exclusive) quantitative criteria that will define desired conditions and guide progress toward reaching those conditions. Age structure of pine population is another important criterion for desired pine stand condition. Cover was selected because it is relatively easy to measure and because the cover of different vegetative components has a significant influence on pine regeneration, rare listed-species success, and faunal habitats. Criteria such as density and basal area are more difficult to measure and interpret, especially with the important re-sprouting shrubs.

Focal Conservation Targets

Conservation targets used in determining desired future condition include the dominant fire-maintained vegetation types including several dominant plant species or grouping of species such as hardwoods, palms, and bunch grasses; and several rare and/or federally-listed plant species and federally-listed animal species and their food sources. The assumption is that managing for viable populations of these species and restoring and maintaining quality habitats will meet both the conservation mission of the Refuge and maintain the biodiversity and ecosystem structure characteristic of Lower Keys terrestrial ecosystems. Pine rockland and marsh species not included as conservation targets are considered to be *ecologically captured* by other focal conservation targets, i.e. maintaining desired future conditions of a few key focal targets will maintain conditions for the other characteristic species. The selection of focal conservation targets is an iterative process. Monitoring and research may point to other targets that need to be considered in the future.

The focal conservation targets considered here are:

- High-elevation pine rockland ecosystem
- Low-elevation pine rockland ecosystem
- Freshwater marsh ecosystem transitional to cordgrass (*Spartina* spp.) salt marsh
- South Florida slash pine (*Pinus elliotii* var. *densa*)
- Key deer (*Odocoileus virginianus clavium*) habitat
- Lower keys marsh rabbit (*Sylvilagus palustris paludicola*) habitat
- Garber's spurge (*Chamaesyce garberi*) populations
- Big Pine partridge pea (*Chamaecrista keyensis*) habitat
- Bartram's hairstreak (*Strymon acis bartrami*) habitat
- Florida leafwing (*Anaea troglodyta floridalis*) habitat
- Pinelands croton (*Croton linearis*) populations

Focal Targets and the Role of Fire

The two fire-maintained ecosystems or broad vegetation types that are focal to the desired conditions are pine rockland and freshwater marsh/transition to cordgrass salt marsh on Big Pine Key, No Name Key, Cudjoe Key and Sugarloaf Key. Little Pine Key was not considered because fire is able to play its natural role because it is uninhabited, i.e. fires that occur there will be monitored and generally allowed to run their course, although participating ecologist felt that the vegetation on Little Pine Key should be monitored to confirm that naturally-ignited fires are sufficient to maintain examples of pine rocklands there.

Pine Rockland:

Pine rockland is a globally imperiled ecosystem found only in the Florida Keys, Everglades National Park and remnant patches in Miami-Dade County. Similar pine rocklands, dominated by a different species of pine (Caribbean pine = *Pinus caribea* var. *bahamensis*) is found on four islands in the Bahamas. Florida's pine rockland is composed of an open overstory of south Florida slash pine and a mid-layer and ground cover of primarily tropical and a few temperate shrubs (many of which can reach tree size if left unburned), palms and herbaceous species, predominately grasses. The percentage of tropical species is higher in the Keys than on the mainland probably due to the incidence of occasional frost on the mainland. The stature of hardwoods depends largely on the time since last burn. The density, i.e. cover, of shrubs is primarily a function of the frequency component of the fire regime.

What remains of this ecosystem represents less than 3 percent of its original extent (Noss *et al.* 1995). The pine rocklands of Everglades National Park have been maintained using prescribed fire since the 1960's and the role of fire has been well-established and, through adaptive management improvements, fire regimes and desired fire effects have been and are continually reassessed. Protected remnants in Miami-Dade County are threatened by lack of fire and invasive species problems, although a few sites are being periodically burned. Those in the NKDR have been degraded by insufficient burning and problems when fire is applied to long unburned sites, particularly the mortality of mature pines. Prescribed burning since 1985 has been sporadic and until recently focused on reducing hazardous fuels rather than for ecological objectives (Bergh & Wisby 1996). The Key's pinelands are also threatened by sea level rise (Ross *et al.* 1994), and are periodically affect by storm surge (Figure 1).

Figure 2. Pines killed on Big Pine Key by storm surge of hurricane Wilma in 2003. Loss of pines makes sites more difficult to burn because they lack the important fuel input of pine needle litter. Photo by Chad Anderson.

In the NKDR, pine rockland is found on Big Pine Key, Little Pine Key, No Name Key, Cudjoe Key, and Sugarloaf Key covering a total of approximately 1750 acres (708 ha). It tends to occur at mid-to-higher elevations between 0.7-1.3 meters (2.3-4.3 feet) in the interior portion of the islands that have a freshwater lens (Ross *et al.* 1992a & b). The total matrix of fire-maintained pineland and freshwater marsh covers 2,244 acres (908 ha). The current largest extent of pine and freshwater marsh is on Big Pine Key with pines covering 1,382 acres (559 ha) and marsh 429 acres (173 ha). Development in the Keys has reduced the historical extent of pine rockland in the Keys by at least 33 percent (Folk 1991). Today, there are less than 1000 ha of pine rockland in the Keys (Snyder *et al.* 2005). A sea level rise of approximately 15 cm over the past 70 years has also been responsible for a contraction of pine rockland vegetation (Ross *et al.* 1994).

Pine rockland is also found on four of the islands of the Bahamas and on the Turks & Caicos. Although the pine species on these islands in Caribbean pine (*Pinus caribaea* var. *bahamensis*) rather than south Florida slash pine (Correll & Correll 1982; Myers *et al*. 2004) they are structurally and functionally similar to south Florida's pine rockland.

In the Keys, pine rockland forms the fire-maintained matrix that includes both the fire-maintained freshwater marshes and fire-influenced tropical hammock and mangrove vegetation. The pine rockland substrate is oolitic limestone and there is very little soil development, hence the name "rockland". The sparse soils are primarily marls and organic debris that accumulates in crevices and solution holes in the surficial rock. The rockland is usually underlain by a freshwater lens. Very slight changes in elevation, and thus depth to water table, produce marked differences in vegetation characteristics.

Pine rocklands have the highest plant species diversity of all vegetation types in the Florida Keys. Throughout its southern Florida range there are 250 plants species--over 100 are tropical hardwoods, 42 species are endemic to southern Florida, 18 are restricted to pine rocklands, and 5 occur only in the Florida Keys. (Bradley & Gann 1999; Snyder *et al.*1990; Avery & Loope 1980).

For the purposes of defining desired future condition, pine rockland is divided into *high-elevation* and *low-elevation associations* as described and delineated by Ross *et al.* (1992a) (see Figures 3 & 4). Pine rockland in both types is characterized by an open stand structure of moderately tall, mature pines and scattered individuals and clumps of pines in younger age classes; a sparse mid-story of shrubs and palms; and a diverse ground cover comprised of

Figure 3. An Example high-elevation pine rockland on Big Pine Key. Compare this structure with Figure 4. Photo by Chad Anderson.

mainly grasses and/or sedges, forbs, palm and pine regeneration, and scattered low-stature shrubs. Spatially, the forest floor is a mixture of groundcover species and patches of bare rock. Differences in species com-position of the mid-story and groundcover, and hydroperiod distinguish the two types. These differences are listed in Table 1 on the next page.

Figure 4. Example of low-elevation pine rockland on Big Pine Key. Note the high amount of exposed rock, the relatively lower stature of the pines, and scattered pine mortality likely due to storm surge. Photo by Chad Anderson.

Table 1. General Differences between Pine Rockland Types (Adapted from Ross *et al.* 1992a)

High-elevation Pine Rockland	Low-elevation Pine Rockland
• Flooded only during storm surge events. • Mean elevation ~1.0 meter. • Considered upland vegetation.	• Flooded for short periods of time (up to several months) each year. • Mean elevation ~0.6 meter. • Greater abundance of brackish-water tolerant species. • May meet legal definition of wetland. • Immediate threat by rising sea level.
• Relatively less exposed rock • Relatively more continuous fuel	• Relatively more exposed rock • Relatively less continuous fuel
• Presence of characteristic fern species: *Anemia adiantifolia* *Pteridium aquilinum* *Pteris longifolia*	• These fern species generally absent.
• Characteristic shrubs and palms: *Coccothrinx argentata* *Thrinax radiata* *Pisonia rotundata* *Psidium longipies*	• High relative abundance of *Conocarpus erecta.* • Greater relative cover of *Brysonima lucida* *Manikara bahamense*
• Greater representation of grasses (Poaceae): *Schizachyrium gracile* *S. rhizomatum* *Sorghastrum secundum*	• Greater representation of sedges (Cyperaceae): *Cladium jamaicense* *Schoenus nigricans* *Dichromena floridensis*
• Relatively higher herbaceous diversity. High occurrence of rare, listed, and endemic species. • Preferred habitat for: *Chamaecrista lineate* var. *keyensis* *Chamaesyce deltoidae* var. *serpyllum* *Linum arenicola*	• Relatively lower herbaceous diversity. • Limited occurrence of rare, listed, and endemic species. • Preferred habitat for: *Chamaesyce porteriana* var. *scoparia*
• Relatively higher pine regeneration density. • Larger statured pines	• Relatively lower pine regeneration density. • Smaller statured pines

Within each of the elevation types, there are *seral* or successional stages that represent the degree of vegetation development or structural and species changes in the absence of fire. Although species composition and relative abundance of species are different in the two types, they have similar vegetation structures, i.e. open, multi-age pine stands, a mid-level shrub layer, an herbaceous ground cover layer, and exposed rock. Their successional trajectories in terms of structure appear similar and fire plays the same general role, although there may be differences in the rate of vegetation change in the absence of fire. Details of the fire regime may be different due to differences in fuels and the presence or absence of standing water. Because of their different composition, disturbance regimes, and threats, Ross *et al.* (1992a) recommend that the two types should be treated as separate subcategories of pineland where each would have the same percentages of the three seral stages. It does not necessarily mean that the types should be managed separately nor necessarily separated from each other into discrete burn units. The two types will likely be exposed to somewhat different fire regimes in that the low-elevation type may have a narrower burn window, a longer fire return interval, and more patchy burns because of periods of standing water, a greater percentage of exposed rock surface, and less continuous fuel (due to amount of exposed rock and less pine needle litter). Monitoring and comparative research should take place in each type and the results will determine how different management approaches (fire regimes and burn prescriptions) might be applied.

