THE USE OF FIRE IN WETLAND PRESERVATION AND RESTORATION: ARE THERE RISKS?

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ABSTRACT

We identify and discuss the potential risks associated with implementing a prescribed fire program in Florida's Upper St. Johns River basin and evaluate how these risks are being addressed. Specific risks are the threat of cattail (*Typha* spp.) expansion in recently burned nutrient-rich areas, and the potential threat prescribed burning poses to endangered species, particularly nesting snail kites (*Rostrahamus sociablis plumbeus*) in a fragmented habitat matrix. We discuss the ecological basis for the use of prescribed fire in the upper basin, including the risks associated with fire exclusion. Altered water budgets, increased nutrient levels, and perhaps a decrease in fire frequency during the past half century have been accompanied by substantial increases in the acreage dominated by willow (*Salix caroliniana*) and cattail in the basin. To determine the efficacy of fire at reducing willow cover and its effect on mixed sawgrass (*Cladium jamaicense*) and cattail communities, an experimental burn of 316 hectares was conducted in June 1994. Burning caused a significant ($P<0.05$) reduction in both cover and density of willows taller than 1.5 meters. Average willow cover was 65% less than preburn levels after one year. Willows not killed by the fire responded with increased sprout production. Average density of willow sprouts increased from 0.11 sprouts per square meter preburn to 3.65 sprouts per square meter postburn ($P<0.05$). In burned sites dominated by a mixed sawgrass-cattail community, sawgrass density was unchanged; however, cattail densities more than doubled ($P<0.0001$). The greatest increases in cattail densities occurred at sites which had low cattail densities prior to the burn. Soil phosphorous levels at unburned sites declined significantly by mid-June, whereas soil phosphorous at burned sites remained elevated above levels reported to favor cattail expansion through mid-July. Fire is frequently prescribed by managers to reduce woody shrubs and enhance the vegetation mosaic in wetlands. Managers must consider the potential for negative impacts from fires (such as accelerated cattail expansion), and the potential negative impacts to endangered species. Managers must develop methods for weighing these risks against expected benefits. A better understanding of biotic responses to interactions of fire, hydrology, and nutrients is needed.

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INTRODUCTION

The St. Johns River Water Management District is attempting to protect and restore over 60,000 hectares of former and existing herbaceous marsh located in the headwater region of Florida's St. Johns River (Kushlan 1990, Campbell et al. 1984). Marsh restoration and preservation efforts center around reestablishing a natural hydrologic regime, limiting nutrient loading, and reinstituting the natural role of fire.

Fire is widely acknowledged to be an important determinant of vegetation community structure and stability in South Florida wetland ecosystems (Loveless 1959, Robertson 1962, Hofstetter 1974, Wade et al. 1980, Kushlan 1990, Gunderson 1994). Despite the widespread acceptance and use of fire as a vegetation management tool, however, ecosystem responses to fire for the most part, remain poorly understood. Much of this lack of understanding is because fire in wetland systems does not act independently to influence plant community dynamics, but interacts synergistically along with hydrology (Gunderson 1994) and nutrient availability (Kushlan 1990, Davis 1994). In addition, few studies assess relationships between the fauna of these wetlands and fire (Wade et al. 1980).

Wetland managers in the St. Johns basin cannot afford to wait for all the research questions about fire and its effects to be answered before implementing a burning program. In the absence of burning, fuel loads build up and the potential for destructive wildfires increases (Wade et al. 1980). Vegetation shifts, such as woody shrub encroachment into herbaceous marsh may occur, and the value of the wetland habitat to certain wildlife species may be reduced (Craighead 1971, Wade et al. 1980, Wright and Bailey 1982, Robbins and Myers 1992). Despite these apparent justifications for fire, however, we are concerned about using fire on a large spatial scale in a basin that has experienced altered hydrologic regimes and increased nutrient loading (Lee et al. 1995). Can we assume that fire today has the same impact that it had under pristine conditions? One area of concern is cattail (*Typha spp.*) encroachment, which has been occurring throughout the basin. The literature suggests that cattail expansion may be further facilitated by fire (Urban et al. 1993). While cattail encroachment may be temporary in more oligotrophic systems, in eutrophic systems this shift appears to be longer-term (Davis 1994). Another concern is about how fire may directly affect threatened or endangered species in a habitat matrix that has been greatly reduced and fragmented.