For the purpose of describing desired future conditions, three seral stages are identified that apply to both high- and low-elevation pine rocklands. They are:

1. *Early-seral* = minimal mid-story (shrub layer). See Figure 5. Woody shrubs compose less than 20% cover throughout the stage. The average height of the shrubs is less than or equal to 1.6 meters. High diversity herbaceous layer, i.e. in excess of 20 species. Palms species present but widely scattered with some regeneration; lower abundance and fewer species in low-elevation type. Pine stands are open and multi-aged. Density and age structure vary widely in both high- and low-elevation types. Scattered pine regeneration of varying density, primarily in gaps and other open areas. Little or no duff accumulation. Fire regime: frequent 3-7 years; low intensity/low severity surface fires; variability in season of burn; more patchy burns in the low-elevation type which may have some areas escape burning for more than 7 years.

2. *Mid-seral* = combined woody shrub and palm cover between 20-80%; height 1.6 - 3 meters. See Figure 6. Pine stands open and multi-aged. Limited pine regeneration. Duff accumulating. Fire history: unburned for more than 7 years, but less than 15 years. Probably can be maintained with a fire-return interval of 7 to 15 years, but may require a return to the early-seral stage through a period of frequent burning, especially if the interval has been at the upper end of that range for an extended period.

3. *Late-seral* = tall broadleaf and palm component with ≥ 80% cover, height 2 - 3 meters. See Figure 7. Lower diversity ground cover than early- and mid-seral stages. Not sufficient pine regeneration to replace older trees. Pine regeneration may be lacking altogether. Most herbaceous species will be absent. Duff layer well developed and nearly continuous. Little exposed rock. A transitional stage to hammock. Fire history: unburned for more than 15 years. There is probably not a fire regime that can maintain the late-seral stage with pine at a particular place on the landscape. To maintain this stage in the landscape, the site would need to return to an earlier successional stage to

allow pine establishment, i.e. to have this stage always present, it may need to move around the landscape.

Figure 5. Early-seral pine rockland on Big Pine Key. Note herbaceous ground cover, scattered shrubs and palms, and multi-aged pines. Photo by R. Myers.

Figure 6. Mid-seral pine rockland on Big Pine Key. Note dense layer of palms. In other situations hardwood shrubs may dominate. Photo by Chad Anderson

Figure 7. Late-seral pine rockland on Big Pine Key where hardwoods and tall palms dominate the mid-story. Photo by Chad Anderson.

It is important to emphasize that the early-seral stage is maintained by a <u>specific</u> repeated pattern of burning (fire regime), and the other two occur when fire has been excluded for a given period of time. Although burning a mid- or late-seral site would have the immediate effect of reducing hardwood cover and stature, the site will not immediately return to an earlier seral stage, because the abundant shrubs would rapidly re-sprout with a greater number of stems (i.e. density might increase from pre-burn levels), and continue to dominate the understory. It would take a <u>series</u> of frequently applied burns (perhaps as frequent as every 2-3 years--the number of burns needed is unknown at this time) to reduce the number of shrubs and palms, stimulate herbaceous development, and return the site to the early-seral stage. Burning the mid-seral stage every 10 to 12 years could maintain it as such but it could possibly lead to a greater shrub cover over time due to the increase in the number of stems through re-sprouting and shrub seedlings having the time to reach a reproductive age along with gaining the capacity to re-sprout after being top killed.

Freshwater & salt marsh:

Freshwater wetlands in the NKDR occur in shallow basins and depressions usually embedded within pine rockland, and sometimes within hammock or buttonwood thickets (see Figure 8). Freshwater marshes sometimes transition to salt marsh, and depending on elevation, salinity effects, and juxtaposition with other vegetation types they can become buttonwood thickets or mangrove in the absence of fire. Variability of vegetation within marshes is a function of hydroperiod, soil types (including bedrock exposure), degree of brackish water exposure, and fire history. Standing water can persist for extended periods and water level x fire interactions likely have impacts on vegetation responses and species composition. Dominant species in freshwater marsh are sawgrass (*Cladium jamaicensis*), white-top sedge (*Rhynchospora floridensis*), spikerush (*Eleocharis* spp.), and leather fern (*Acrostichum aureum*), and buttonwood. Sawgrass and sedges are the primary fuels that carry fire.

Figure 8. Fresh water marsh with scattered buttonwood on Big Pine Key. Photo by Chad Anderson.

Freshwater marshes vary in size with the largest around 250 acres (Folk 1991). Their total area in the Refuge is 494 acres (200 ha). Their greatest extent is on Big Pine Key (428 acres = 173 ha), but they also occur on Cudjoe (23 acres = 9 ha), with only a few acres each on No Name, Upper Sugarloaf, Big Torch, Little Pine, and Howe Keys.

Where halophytic (salt tolerant) species become more important as the effects of brackish water and salt water intrusion from storm surge become more evident, freshwater marshes grade into buttonwood transitional communities and/or salt marsh (Figure 9). Flammability of salt marsh depends on species composition. Those dominated by a continuous cover of cordgrass (*Spartina* spp.) are most prone to periodic burning. These fires are largely responsible for limiting the encroachment of buttonwood and mangrove species. The total area of salt marsh on the Refuge is 617 acres (250 ha), although only a small portion of this area is cordgrass, the rest being buttonwood-dominated scrub salt marsh and open scrub salt marsh, which is dominated by halophytic plants such as Keys grass (*Monanthocloe littoralis*) and saltwort (*Batis maritima*) which are non-pyrogenic. A management question is where, when and how fire should be used to expand the extent of cordgrass salt marsh that may benefit the endangered lower keys marsh rabbit and the silver rice rat (*Oryzomys palustris natator*) [which is almost exclusively limited to cordgrass salt marsh, although it may use and travel through adjacent habitats (Goodyear 1987; Forys 1996)]. For example there are a total of 748 acres (303 ha) of buttonwood transition vegetation within

Figure 9. Cordgrass (Spartina spp.) marsh occurs in wetlands periodically influenced by brackish water. In the absense of fire buttonwood and mangrove vegetation will encroach into them reducing habitat for the Lower Keys marsh rabbit and other species that require open grassy habitats (See Figure 10). Photo by Chad Anderson.

the Refuge which presumably could be marsh. Sea level rise will gradually convert adjacent freshwater marshes to more salt tolerant types. These could become fire-maintained herbaceous marshes dominated by cordgrass or woody vegetation dominated by buttonwood and mangrove species (Figure 10).

Figure 10. Cordgrass marsh being invaded by buttonwood. In the continued absence of fire the buttonwoods will eventually shade out the herbaceous vegetation. Photo by Chad Anderson.

South Florida slash pine:

South Florida slash pine (*Pinus elliotii* var. *densa*) is unquestionably associated with fire. Its adaptations to fire and its stand dynamics have already been described in this report. It is important that the pine population on the Refuge as a whole as well as on each of the pine island is uneven-aged. However, there can be a wide range of proportions of the different ages, with some stands without significant regeneration, others missing significant mid-aged individuals. There is also a wide range of acceptable stand densities. Dense reproduction and younger stands will thin under appropriate fire prescriptions. Open areas without pine cover, or with sparsely spaced trees, will be receptive to seed germination if they are burned frequently enough to limit hardwood and palm cover. Prescribed fires can be planned seasonally to prepare exposed mineral soil prior to pine seed release, or planned to occur in seed mast years.

Key deer habitat:

The Key deer permanently inhabits those lower keys with permanent freshwater sources, but will move to other islands during the wet season. The center of its population is Big Pine and No Name keys. They range through mangrove, pine rockland, hammock, salt marsh/buttonwood transition and freshwater wetlands, although pineland and freshwater marshes provide their primary water sources (Folk 1991; Lopez 2001). They will feed on a wide variety of plants, but the majority of their diet consists of the mangrove species and thatch palm berries (Klimstra & Dooley 1990). Other important forage species include blackbead (*Pithecellobium keynse*), dilly fruits (*Manilkara bahamensis*), acacia (*Acacia pinetorum*), Indian mulberry (*Morinda royoc*), and pencil flower (*Stylosanthes hamata*), but 164 species are included in their diet (Klimstra & Dooley 1990). A portion of the population is concentrated in residential areas where food preferences include ornamental plants and where they are fed by tourists and residents (Folk & Klimstra 1991; Lopez 2004b). These have been called “urban” or “semi-domesticated” deer.

Although the Key deer was near extinction in the 1950’s and is currently listed as endangered because of its restricted range and habitat fragmentation, since the 1990’s the population has grown rapidly and it appears to have exceeded carrying capacity on Big Pine and No Name keys (Barrett 2004; Lopez 2004a). The current deer population size has had impacts on several once-common forage species such as black torch (*Erithalis fruticosa*) and joewood (*Jacquinia keyensis*) that have been greatly reduced on Big Pine and No Name keys (Barrett 2004; Barrett & Stilling 2006; Barrett *et al.* 2006). A number of the Key deer’s important food plants occur primarily in pine rocklands. Fire not only maintains this habitat but also stimulates re-sprouting, increases palatability via nutrient enhancement of re-growth, maintains food plants at an accessible stature, and keeps fresh water sources open and accessible. Some preferred species suffer heavy browsing after a burn which may slow recovery of the understory (Barret 2004). Snyder *et al*. (2005) observed heavier deer browse in recently burned pine rockland. Barrett (2004) suggests that fire may not be the sole deterrent to hardwood encroachment into pine rocklands and that Key deer browsing may be an important factor in maintaining open pine rocklands, or at least slowing the succession to woody vegetation. It should be noted that deer herbivory may have significant influence on pineland species composition and understory structure.

Lower Keys marsh rabbit habitat:

The Lower Keys marsh rabbit (*Sylvilagus palustris hefneri*) is found predominantly in the fire-maintained salt marsh dominated by cordgrass, and fire-maintained fresh water marshes dominated by sawgrass. They also use and travel through other vegetation types, including pine rockland and coastal beach berm vegetation. Rabbit populations have been in decline for a variety of reasons, one being the change from graminiod to woody vegetation cover (Faulhaber *et al.* 2007). The amount of thick graminoid cover has been found to be the single most important factor in determining the quality of habitat and rabbit utilization persistence (Forys & Humphreys 1999a &1999b). The dense graminoid ground cover seems to provide the cover needed for nests and escape from predators. Woody vegetation in marshes provides perches for avian predators. The herbaceous ground cover also provides the rabbit's primary food sources. Researchers agree that management actions that increase the amount of suitable habitat by reversing the encroachment of woody vegetation, particularly buttonwood, are paramount to halting the downward population trend (Schmidt *et al.* 2010; Faulhaber *et al* 2007; Forys & Humphreys 1999a &1999b), although factors other than fire, such as predation by domestic cats may be partially responsible for the rabbit's population decline. A habitat-appropriate prescribed fire regime and mechanical removal of buttonwood are the most viable options to restore and maintain habitat.

Garber's spurge populations:

Garber's spurge *(Chamaesyce garberi*), a Federally-listed threatened species and endangered by the State of Florida, is found in a variety of open to moderately shaded habitats in south Florida and the Florida Keys. In the Keys, it grows in pine rocklands, open calcareous flats, and on calcareous sands of beach ridges—all habitats require disturbance, either fire or storm surge overwash. Most populations are quite small and disjunct. Although there are no published studies on the role of fire in maintaining populations in the pine rocklands, observations and monitoring at the Refuge point to frequent fire as the process that maintains the open conditions favored by the species.

Big Pine partridge pea populations:

Big Pine partridge pea (*Chamaecrista keyensis*), a candidate species for Federal listing and listed Endangered by the State of Florida, was once found on several of the pine rockland keys in the Refuge, but now appears to be limited to Big Pine Key (Ross & Ruiz 1996). Fire exclusion concomitant with increasing woody cover is considered the primary reason for the loss of habitat (Snyder *et al.* 1990). Individual plants suffer some mortality from fire, but it has the ability to re-sprout. Winter season burns appear to marginally benefit the population more than summer burns although a mixed-season burn regime is considered best suited to the maintenance of the Big Pine partridge pea, while at the same time benefiting other species (Lui *et al.* 2005b). The species also has a soil seed bank and germination takes place after fire. It is not known if heat from fire or post-fire conditions stimulates seed germination, but it has been shown that burns with relatively higher fire intensities produce a greater number of fruits and fruiting plants (Lui *et al.* 2005a). The research results of Lui *et al.* (2005a) suggest that very frequent fires, i.e. 1-3 years may not produce sufficient intensity to affect the increase in fruiting response, but caution that too infrequent of fire would allow shrub and palm growth and further encroachment that would negatively affect the Big Pine partridge pea habitat.

Bartram's hairstreak butterfly habitat:

The habitat of Bartram's hairstreak is pine rockland. Its single larval host plant and primary nectar source is pinelands croton (*Croton linearis*), a species that is largely restricted to early-seral, fire-maintained stage of pine rockland, although it is occasionally found in coastal scrub. The butterfly was once found throughout the pinelands of the Lower Keys, but it is now limited to Big Pine Key, as that is the only remaining location of its host plant. There are about 600 acres (243 ha) of croton on Big Pine Key (Chad Anderson, *personal communication*). Fire is considered crucial to maintaining the habitat of its host plant (Salvato 2001) and thus this butterfly, along with the Florida leafwing. Like Florida leafwing (described below), fire may kill egg and larval stages. Salvato (2001) states that Bartram's hairstreak has weaker flight abilities than Florida leafwing and does not seem to stray too far from croton patches. This fact points to the need to avoid burning large areas of croton at one time and perhaps to leave unburned patches of croton in each burn unit in which it occurs. On the other hand, unpublished data from J. Sadle in Everglades National Park has shown that a restored *Croton* population 2 km from other pinelands was colonized by Bartram's hairstreaks and Florida leafwings within weeks of the plants reaching appropriate size (6-months to a year post-burn). This finding reduces the need for directly creating refugia on small islands like Big Pine Key as unburned patches of *Croton* readily occur or exist in unburned areas.

Florida leafwing butterfly habitat:

Florida leafwing has not been seen on Big Pine Key since 2006 and may have been recently extirpated. Reduction in *Croton* and overall reduction in pine rockland are assumed to be the causes of the reduction of the butterflies historic range, but in the Keys the use of pesticides for mosquito control has likely had a significant negative impact on the population. Like Bartram's hairstreak, it has a single larval host plant—pinelands croton. Florida leafwing is most abundant on Long Pine Key in Everglades National Park and it may have the only viable population. Long Pine Key has had a 50-year history of prescribed burning that has been effective in maintaining croton populations (i.e. early-seral pine rocklands). The butterfly appears to need edges of hardwood hammock for mating that are located near pineland croton food sources. Fire maintains conditions for croton populations. Fire also creates and maintains hammock/pineland edges. The Florida leafwing has strong flight abilities, can flee to refugia during fires, can readily disperse to scattered patches of croton, and can rapidly re-colonize burned areas as the vegetation and croton recover. Immature stages (eggs & larvae) are killed by fire. Too frequent burning may destroy host plants before they have had time to recover (Salvato & Hennessey 2004) although recent monitoring has shown that croton re-sprouts are utilized by Florida leafwing 6 months post-burn (Land 2008). There are many unknowns surrounding the Florida leafwing including, but not limited to population size, extent of the existing population, the extent of *Croton*, the effect of fire frequency on seed production and successful spread from and within existing croton patches.

Pinelands croton populations:

Croton coverage can change with drought, flooding, fires and hurricanes. In 2005, biologists at Everglades National Park began monitoring the response of *Croton* to prescribed fire (Land 2008). Their preliminary results show that 97 percent of *Croton* re-sprouts after low-intensity summer burns and the re-growth is used by Florida leafwing within 6 months. They recommend burning under low-intensity conditions to facilitate leaving unburned patches of *Croton* in burn units. Observations by Chad Anderson (USFWS) on Big Pine Key suggest that low-intensity burns result in low *Croton* mortality, but limit seed germination, while higher-intensity burns cause higher *Croton* mortality but create conditions for or stimulate seed germination. More research is needed on desired size of the patches and effective seed dispersal and establishment from seed.

Fire Regimes for Pine Rockland and Marshes

The general character of fire regimes for both pine rockland and freshwater marsh are similar (frequent, relatively low-intensity surface fires burning in grassy fuels), and the two ecosystems are juxtaposed in the landscape and are closely linked. Fires originating in one are likely to burn into the other. Both are subject to the same weather conditions; the fine fuels are primarily graminoids, although the species are different and pine rockland fuels will have a larger pine litter and palm frond component. Marsh recovery is also influenced by water level at the time of burn and in the days and weeks following a burn.

Fire return interval or fire frequency is considered the primary driving fire regime component determining vegetation type and structure. The *fire return interval* needed to maintain mainland pine rocklands and marshes has been described variously as ranging between 3-7 years for pine rocklands (Wade *et al*. 1980) to 2-15 years for freshwater marshes (Wade *et al.* 1980), although the mean interval in the Keys may be slightly longer due to the more xeric conditions compared to peninsular pine rocklands. The lower limit of these intervals is determined by how long it takes for fuel to accumulate to carry the next fire; the upper limit is determined by the time it takes for herbaceous endemics and grasses to be shaded out by a developing hardwood and/or palm layer (Snyder *et al.* 1990). Thus, these limits are determined by site productivity. The more productive the site the faster fuels accumulate, the faster the growth of hardwoods, and the shorter the time it takes for the shrub layer to shade out the herbaceous layer. Brancroft (1977) noted for Long Pine Key in Everglades National Park that hardwoods can be kept at desired levels with a return interval of 3-7 years on productive sites, and 6-8 years on lower productivity sites, once hardwoods have been restored to a desired level. Where hardwoods cover is greater than desired the site can be burned as frequently as fuels are available (within 2-3 years) for 3 or 4 cycles (Hofstetter 1973) On productive pine rockland sites, the growth of hardwoods can effectively convert a site in as little as 15 to 20 years (Wade *et al.* 1980). It has been argued that because the pine rocklands in the Keys are more xeric and less productive than those on the mainland due to lower rainfall, the appropriate mean fire return interval is a few years longer in the Keys than on the mainland. However, it has not been established that NKDR pine rocklands need a year or two longer to develop fuels that would carry fire across a burn unit, nor has there been a consistently applied prescribed fire regime to determine long-term fire frequency effects and needs. This begs for a prescribed fire program that can consistently apply prescribed fire throughout the fire-maintained habitats at the NKDR.

Studies have demonstrated that *season of burn* and *fire intensity* are important to pine population dynamics, shrub and palm survival, and rare plant population dynamics (Snyder *et al.* 2005; Lui *et al*. 2005a & 2005b). Season, intensity and frequency are closely linked and a change in one affects the other. For example, the greater the frequency the lower the fuel loads thus the lower intensity. Winter season fires tend to be of lower intensity than summer season burns due to low air and fuel temperatures (Snyder *et al.* 2005). Seasonal effects of burning in marshes have not been as thoroughly studied as in pine rocklands.