Increasing our understanding of the ecological impacts of fire in the upper St. Johns River basin presents a challenge, especially given our limited funding and personnel and the extent of the area to be managed. As with most agencies, after the decision to use fire has been made, most of the limited funds and resources available are expended on the technical aspects of ignition and fire control (Johnson and Miyanishi 1995). Management success is often measured as the percentage of the targeted area burned, and the ecological benefits are assumed. As a result, usually only casual short-term observations are made about fire effects. Potential negative impacts may go unnoticed.

There are risks associated both with having, and not having, a prescribed fire program. The purpose of this paper is to identify and discuss some of the potential risks associated with implementing a prescribed fire program in the upper St. Johns system as it exists today and discuss how these risks are being addressed. Specific risks addressed are potential negative impacts to endangered species and the threat of cattail expansion. In addition, we discuss the ecological basis for the use of prescribed fire as well as some of the risks associated with fire exclusion. Finally, we describe future research needs and direction for the continued development of the district's fire management program for wetlands.

THE UPPER ST. JOHNS RIVER BASIN

The St. Johns River is located in east central Florida. It flows over 485 kilometers from its headwaters near Vero Beach to Jacksonville (Figure 1). The upper basin of the St. Johns River consists of a series of lakes surrounded by extensive floodplain marsh that stretches from the Florida Turnpike near Vero Beach to Lake Poinsett, a distance of approximately 128 kilometers. Within the upper basin the river has a shallow gradient of only 3.8 centimeters per kilometer (Lowe et al. 1984). The climate of the upper basin is considered semi-tropical and yearly rainfall averages approximately 136 centimeters per year. Most of the rainfall occurs within a 5-month period from June to October (Lowe et al. 1984). The floodplain marshes in the upper basin are similar in structure and composition to the northern Everglades. Marsh vegetation communities consist of a mosaic pattern of sawgrass (*Cladium jamaicense*), marsh maidencane (*Panicum hemitomon*), wet prairie, tree islands, shrub swamp, deep water slough, and cypress (*Taxodium spp.*) swamp (Sincock 1958, Lowe 1986).

Anthropogenic Impacts

The lakes and marshes of the upper St. Johns River once encompassed an area greater than 173,000 hectares (Lowe et al. 1984). Since the turn of the century the topography of the basin has been drastically modified, primarily to support agricultural development (Brooks and Lowe 1984). More than half of the original marsh has been drained, while the remainder has been channelized and subdivided by levees, ditches, and causeways. The result has been a loss of greater than 65% of the 100-year floodplain and 42% of the annual floodplain (Brooks and Lowe 1984). Development of the floodplain has dramatically altered natural hydrologic cycles by increasing flood stages and peak flood discharges, decreasing dry season flows, and altering seasonal hydrologic patterns. Because of the significant amounts of water captured behind levees or diverted to the ocean, average flows into the river have decreased to only about 55% of the predevelopment levels (Tai and Rao 1982). In conjunction with floodplain and habitat loss, there have been significant declines in the fish and wildlife populations of the basin (Cox et al. 1976, Florida Game and Fresh Water Fish Commission 1981, Lowe et al. 1984).

Along with altered hydrologic regimes, natural fire regimes have also been modified by floodplain development, although data on historical fires and their impacts are scarce. With lower water levels there was apparently increased burning of the floodplain, primarily by ranchers and hunters. During the 1970's the marsh between the Fellsmere Grade and Lake Washington burned annually (Cox, personal communication, 1996). Areas south of the Fellsmere Grade burned less frequently. Lee et al. (1995) reported that from 1986–1993 arson accounted for 32% of the fires recorded in the upper basin while 23% were caused by lightning. Arson fires occurred more uniformly throughout the year, whereas lightning fires primarily occurred from May through August.