Conceptual Ecological Model for Pine Rockland & Marsh

Conceptual ecological models are diagrams that simplify complex ecological information and hypotheses into a format that readily illustrates and interprets relationships between various ecosystem states, e.g. the three seral stages described in this report for pine rocklands in the Keys and the forces or influences that maintain the stages or allow or cause them to change to another stage. In February 12, 2010, the Pine Rocklands Working Group held a workshop at Fairchild Tropical Gardens that produced several alternative models for pine rocklands (Myers 2010). These models focused on the pine rockland ecosystem throughout its range. Presented here are several models modified to present conditions specific to the pine rocklands in the NKDR. They show the three seral stages described for the NKDR along some of the information and outcomes outlined in this report. The pine rockland and marsh models are presented in Figure 11a&b.

Figure 11a. Simple conceptual ecological model showing possible relationships between fire frequency and seral stage in Keys pine rockland, and possible treatment regimes to return to earlier stages. Beyond ~25-35 years, the vegetation is assumed to be hardwood hammock even though there may still be emergent pines and other pine rockland features present.

Figure 11b. Ecological model illustrating freshwater marsh and cordgrass salt marsh and their relationship between each other and with other vegetation types on the NKDR. Fire is a vital process determining seral stage within a marsh type (i.e. transitions = arrows within a marsh type are controlled largely, but not solely, by fire regime or fire regime changes). The trajectory toward woody vegetation follows a trend of decreasing fire frequency. Hydrological processes (hydroperiod, tidal influences, storm surge and salinity) predominate in separating salt marsh from freshwater marsh and related hardwood vegetation. As part of these processes, sea-level rise will cause shifts as indicated.

Desired Future Conditions

General Assumptions:

1. Pine rockland is separated into high-elevation and low-elevation types, both of which should be maintained in the landscape.

2. A considerably greater percentage of each elevation type should be maintained in the early-seral stage and the least amount in the late-seral stage.

3. Within each seral stage, a range of conditions should be present, i.e. vary density of pines, hardwoods, palms and herbaceous species.

4. Pine stands have a wide range of acceptable conditions with respect of age structure stem density and canopy cover. This variability is present in both high-elevation and low-elevation stands, although low-elevation stands are more susceptible to broad die-offs due to storm surge. There are also areas where fire, both wild and prescribed, has killed a large number of pines. Across the landscape, there should be multiple age classes, ranging from stands or patches of old-growth to areas or patches of regeneration. These patches of varying sizes can be even-aged and are determined largely by disturbance history, gap formation and gap size. *Goal:* maintain multi-aged pine population and even-aged stand patchiness within any given treatment unit and within each of the two elevation types.

5. Mid-story and ground cover vegetation structure and species composition is the most important criteria in quantifying desired future conditions for both high- and low-elevation pine rockland as increasing shrub/palm cover has the greatest negative effect on pine regeneration and rare species viability. Percent canopy cover of shrub and palms will be the primary diagnostic in the evaluation of mid-story condition.

6. Although considerable variability in mid-story density and coverage is acceptable, a continuous cover of mid-story vegetation over large areas should be avoided because a dense mid-story does not provide suitable habitat or regeneration conditions (niches) for rare plant species regeneration and focal fauna habitat.

7. Marshes are separated into freshwater characterized by the abundance of sawgrass and salt marsh dominated by cordgrass. Canopy cover of shrubs, particularly buttonwood is the primary diagnostic of seral stage and condition.

8. Although a wide range of shrub canopy cover is possible, for the purpose of defining desired future condition marshes are divided into three seral stages similar to the shrub canopy cover percentages in the pine rocklands.

9. A considerably greater percentage of the early-seral stage of both marsh types should be maintained in the landscape; the least amount should be in the late-seral stage.

Time-frame:

A key component of desired future condition is the time-frame within which the conditions will be reached. The time-frame is frequently based on time to reach maturity or "old-growth" of dominant woody species such as the pine and/or the time to reach a desired age structure. Another criterion could be the time it takes for reference conditions to change to something that would be difficult to restore if active management and restoration efforts are not pursued. For example, scientists generally agree that pine rockland on the mainland will approach hammock vegetation in something greater than 25 years (Alexander 1967; Wade *et al.* 1980), while on the more xeric keys pine rockland may persist for 50 years (Alexander & Dickson 1972). In both locations, old emergent pines would still be present for decades. A third criterion could be the number of fire cycles needed to restore existing conditions to desired shrub cover conditions; for example, it may take a number of fire cycles to kill enough re-sprouting shrubs and palms to reach desired percent cover. As a general time-frame, it may take around 30 years to have the Refuge's pine rocklands and marshes approach desired conditions. This would require burning each point in the pine rocklands between 3 and 10 times over the next 30 years in order to restore and maintain desired early-seral conditions over the majority of the extant pine rocklands. The frequency on a particular site would depend on current conditions and the effort needed to alter existing conditions. The primary difference between desired conditions on Big Pine Key and on the other keys is the time it would take to reach the desire future conditions. Much of Big Pine Key may approach desired conditions in considerably less than 30 years. In contrast, Sugarloaf, Cudjoe and No Name Keys may need more than 30 years to reach desired conditions given the current conditions of dense shrub cover, few pines, organic matter accumulation, and limited open areas. Monitoring may show that low-elevation and high-elevation types need somewhat different fire regimes and burn prescriptions.

The desired future conditions for pine rockland types and marsh types are given in Table 2a&b.

Table 2a.

Desired Future Conditions—Pine Rocklands

Pine Rockland Landscape Context

High & low elevation pine rockland*:

*****The two types will be monitored separately with the goal of maintaining the percentage below in each elevation type. High and low elevation pine rockland will have essentially the same structure but different mid-story and ground cover species composition, e.g. low elevation will have buttonwood and sawgrass, which are largely absent in the high elevation pinelands; rare herbaceous species are largely absent, and plant species richness is lower.

- 70% of landscape of each pine rockland types in early-seral stage.
- 20% of landscape of each pine rockland type in mid-seral stage.
- 10% of landscape of each pine rockland type in late-seral stage
- Areas of largely dead pine stands resulting from storm surge damage will continue to be managed as pine rockland, although there may be a propensity for these sites to become freshwater marsh over the time frame of reaching desired conditions as sea level rises. The justification is that rockland is such a rare ecosystem that potential sites should not be abandoned until climate change effects are unequivocal. The fire regime in marsh and pine rockland is essentially the same, but some individual burns may be planned with pine regeneration and pine seedling/sapling survival in mind. Some planting or seeding of pines may be needed in areas without pines. Lower elevation areas may tend toward the low end of pine percent cover.
- *Supporting research sources:*

  Ross *et al.* 1992a

Pine Rockland Vegetation Structure & Dynamics

South Florida Slash Pines:

- *Cover:* 10 to 50% pine canopy cover.

  Justification: Pine density can be highly variable. Greater than 50% canopy cover negatively impacts herbaceous species diversity and limit pine regeneration. Because of the importance of pine needle litter in

PR Vegetation Structure & Dynamics, continued:

producing a continuous fuel layer, the higher end of the canopy cover range should probably be favored. Some instances of stands of pines reaching 70% cover are acceptable.

Supporting research sources:

O'Brien *et al.* 2010
Bradley & Saha 2009
O'Brien *et al.* 2008

- *Pine Age/DBH Distribution:* Broad landscape-level multi-aged pine distribution (determined generally by diameter size class = DBH) with a reversed J-shaped to U-shaped age distribution; some even-aged clumps or stands of pine, clumps will be of different ages.

  Justification: All life history and stand dynamics research strongly indicates that south Florida Slash pine and similar fire-adapted subtropical pines develop these age distributions under an ecologically appropriate fire regime and episodic disturbances. A U-shaped distribution (numerous older trees, few sapling sized trees, and many seedlings) might be expected in south Florida Slash pine because it lacks a fire-tolerant seedling stage but older trees are fire-tolerant. Reproduction is abundant on burned sites, but many young trees are killed when very frequent fires occur (i.e. 3 year interval or less), at times eliminating entire cohorts.

  Supporting research sources:

  Myers & Rodríguez 2009
  O'Brien *et al.* 2008
  Ross *et al.* 1992a

- *Pine Regeneration:* Pine seedlings and saplings in gaps of varying sizes; gap size and distribution may vary widely depending on disturbances such as storm surge, wind throw, fire hot spots, lightning killed trees, and insect caused mortality. Gap dynamics and size may be greater in low elevation pine rockland due to periodic storm surge. In some cases pine mortality may be extensive. The planting or direct seeding of pines should be evaluated for areas where pines have been eliminated due to storm surge and pine stand damaging fires.

  Justification: South Florida slash pine regenerates best on fire-exposed mineral soil with direct sunlight. It also has a fire-sensitive seedling that generally requires at least a fire-free period of 3 years, and more likely 5 years, to reach a height to for some saplings to survive a low-intensity fire. In Everglades National Park, where pine rocklands are routinely burned every 3 years, pine regeneration appears inadequate to develop

Vegetation Structure & Dynamics, continued:

multi-aged forests. It has been proposed that an interval of 5-7 years may be needed to adequate regeneration to become established (Ruiz & Ross 2001). More frequent fires can occur once regeneration is established in order to derive other desired fire effects. Canopy gaps caused by dead trees that then burn exhibit conditions for successful germination. Because canopy pines are no longer present to produce needle litter fuel, gaps are more likely to escape burning or burn at very low intensity and be patchy, thus increasing the likelihood of pine seedling survival.

Supporting research sources:

O'Brien *et al.* 2008
Ruiz & Ross 2001
Hofstetter 1973

- *Pine Mortality:* Broad areas of pine mortality are expected and acceptable from recurring episodic events (storm surge; wind damage, fires). These will be more prevalent and recurring in low-elevation pine rocklands. Fire-caused mortality of mature pines from prescribed burns should be limited to individual trees to small clumps of trees where fuels are heavy, e.g. dense clumps of palms. Thickets of sapling to pole sized pines can be effectively thinned with prescribed fire

  Supporting research sources:

  Sah *et al.* 2010
  Ross *et al.* 2009
  Bradley & Saha 2009
  O'Brien *et al.* 2008

Thatch Palms:

- *Cover:* 15-25% thatch palm cover, 3 feet or taller.

  Justification: cover greater than 25% would likely shade out herbaceous layer and limit pine regeneration.

  Management trigger: palm cover >25% may require mechanical removal to reduce density before prescribed fire can be applied because the flammability of palm fronds can cause intense fires that may damage pines beyond an acceptable level, and may create difficult fire control situations.

Vegetation Structure & Dynamics, continued:

Supporting research sources:

Snyder *et al.* 2005
Cooley 2004
Bradley & Saha 2009

Shrubs (woody vegetation < 8 feet high):

- *Cover:* 5-30% cover of fire-adapted shrub species, i.e. species that have the ability to persist in frequently burned pine rocklands because of their capacity to re-sprout after being top kill be fire. They may also respond reproductively after fire. These species include, but are not limited to croton (*Croton folia*), locust berry (*Byronima lucida*), stoppers (*Eugenia* spp.), poisonwood (*Metopium toxiferum*), etc. Some have the capacity to reach tree-size (>8 feet) and be part of the composition of hardwood hammock.

  Justification: Shrub cover more than 20% will detrimentally impact herbaceous diversity and pine regeneration. Shrub density also diminishes herbaceous species needed for lower key marsh rabbit in lower elevation pine rockland. Shrub presence is important because they serve as food sources for butterflies, key deer and a variety of bird species, as well as providing habitat cover and nesting sites for some of these species.

- *Supporting research sources:*

  Bradley & Saha 2009
  Barrett 2004
  Ross *et al.* 1992a

Hardwood Trees (> 8 feet):

- *Cover:* <5% tree canopy cover of tree-sized species. Within that percentage cover be sure to maintain some large (8 inch DBH) poisonwood trees (*Metopium toxiferum*).

- *Justification:* Tree canopy cover negatively impacts herbaceous diversity and pine regeneration. All tree species are common in later seral stage pine rockland, transition zones and hammocks.* Poisonwood berries are an important seed source for the white crowned pigeon.**

- *Supporting research sources:*

  * Bradley & Saha 2009
  ** Wilmers *personal communication*

Vegetation Structure & Dynamics, continued:

Herbaceous Layer:

- *Cover:* >25% cover of graminoids and forbs. (*Note:* some areas have up to 90% bare rock where it would be impossible to reach the desired herbaceous cover).

- *Justification:* Well-established herbaceous layer needed to provide fine fuels to support a regime of frequent fire with seasonal variability, and would maintain diversity of the herbaceous layer, including rare species and food sources for butterflies.

- *Supporting research sources:*

  Bradley & Saha 2009
  Lui *et al.* 2005a & b
  Salvato 2001
  Ross *et al.* 1992a

Species Composition

Ground Cover:

- *Presence of species of special concern:* At a minimum, maintain current population levels of *Evoluvulus convolvuloides* (bindweed dwarf morning glory), *E. grisebachii* (Grisebach's dwarf morning glory), *Linum arenicola* (sand flax), *Chamaecrista lineate* var. *keyensis* (Big Pine partridge pea) , *Chamaesyce deltoidea* ssp. *serpyllum* (wedge spruge), *Chamaesyce garberi* (Garber's sandmat) & *Croton linearis* (pineland croton). Increase as fire frequency increases in long-unburned areas and herbaceous ground cover increases. These species are primarily limited to high-elevation pine rockland.

- *Justification:* Herbaceous species of special concern tend to be limited to areas already at or near the desired future condition, i.e. those that have burned most frequently since 1960. Species richness is greatest in frequently burned sites compared to long-unburned sites. Little is known about the dispersal ability of these species into restored areas as fire regimes are re-established and long unburned pinelands approach desired conditions. Continued monitoring and additional research is needed.

Vegetation Structure & Dynamics, continued:

- *Supporting research sources:*

  Bradley & Saha 2009
  Salvato & Hennessey 2004
  Bergh & Wisby 1996
  Ross *et al.* 1992a

Soil, Rock & Duff

Rock & Soil Exposure:

- *Exposure:* Maintain >10% bare rock/soil exposure.

- *Justification:* Less than 10% soil/rock exposure indicates that litter accumulation exceeds conditions suitable for pine seedling establishment and regeneration of herbaceous species.

- *Supporting research sources:*

  Ross *et al.* 1992

Duff & Organic Matter:

- *Accumulation:* Restrict duff layer with a depth of 1 inch or greater to less than 10% of pineland area.

- *Justification:* A deeper and more extensive duff layer is an indicator of insufficient burning to counteract litter accumulation. In long-unburned sites, litter and duff matter accumulation may exceed 1 foot. A well-developed duff layer favors the regeneration of shrubs at the expense of herbaceous species and pines. Smoldering combustion in duff layer produces more severe burn effects, i.e. increased pine mortality because surficial roots and bole are heat damaged. Heat damaged pine may be more susceptible to insect infestations. Duff accumulation makes burning more difficult and expensive, i.e. excessive smoke production, mop-up and control problems.

- *Supporting research sources:*

  O'Brien *et al.* 2010
  Snyder *et al.* 2006
  Ross *et al.* 1992b

Desired Functional Processes

Fire regime:

- *Ignition source:*
    - Prescribed fire replaces wildfire except on Little Pine Key.
- *Fire frequency:*
    1. On restoration areas, plan for burns every 2-4 years until desired mid-story and ground cover conditions are reached. Initially reduce fuels mechanically in areas where fuel loads and human context make initial burns difficult. Desired shrub and palm reduction will need repeated burns to reduce re-sprouting and reduce the number of individuals.
    2. In critical wildland-urban interface areas, i.e. adjacent to homes, plan for burns every 2-4 years indefinitely. A few long unburned areas will be allowed to succeed to hammock.
    3. In maintenance areas, plan for a range of frequencies between 3 to 10 years to attain an average of 5 years, i.e. slightly weighted toward the higher frequencies.
    4. *Triggers:*
        1) When shrub, palm, and pine cover increase toward upper desired limit. However, this should not be the sole criteria triggering burning as an increase in cover of these groups, particularly toward the upper desired limit, may make it difficult to return to a lower cover level without a series of very frequent burns because of an increase in the number of shrubs and their ability to re-sprout producing multiple stems and greater density.
        2) When duff and organic matter exceed desired limit.
        3) A fuel load trigger can also be developed based on potential fire behavior.
- *Supporting Research Sources*

  Horn & Grissino-Mayer 2010
  Bradley & Sah 2009
  Snyder *et al.* 2005
  Ross *et al.* 1992a
  Hofstetter 1973

Desired Functional Processes—Fire Regime, continued:

- *Intensity/Severity:*
    - Generally, low-intensity fires burning in surface fuels, but plan sequential burns under different conditions, i.e. weather and season to get variable intensities.
    - Use ignition techniques to control intensity and fire effects as needed.
    - Favor slower moving fires, without mass ignition (i.e. aerial

      ignition, multiple lines of fire), in critical wildlife areas to limit possible direct effects on individuals animals and to facilitate their escape.
    - Accept and plan for some patchy burns, and varying intensity effects.
    - Plan burns in high fuel load areas to reduce fuels gradually over time with a sequence of burns.
    - In storm surge damaged pine stands, focus on intensities and frequencies that will reduce shrub and duff cover, and favor pine regeneration.
    - Supporting Research Sources:

      O'Brien *et al.* 2010
      Sah *et al.* 2006
      Lui *et al.* 2005a

- *Season:*
    - To meet burn schedule, plan burns to take advantage of a wide burn window, i.e. year round when ever fuels are available and individual burn objectives can be met.
    - Burn in spring and summer when a primary objective is to reduce shrub cover.
    - Vary the season to maintain biodiversity.
    - Consider burn impacts on egg & larval stages of rare butterflies.

Desired Functional Processes—Fire Regime, continued:

- *Supporting research sources:*

  Snyder 1986
  Lui *et al.* 2005b
  Salvato & Hennessey 2004

- *Pattern of burn:*
  - Avoid burning more than 25% of a specific species habitat or plant species population in one year.
  - Plan burns to leave some croton patches unburned within a burn unit.
  - Where other objectives can be met, use previously burned areas as fire breaks for subsequent burns.
  - Vary boundaries of burn units where possible to avoid permanent fire shadows and artificial burn unit edges.
  - Consider impact on key deer browsing on recently burned areas.
  - *Supporting research sources:*

    O'Brien *et al.* 2010
    Bradley & Saha 2009
    Snyder *et al.* 2005
    Barrett 2004
    Salvato & Hennessey 2004
    Ross *et al.* 1992a

Challenges & Uncertainties
to Reaching and Maintaining Desired Future Condition

- Inability to apply prescribed fire at the level needed to restore and maintain desired conditions due to:
  - Lack of on-site fire management capacity to take advantage of burn windows when they present themselves.
  - Current conditions and fuel loads on a number of sites on Big Pine Key making it difficult to use fire on some sites.

Challenges & uncertainties, continued:

- Current conditions (dense hardwood cover, duff accumulation, *WUI)* on Cudjoe, and No Name keys making it difficult and expensive to apply a restoration fire regime.

- On Sugarloaf Key, WUI is not an issue and relatively recent burns have reduced duff layer. Lack of significant pine overstory to supply fuel and a pine seed source make reaching desired conditions difficult; however Sugarloaf Key pinelands are on the cusp of an alternative stable state (i.e. shift to hardwoods) that point to an immediate need for some type of management intervention if the pine rocklands are to be rehabilitated.