The water quality impacts of floodplain loss and development included increased sedimentation in basin lakes, intensified fluctuations in dissolved oxygen, and increased chloride levels during low water periods (Lowe et al. 1984). Levels of total nitrogen and phosphorous indicate that lakes in the basin are naturally eutrophic, while the interior marshes are more oligotrophic. In the past half-century, runoff from agricultural and urban lands has increased nutrient levels throughout the system. Soil cores taken from different areas of the marsh in 1993 revealed total phosphorous accumulation in soils was 3 to 25 times higher in the 1980's than in the 1920's (Brenner and Schelske 1995). The highest rates of increase have been recorded at sites near sources of nutrient inputs. Average total phosphorous levels in the top 10 centimeters of marsh soil ranged from 330 milligrams per kilogram at relatively unimpacted sites to 2540 milligrams per kilogram at sites near nutrient inflows (Brenner and Schelske 1995). Levels above 450 milligrams per kilogram have been associated with increased cattail occurrence in the Everglades (DeBusk et al. 1994).

Despite the fact the upper basin has been severely impacted by development and floodplain loss, it remains an ecosystem of statewide and national significance. The upper basin still comprises one of the largest contiguous freshwater marshes in Florida and as a result, remains an important area for the preservation of biodiversity. Several of the habitats it contains are considered to be imperiled statewide, and the basin continues to provide habitat for a number of endangered species.

Environmental goals within the upper St. Johns River basin are to restore or preserve, where possible, the natural attributes of species diversity, and abundance, community diversity, and productivity of economically important species (Miller et al. 1996a). To