- Need to mechanically thin palms and hardwoods on some site (cost & public concerns).

- Wildland-urban interface issues particularly smoke concerns.

- Public concern about fire effects on vegetation and important faunal species.

- Funding constraints and determining priorities given those constraints.

- Uncertainty about sea-level rise and unpredictability of other disturbance events*.

- Impact of an increasing key deer population on vegetation, particularly on immediate re-growth of nutrient-rich, palatable forbs and shrubs.**

- Influence of burn frequency on rare butterflies and their host plants.***

- *Supporting research sources:*

  * Ross *et al.* 2009
  ** Barrett 2004
  *** Salvato & Hennessey 2004

Table 2b.

Desired Future Condition—Freshwater & Cordgrass Marshes

Landscape Context

- 70% of marsh landscape in early seral stage, i.e. buttonwood and other hardwood cover <20%.
- 20% of marsh landscape in mid-seral stage, i.e. 20 to 80% buttonwood and other hardwood cover.
- 10% of marsh landscape in late-seral stage, i.e. >80% buttonwood cover and other hardwood cover.

Shrubs in Early-seral Stage—Fresh Water & Cordgrass Marsh

- *Cover:* Less than 20% woody cover with an average height of less than 1 meter.
- *Justification:* All research conclusions regarding on the Lower Keys marsh rabbit habitat point to buttonwood encroachment and herbaceous vegetation decline as the primary factors in marsh rabbit habitat decline.
- *Supporting research sources:*

  Perry 2006
  Faulhaber *et al.* 2007
  Forys 1995

Herbaceous Vegetation in Early-seral Stage—Fresh Water & Cordgrass Marsh

- *Cover:* Greater than 60% herbaceous cover.
- *Justification:* Lower Keys marsh rabbit uses dense bunch grasses & sedges for cover and nesting. Herbaceous vegetation the primary food source for the rabbit.

- *Supporting research sources:*

  Perry 2006
  Faulhaber *et al.* 2007
  Forys 1995

Challenges & Uncertainties—Freshwater & Cordgrass Marshes

- The Refuge faces the same capacity issues as with burning in the pine rockland, i.e. funding, resources and personnel to conduct burns at the level needed to reach desired conditions.
- Same concerns and issues with respect to public concern.
- Need to evaluate most effective ignition pattern to limit direct mortality to Lower Keys marsh rabbit and silver rice rat.
- Uncertainty about sea-level rise and shifts in vegetation types, i.e. expansion of cordgrass salt marsh into freshwater marsh sites; expansion of freshwater marsh into low-elevation pine rocklands.
- Need to monitor and document fire regime component effects to determine the most ecologically-appropriate fire regime.

Glossary

Adaptive management	A structured tool or process that allows decision making in the face of limited knowledge and uncertainty with the aim of improving management over time via monitoring, knowledge acquisition via research, and experience that reduce uncertainty and improve outcomes.
Canopy cover	The percent area of the foliage as projected on the ground. Can refer to multiple layers, i.e. tree crowns, mid-story trees and shrubs, and ground cover shrubs, forms, grasses and tree seedlings, or the percent cover of a particular species or group of species.
Climax vegetation	Vegetation which establishes itself on a given site for given climatic conditions in the absence of human interference or natural disturbance after a long time. It is the quasi-equilibrium state of the local ecosystem.
Desired functional processes	Ecosystem processes such a nutrient cycling, fire, disturbance events, erosion, soil formation that are important in maintaining the viability of an ecosystem.
Desired future condition	Land or resource conditions that are expected to result if clearly defined goals and objectives are fully achieved.
Ecologically-appropriate fire regime	The *fire regime* that will maintain desired ecosystem characteristics and species composition. Similar, but not identical to, the fire regime that allowed the development of component species' life history traits, as it may be constrained by the current human context.
Ecologically captured	Species populations that are maintained or enhanced indirectly by managing for other key species and specific ecosystem structures.
Ecosystem	A dynamic and inter-related complex of plant and animals and their associated environment (soils, geomorphology, climate, weather events) and ecological processes (fire, nutrient cycling, pollination, disturbances) in a particular area.
Environmental criteria	Environmental parameters used to define the condition of an ecosystem, its processes, and its focal species and their habitats.

Federally-listed threatened & endangered species	Species of plants and animals that are protected under various provisions of the Endangered Species Act of 1970.
Fire-adapted	Usually refers to species that have evolved adaptations to survive fire or respond reproductively to it. Sometimes used to describe habitats and ecosystems that are fire-maintained.
Fire behavior	The manner in which a wildland fire spreads and releases heat given the fuel type and conditions, current weather, and extant topography.
Fire climax	The quasi-stable ecosystem state that develops, and is maintained, under a specific fire regime
Fire-dependent	A synonym for *fire-maintained* ecosystem..
Fire frequency	The average number of fires over a given time at a specific location.
Fire-influenced	An ecosystem, habitat or vegetation type that periodically affected by fire but does not require fire.
Fire-maintained	An ecosystem, habitat or vegetation type that requires fire.
Fire-return interval	The time in years between successive fires at a given location or spot on the ground, usually described as a mean or range.
Fire-sensitive	An ecosystem, habitat or vegetation type where most of the species lack adaptations to fire and most of the responses are negative.
Focal conservation targets	Species, habitats and ecosystems that represent the primary focus of conservation and management actions. Can be keystone species (i.e. the dominant species in the landscape that control many of the ecosystem processes), rare species, Federally-listed threatened and endangered species, and other species of special concern, and the habitats of each.
Forbs	Broad-leaved, herbaceous flowering plants as distinguished from grasses and sedges.
Fuels	Living and dead plant material that is capable of burning. Different amounts, kinds and arrangements of fuels

	control *fire behavior* (along with weather and topography).
Fuel load	The total amount of combustible vegetation material (dead and alive) in a given area.
Graminoids	Grasses and other grass-like plants such as sedges and rushes.
Habitat	The environment of a plant or animal that provides that species with all of its life history requirements. A habitat may be subdivided such as foraging habitat, nesting habitat, seed germination habitat.
High-elevation pine rockland	Pine rocklands on the National Key Deer Refuge that occupy relatively higher elevation sites. The ground cover is a diverse array of grasses and forbs that include the suite of rare species characteristic of pine rocklands. Contrast with *low-elevation pine rocklands.*
Historical fire regime	Usually considered the pattern of burning that existed before fire prevention and suppression policies were implemented. Sometimes considered the fire regime that shaped the development of species' life history traits.
Historical range of variability	The range of critical ecological processes and conditions that have characterized particular ecosystems over specified time periods and under varying degrees of human influences. Sometimes refers to conditions in the absence of modern human influences.
Human context	The environmental condition of wildlands in relation to human society, including its opinion, laws, policies, resource use, environmental manipulation, land use actions, and pollution; and how these are expected to change over time.
Intensity	A general term referring to the heat energy release by a fire through all stages of combustion. The heat regime of a wildland fire.
Ladder fuels	Fuels which provide vertical continuity between vegetation strata, thereby allowing fire to carry from surface fuels into the crowns of trees or shrubs with relative ease. Can be dense shrubs, trees or palms of varying height, vines, and *pine needle drape*.
Low-elevation pine rockland	Pine rockland in the National Key Deer Refuge transitional to freshwater marsh characterized by relatively low plant species diversity (*compared to high-*

	elevation pine rockland), a lack of some of the rare species found a slightly higher elevations, and a ground cover dominated by sawgrass and subject to encroachment by buttonwood. Susceptible to storm surge damage. Elevation differences between high- and low-elevation pine rockland is measured in centimeters.
Monitoring	The process of measuring selected environmental and biological parameters to track changes over time.
Niche	The functional role and position of a species (population) within a community or ecosystem, including what resources it uses, how and when it uses the resources, and how it interacts with other populations. Two species cannot occupy the same niche in the same area for a long period of time.
Pine needle drape	The condition where pine needles litter accumulates on lower branches and on shrubs creating *latter fuels.*
Prescribed fire	A fire intentionally set under predetermined conditions, following a written and approved plan by land managers to maintain habitats, meet conservation and biodiversity objectives, and to reduce potentially dangerous fuels that could burn as a catastrophic wildfire.
Prescribed fire regime	A repeated pattern of planned burning designed to reach specific goals or conditions.
Reference condition	An existing example of an ecosystem structure, composition, and function or species population characteristics exhibited at a site that is considered representative of long-term viability. Used in determining management goals and *desired future condition*.
Regeneration niche	The regeneration characteristics of a species and its environment at the time of its establishment, i.e. the component of the *niche* that is concerned with regeneration processes such as seed production and germination success.
Season of burn	The timing of a burn with respect to season or month of the year.
Seral stage	A temporal intermediate stage in vegetation *succession*.
Severity	The impact of the heat produced by a fire on flora, fauna and soils.

Snag	A dead standing tree or tree trunk that may persist in that state for several years.
Succession	The gradual and predictable process of change in an ecosystem brought about by the progressive replacement of one community by another until a stable *climax* is established. Disrupted by disturbance processes.
Surface fire	A fire fueled by leaf litter, grasses, forbs, low shrubs, other low-statured vegetation, and loose woody debris on the soil surface.
Vegetation type	The plant component of an *ecosystem*.
Wildfire	An uncontrolled free-ranging fire started by lightning or accidentally/intentionally by people.
WUI	Wildland Urban Interface = zone where structures and other human developments meet, or intermingle with, undeveloped wildlands posing difficult wildfire fire management issues.

Biographical Sketches—Contributing Experts

Chad Anderson

Biologist, US Fish & Wildlife Service, National Key Deer Refuge, Big Pine Key, Florida. Applied research focuses on the management of Bartram's hairstreak, rare plants and Key deer, along with overall fire effects on vegetation.