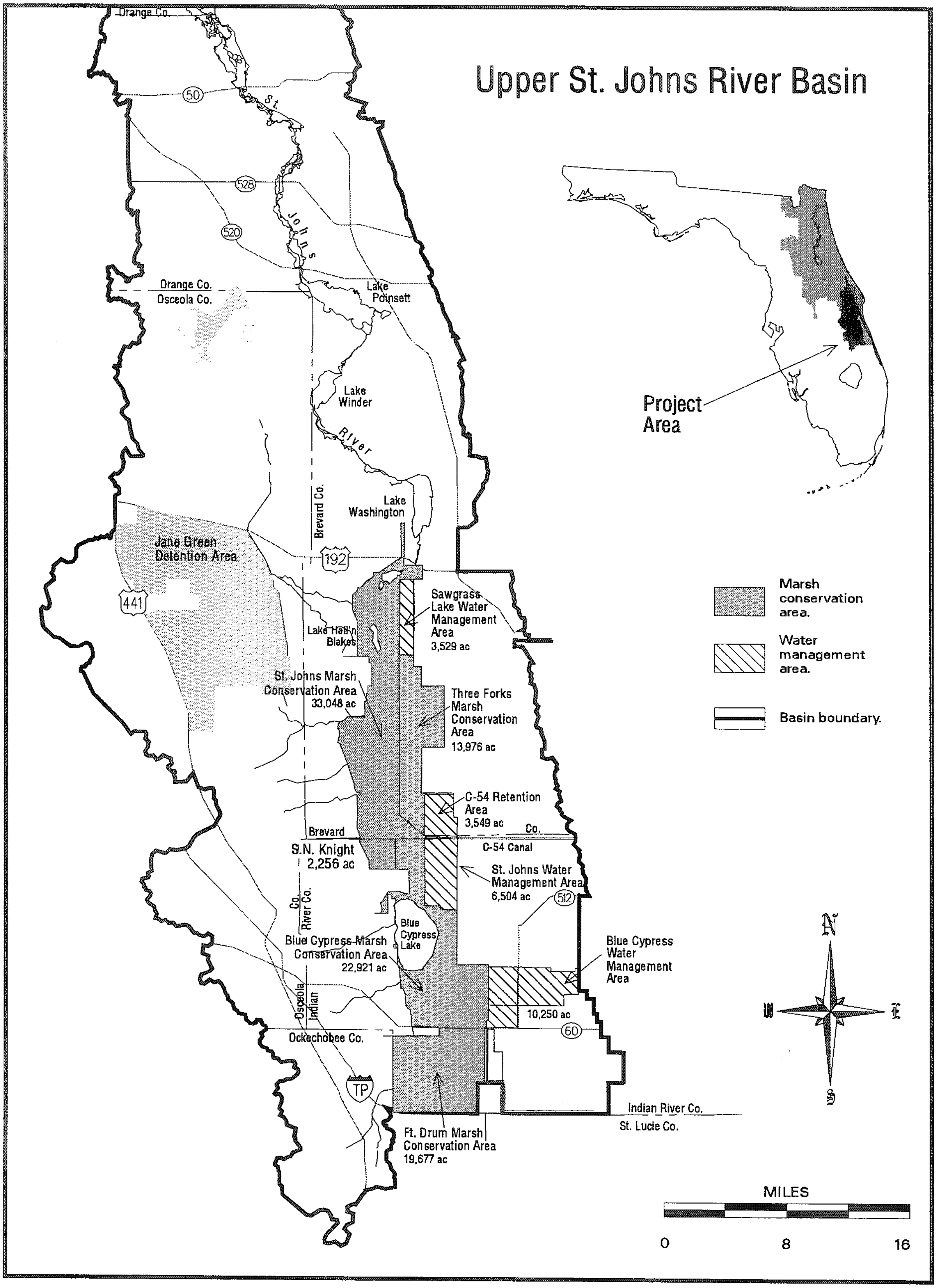


Figure 1. Map of the upper St. Johns River basin.

achieve these objectives, we are focusing on restoring the temporal and spatial attributes of a natural hydrologic regime. By creating a hydrologic regime which mimics the natural condition, optimum soil and vegetation characteristics will be maintained. This, in turn, will help provide other environmental benefits, such as enhanced fish and wildlife habitat and improved water quality.

Along with efforts to re-create the temporal and spatial attributes of a natural hydrologic cycle and reduce nutrient loading, prescribed fire is being used throughout the basin to reduce hazardous fuel loads, to attempt to limit woody shrub (primarily willow *Salix caroliniana*) encroachment, to protect listed species, and to retain physical structure of the ecosystem (see Gordon et al. 1995).

FIRE IN SOUTH FLORIDA WETLANDS

Numerous studies refer to the importance of fire to the maintenance of vegetation communities in South Florida wetland ecosystems (Loveless 1959, Robertson 1962, Hofstetter 1974, Wade et al. 1980, Kushlan 1990, Gunderson 1994). Studies of Everglades peat reveal that fire was indeed common in the Everglades long before the European settlement of Florida (Cohen 1974).

According to Craighead (1971), fire preserves the dominance of the grass and sedge species in the open glade regions by removing the less fire-resistant hardwoods that encroached into these communities. During wet periods, fires consume only the surface litter and prefire plant communities recover quickly. During drier periods, the peat itself may catch on fire, which kills the roots of the existing vegetation and lowers the soil surface (Wade et al. 1980). This may cause a complete shift in plant community composition (Craighead 1971, Lowe 1986) or a conversion to open water (Hoffman et al. 1994).

Lightning is a major cause of fire in Everglades communities (Robertson 1962, Robbins and Myers 1992, Gunderson and Snyder 1994). Native Americans used fire, as did the early white settlers, for hunting and to improve forage conditions (Robertson 1962, Craighead 1971, Robbins and Myers 1992). As South Florida became further settled, fires appeared more frequently and with greater intensity, primarily because drainage activities had increased the length and severity of the dry season (Loveless 1959, Robertson 1962, Craighead 1971, Wade et al. 1980). Additional factors which added to the fire problems were arson, and increased fuel loads due to the fire exclusion policies practiced by resource management agencies (Doran 1982). The pattern of increased fire frequency and intensity continued well into the 1970's, although there is still some uncertainty as to whether the severe fires actually occurred because of drainage activities, or whether extreme fires have always occurred in the system at some intermittent interval (Gunderson and Snyder 1994). Cohen (1974) reported that ancient fires appear to have been restricted to the more fire-tolerant communities in the wetlands, primarily sawgrass, and were not widespread conflagrations which cut across different environments and plant community types.