Chris Bergh

Coastal and Marine Resilience Director, The Nature Conservancy (TNC), Sugarloaf Key, Florida. Chair of the Pine Rocklands Working Group. Responsible for fire management of TNC properties on Big Pine Key. Fire management expertise in the Bahamas. Research interests: fire history in pine rocklands, climate change impacts in the Florida Keys, invasive species issues in Florida & the Caribbean.

Keith Bradley

Assistant Director and Research Biologist, Institute for Regional Conservation (IRC), Miami, Florida. Responsible for projects for federal and state agencies including the floristic inventories of Big Cypress National Preserve, Biscayne National Park, and the National Key Deer Refuge, the monitoring of exotic plants in southern Florida, the preparation of status surveys of candidate species for federal listing under the Endangered Species Act, and the demographic monitoring of endangered plants.

Dana Cohen

Fire Management Specialist, U. S. Fish & Wildlife Service, National Key Deer Refuge. A fire ecology, fire effects monitoring, and fuels expert with experience in Everglades National Park and a variety of other national parks throughout the country; professional expertise in studying, implementing and promoting accountable and effective fire management programs.

David Crane

District Manager, Everglades District Field Unit, Florida Division of Forestry, Davie, FL. Considerable fire management expertise in south Florida and the Florida Keys.

Alison Higgins

Land Conservation Program Manager, The Nature Conservancy, Florida Keys Program. Direct oversight of fire management needs on The Nature Conservancy's land holdings on Big Pine Key. Coordinator of the Florida & Caribbean Fire & Invasives Species Learning Network.

Philip Hughes

Ecologist, USDI Fish & Wildlife Service, National Key Deer Refuge. Research focus on the Lower Keys marsh rabbit and wildlife habitat issues.

Stephen Laine

GIS technical expert in the Natural Resources Branch at Eglin Air Force Base in Niceville, FL. Has helped develop and use a fire management prioritization model for Eglin Air Force Base and Blackwater River State Forest.

Anne Morkill

Refuge Manager, National Key Deer Refuge, USDI Fish & Wildlife Service, Big Pine Key, FL.

Dr. Ronald Myers

Fire Management Consultant with *Grupo Caras del Fuego* (Faces of Fire Group), Tallahassee, FL. A fire ecologist and fire applications expert with research focus on fire regimes in the southeast USA and in Latin America. Research interests include fire ecology, fire behavior & fire effects, the role of fire in tropical pine ecosystems, invasive species, and the application of ecological research to land management activities particularly prescribed fire.

Dr. Joseph J. O'Brien

Research Ecologist, USDA Forest Service, Center for Forest Disturbance Science, Athens, Georgia. Research focus on plant ecophysiology, disturbance ecology, fire ecology, using fire for restoration and conservation of biodiversity, and tropical forest ecology. Co-Coordinator for Latin American and Caribbean fire ecology and management team for USDA Forest Service International Program. Studies include terrestrial plant community ecology, ecosystem processes, fire ecology, and subtropical pine forest dynamics in the Florida Keys, Everglades National Park, and the Bahamas.

.

Dr. Michael S. Ross

Associate Research Scientist, Southeast Environmental Research Center, Florida International University, Miami, Florida. Formerly Research Scientist and Principal Investigator, Florida Keys Terrestrial Ecosystem Study, Ecosystem Research Unit, National Audubon Society, Tavernier, Florida. Research includes ecosystem dynamics, disturbance ecology, fire ecology and ecological site classification in the Florida Keys.

Dr. James R. Snyder

Research Biologist, U.S. Geological Survey, Southeast Ecological Science Center, Big Cypress National Preserve Field Station, Ochopee, Florida. Research includes long-term study of fire regimes in south Florida pinelands and wetlands (Florida Keys, Everglades National Park, and Big Cypress National Preserve), developing ecological criteria for prescribed fire in NKDR pine rocklands, season of burn effects in pine rocklands.

Dr. Susan L. Wilder

Regional Fire Ecologist, U. S. Fish & Wildlife Service, Southeast Region Fire Management Branch, Lacombe, LA.

Thomas Wilmers

Biologist, USDI Fish & Wildlife Service, National Key Deer Refuge, Big Pine Key, FL. Research focus on the ecology of Key deer and habitat requirements of other vertebrates.

Steve Zavalney

Deputy Fire Marshall, Monroe County Fire Rescue & Fire Prevention, Marathon, FL.

References

Albritton, J. W. 2009. A 1700-year history of fire and vegetation in pine rockland of National Key Deer Refuge, Big Pine Key, Florida: charcoal and pollen evidence. Master's Thesis, The University of Tennessee, Knoxville, TN.

Alexander, T. R. 1967. A tropical hammock on Miami (Florida) limestone—a twenty-fire-year study. *Ecology* 48:863-867.

Alexander, T. R. & J. H. Dickson, III. 1972. Vegetational changes in the National Key Deer Refuge—II. *Quarterly Journal of the Florida Academy of Sciences* 35:85-96.

Avery, G. N. & L. L. Loope. 1980. Endemic taxa in the flora of south Florida. South Florida Research Center Technical Report T-558.

Bancroft, L. 1977. Fire prescriptions of FY77 prescribed burns. Annual report to USDI National Park Service, Everglades National Park, Homestead, FL.

Barrett, M. A. 2004. An analysis of key deer herbivory on forest communities in the Florida Keys. PhD Dissertation, University of South Florida, Tampa, FL.

Barrett, M. A. & P. Stiling. 2006. Effects of Key deer herbivory on forest communities in the Lower Florida Keys. *Biological Conservation* 129:100-108.

Barrett, M. A., P. Stiling, and R. R. Lopez. 2006. Long-term changes in plant communities influenced by Key deer herbivory. *Natural Areas Journal* 26:235–243

Barrett, S. W. T. DeMeo, J. Jones, J. D. Zeiler & L. Hutter. 2006. Assessing ecological departure from reference conditions with fire regime condition class (FRCC) mapping tool. USDA Forest Service Proceedings RMRS-P-41, pages 575-585.

Bergh, C. & J. Wisby. 1996. Fire history of Lower Keys pine rocklands. The Nature Conservancy, Key West, FL.

Bradley, K. A. & G. Gann. 1999. The pine Rockland forests of southern Florida. *The Palmetto* 19:12-19.

Bradely, K. A. & S. Saha. 2009. Post-hurricane responses of rare plant species and vegetation of pine rocklands in the Lower Florida Keys. Report to the USDI Fish & Wildlife Service submitted by The Institute for Regional Conservation, Miami, FL.

Carlson, P. C., G. Tanner, J. Wood & S. Humphries. 1993. Fire in key deer habitat improves browse, prevents succession, and preserves endemic herbs. *Journal of Wildlife Management* 57:914-918.

Cooley, H. C. 2004. *Palm fuel dynamics in fire-sustained pine forests in the Florida Keys.* M.S. Thesis, Florida International University, Miami, FL. 75 pp.

Correll, D. S. & H. B. Correll. 1982. *Flora of the Bahamas Archipelago.* A. R. Gantner Verlag.

Faulhaber, C. A., N. D. Perry, N. J. Silvy, R. R. Lopez, P. A. Frank, P. T. Hughes & M. J. Peterson. 2007. Updated distribution of the Lower Keys marsh rabbit. *Journal of Wildlife Management* 71:208-212.

Folk, M. L. 1991. Habitat of the Key Deer. PhD. Dissertation, Southern Illinois University, Carbondale, IL.

Folk, M. L. & W. D. Klimstra. 1991. Urbanization and domestication of the key deer (*Odocoileus virginianus clavium*). *Florida Field Naturalist* 19:1-9.

Forthman, C. A. 1973. The effects of prescribed burning on sawgrass. MS Thesis. University of Miami, Coral Gables, FL 83 p.

Forys, E. A. & S. R. Humphrey. 1999a. The importance of patch attributes and context to the management and recovery of an endangered lagomorphs. *Landscape Ecology* 14:177-185.

Forys, E. A. & S. R. Humphrey. 1999b. Use of population viability analysis to evaluate management options for the management of Lower Keys marsh rabbit. *Journal of Wildlife Management* 63:251-260.

Frost, C. C. 1995. Presettlement fire regimes in southeastern marshes, peatlands, and swamps. Pages 39-60 *In:* S. I. Cerulean & R. T. Engstrom (eds.). *Proceedings of the 19th Tall Timbers Fire Ecology Conference, Fire in Wetlands: A Management Perspective.* Tallahassee, FL.

Gagnon, Paul, Heather Passmore, William Platt, Jonathan Myers, C. E. Timothy Paine, and Kyle Harms. 2010. Does pyrogenicity protect burning plants? *Ecology:* In press.

Gann, G. D., K. A. Bradley & S. W. Woodmansee. 2009. Floristic inventory of south Florida Database. Institute for Regional Conservation. http://regionalconservation.org/ircs/database/database.asp

Goodyear, N. C. 1987. Distribution and habitat of silver rice rat, *Oryzomys palustris natator. Journal of Mammology* 68:692-695.

Gunderson, L. H. & J. R. Snyder. 1994. Fire patterns in the southern Everglades. *In:* S. Davis & J. Ogden (eds.). *Everglades: the ecosystem and its restoration.* St. Lucie Press, Delray Beach. FL.

Hofstetter, R. H. 1973. Effects of fire on the ecosystem: an ecological study of the effects of fire on the wet prairie, sawgrass glades, and pineland communities of south Florida. Final Report EVER-N-48, NTIS No. PB-231940, USDI National Park Service, Everglades National Park, Homestead, FL.

Horn, S. P. & H. D. Grissino-Mayer. 2010. Sedimentological and dendrochronological evidence of fire history in the National Key Deer Refuge, Florida Keys, USA. Interim Report, USDI Fish & Wildlife Service Grant Agreement No. 401019G519.

Klimstra, W. D. & A. Dooley. 1990. Foods of the Key deer. *Florida Scientist* 53:264-273.

Klukas, R. W. 1973. Control burn activities in Everglades National Park. Pages 397-425 In: *Proceedings of the 12th Tall Timbers Fire Ecology Conference.* Tallahassee, FL.

Kushlan, J. A. 1990. Freshwater marshes. Pages 324-363 *In:* R. L. Myers & J. J. Ewel (eds.). *Ecosystems of Florida*. University of Central Florida Press. Orlando, FL.

Land, A. 2008. Pineland croton and butterfly habitat in Everglades National Park. *Rx Effects* 1:2-6.

Liu, H., E. S. Menges, J. R. Snyder, S. Koptur, M. S. Ross. 2005a. Effects of fire intensity on vital rates on an endemic herb of the Florida Keys, USA. *Natural Areas Journal* 25:71-76.

Liu, H., E. S. Menges & P. F. Quintana-Ascencio. 2005b. Population viability analysis of *Chamaecrista keyensis:* effects of fire season and frequency. *Ecological Applications* 15:210-221.

Lopez, R. R. 2001. Population ecology of the Florida Key Deer. PhD Dissertation, Texas Agricultural and Mechanical University, College Station, TX.

Lopez, R. R. 2004a. Population density of the endangered Florida Key deer. *Journal of Wildlife Management* 68:570-575.

Lopez, R. R. 2004b. Habitat use patterns of Florida Key deer: implications of urban development. *Journal of Wildlife Management* 68:900-908.

Lowe, E. F. 1986. The relationship between hydrology and vegetational patterns within the floodplain marsh of a subtropical Florida lake. *Florida Scientist* 49: 213-233.

Main, M. B. & G. Tanner. 2006. Effects of fire on Florida's wildlife and wildlife habitat. Institute of Food and Agricultural Science (IFAS). WEC 137. Gainesville, FL.

Medina, A., M. Baker & D. Neary. 1996. Desirable functional processes: a conceptual approach for evaluating ecological condition. USDA Forest Service General Technical Report RM-GTR-272, pages 302-311.

Mutch, R. W. 1970. Wildland fires and ecosystems—a hypothesis. *Ecology* 51:1046-1051.

Myers, R. L. 2010. Pine rockland fire management decision-making workshop: a synopsis. Pine Rockland Working Group. http://fl.biology.usgs.gov/pineland/pdf/Pine_Rocklands_Fire_Workshop_Synopsis.pdf

Myers, R. L. 2006. *Living with Fire: Sustaining Ecosystems and Livelihoods through Integrated Fire Management.* The Nature Conservancy, Global Fire Initiative, Arlington, VA.

Myers, R. L. 2000. Fire in tropical and subtropical ecosystems. *In:* J. K. Brown & J. K. Smith (Eds.). *Wildland Fire in Ecosystems: Effects of Fire on Flora.* USDA Forest Service General Technical Report RMRS-GTR-42 Vol. 2. Ogden, UT.

Myers, R. L. & D. A. Rodríguez-Trejo. 2009. Fire in tropical pine ecosystems. Pages 557-605 *In:* M. A. Cochrane (ed.). *Tropical Fire Ecology: Climate Change, Land Use, and Ecosystem Dynamics.* Springer-Praxis, Chichester, UK.

Myers, R. L., D. Wade, C. Bergh. 2004. Fire management assessment of the Caribbean pine (*Pinus caribaea*) forest ecosystems on Andros and Abaco islands, Bahamas. Global Fire Initiative Publication 2004-1, The Nature Conservancy, Arlington, VA.

Noss, R. F., E. T. LaRoe III & J. M. Scott. 1995. Endangered ecosystems of the United States: a preliminary assessment of loss and degradation. USDI National Biological Service Biological Report 28.

O'Brien, J. J., J. K. Hiers, R. J. Mitchell, J. M. Varner, J. Mordecai. 2010. Acute physiological stress and mortality following fire in a long-unburned longleaf pine ecosystem. *Fire Ecology* 6:1-12.

O'Brien, J. J., K. A. Mordecai, L. Wolcott, J. Snyder & K. Outcalt. 2010. Fire management field guide: hazardous fuels management in subtropical pine flatwoods and tropical pine rocklands. Joint Fire Sciences Program grant 5-2-02. Southern Research Station, Asheville, NC.

O'Brien, J. J., J. Hiers, M. Callaham, R. Mitchell & S. Jack. 2008. Interactions among overstory structure, seedling life history traits, and fire in frequently burned Neotropical pine forests. *Ambio* 37:542-547.

O'Brien, J. J., R. Mitchell, K. Hiers & M. Callaham. 2008. Exorcising "natural" management. Presentation at the 2008 Pine Rocklands Conference: rockland forests in a changing world. Miami, FL.

Perry, N. D. 2006. Lower Keys marsh rabbit and the silver rice rat: steps toward recover. MS Thesis. Texas A & M University, College Station, TX.

Platt, W. J. 1999. Southern pine savannas. *In:* R. C. Anderson, J. S. Fralish & J. M. Baskin (eds.). *Savannas, Barrens, and Rock Outcrop Plant Communities of North America.* Cambridge University Press, Cambridge, UK.

Ross, M. S., J. J. O'Brien, R. G. Ford, K. Zhang & A. Morkill. 2009. Disturbance and the rising tide: the challenge of biodiversity management on low-island ecosystems. *Frontiers in Ecology and the Environment* 7:doi10:1890/070221.

Ross, M. S. & P. Ruiz. 1996. A study of the distribution of several south Florida endemic plants in the Florida Keys. Report to the USDI Fish & Wildlife Service, Vero Beach, FL.

Ross, M. S., J. J. O'Brien & L. da Silveira Lobo Sternberg. 1994. Sea level rise and the reduction of pine forest in the Florida Keys. *Ecological Application* 4:144-156.

Ross, M. S., J. J. O'Brien & L. Flynn. 1992a. Vegetation and landscape ecology of central Big Pine Key. Report to The Nature Conservancy, Travernier, FL.

Ross, M. S., J. O'Brien & L. Flynn. 1992b. Ecological site classification of Florida Keys terrestrial habitats. *Biotropica* 24:488-502.

Ruíz, P. L. & M. S. Ross. 2001. Population dynamics of *Pinus elliottii* var. *densa* in Everglades National Park: a case for less frequent prescribed fire. Natural Areas Association Conference, Cape Canaveral, FL.

Sah, J. P., M. S. Ross, J. R. Snyder & D. E. Ogurcak. 2010. Tree mortality following prescribed fire and storm surge events in slash pine (*Pinus elliottii* var. *densa*) forests in the Florida Keys, USA. *International Journal of Forestry Research:* Article ID 204795, 13 pages. doi:10.1155/2010/204795.

Sah, J. P., M. S. Ross, J. R. Snyder, S. Koptur & H. C. Cooley. 2006. Fuel loads, fire regimes, and post-fire fuel dynamics in Florida Keys pine forests. *International Journal of Wildland Fire* 15:463-478.

Salvato, M. H. 2001. Butterfly conservation and host plant fluctuation: the relationship between *Strymon acis bartrami* and *Anaea troglodyta floridalis* on *Croton linearis* in Florida. *Holartic Lepidoptera* 8:53-57.

Salvato, M. H. & M. K. Hennessey. 2004. Notes on the status and fire-related ecology of *Strymon acis bartrami. Journal of the Lepidopterists' Society* 54:223-227.

Schmidt J. A., R. A. McCleery, P. M. Schmidt, N. J. Silvy, and R. R. Lopez. 2010. Population estimation and monitoring of an endangered lagomorphs. *Journal of Wildlife Management:* In press.

Snyder, J. R. 1986. The impact of wet season and dry season prescribed fires on Miami Rock Ridge pineland, Everglades National Park. *South Florida Research Center Report No. SFRC-86/06.*

Snyder, J. R. 1991. Fire regimes in subtropical south Florida. *Proceedings of the 17th Fire Ecology Conference* 17:303-319.

Snyder, J. R. & G. Ward. (1987). The effects of season of burning on the flowering response of subtropical prairie plants. *Bulletin of the Ecological Society of America* 68:419.

Snyder, J. R., M. Ross, S. Koptur & J. Sah. 2005. Developing ecological criteria for prescribed fire in south Florida pine rockland ecosystems. 2005. Final report: USGS Open File Report OF 2006-1062.

Snyder, J. R., A. Herndon & W. B. Robertson. 1990. South Florida rockland. *In:* R. L. Myers & J. J. Ewel (Eds.). *Ecosystems of Florida.* University of Central Florida Press, Orlando, FL.

Spier, L. P. & J. R. Snyder. 1998. Effects of wet- and dry-season fires on *Jacquemontia curtisii,* a south Florida pine forest endemic. *Natural Areas Journal* 18:350-357.

Sutter, R. D., J. J. Bachant, D. R. Gordon & A. R. Litt. 2001. An assessment of desired future conditions for focal conservation targets on Eglin Air Force Base. Report to the Natural Resouces Division, Eglin Air Force Base, Niceville, FL by The Nature Conservancy, Gainesville, FL.

The Nature Conservancy. 2010. Initial estimates of the ecological and economic consequences of sea level rise on the Florida Keys through 2100. http://www.frrp.org/SLR%20documents/FINAL%20-%20Aug%2021%20-WITH%20COVER.pdf

USDI Fish & Wildlife Service. 2009. Species assessment and listing priority: Florida leafwing butterfly (Anaea troglodyte floridalis.

Varner, J.M., D.R. Gordon, F.E. Putz, and J.K. Hiers. 2005. Novel fire effects in southeastern pine forests: smoldering fire and overstory pine mortality. *Restoration Ecology* 13: 539-544.

Wade, D., J. Ewel & R. Hofstetter. 1980. *Fire in South Florida Ecosystems.* USDA Forest Service General Technical Report SE-17, Asheville, NC.