As a result of the severe fires and changing attitudes about the role of fire as a natural ecosystem process (Wright and Bailey 1982), considerable attention began to be focused on ways to integrate fire management, including the use of prescribed fire, into resource management plans (Doran 1982, U. S. National Park Service 1982, Johnson and Crossett 1991, Robbins and Myers 1992). Prescribed fire is now used routinely as a management tool in South Florida herbaceous wetlands to eliminate hazardous fuel loads, minimize the impact of arson fires, manage wildlife habitat, maintain natural plant community associations, and control undesirable vegetation (U. S. National Park Service 1982, Fox 1991, Johnson and Crossett 1991, Robbins and Myers 1992 , Lee et al. 1995).

RISKS OF FIRE EXCLUSION

Accumulation of Hazardous Fuel Loads

The most frequently stated risk associated with fire exclusion relates to the potential accumulation of hazardous fuel loads (Wade et al. 1980). If excessive fuel loads become ignited, wildfires which burn more intensely and are harder to control often result. Uncontrolled wildfires pose a significant threat to urban areas because of the potential for loss of life and property, and impacts of smoke (Wade et al. 1980).

Wildfires can adversely impact natural systems if they are intense enough to dramatically alter the habitat by killing all vegetation, including fire-adapted plant species, or if they cause extensive mortality to wildlife populations. Wildfires can threaten localized populations of endangered species. An example involves the recent extinction of the dusky seaside sparrow (*Ammospiza maritime nigrescens*), which was found only within a few hundred square kilometers in the upper St. Johns River basin in Brevard County, Florida (Baker 1978). Mosquito spraying, and impounding marshes for mosquito control and waterfowl management, greatly reduced suitable habitat for the dusky. Habitat was further reduced by road construction, urbanization, and drainage activities. With development, the use of prescribed fire became very limited and fuel loads in the remaining habitat units increased. Subsequently, a series of more severe wildfires in this habitat decimated the remaining sparrow population (Harris 1988).

Managing hazardous fuel loads in wetlands is a complex problem since many plant species, such as sawgrass, regrow rapidly after a fire (Loveless 1959, Alexander 1971, Forthman 1973, Van Arman and Goodrick 1979, Herndon and Taylor 1986, Lee at al. 1995). This leads to the question; when does a fuel load accumulation become hazardous? To help answer this question and more effectively establish priorities for the use of prescribed fire, we suggest defining more specifically what constitutes an unacceptable level of ecological fire harm, regardless of whether it occurs as a result of either wild or prescribed fire. The issue of unacceptable fire needs to be addressed for individual project areas or habitats since management goals for areas may vary, and because the remaining wetland landscape is highly fragmented. An example of unacceptable fire damage can occur when fuel and related weather conditions combine to create a fire that burns an entire management area. This is undesirable from a faunal perspective, even though long-term detrimental effects on the vegetation community may not be observed. Another example is the risk fire poses to endangered species. Obviously, active nesting sites of endangered birds should not be burned regardless of fuel load conditions. Defining what constitutes an unacceptable level of fire harm would help us more firmly establish what constitutes a hazardous fuel load and thus, more effectively set yearly priorities for the burn program.

Woody Shrub Invasion

Another frequently stated risk associated with fire exclusion is the invasion and eventual replacement of herbaceous marsh vegetation by shrubs. Shrub swamps are typically dominated by species such as willow, wax myrtle (*Myrica cerifera*), red maple (*Acer rubrum*), buttonbush (*Cephalanthus occidentalis*) and dahoon holly (*Ilex cassine*). A widespread change of herbaceous marsh to shrub swamp is likely to alter food-web dynamics through changes in energy inputs as well as water flow and evapotranspiration rates. This conversion would also lead to a decrease in biodiversity since herbaceous floodplain marsh is listed as an imperiled community type in Florida (Florida Natural Areas Inventory and Florida Department of Natural Resources 1990).

Loss of Species Diversity and Structural Complexity

It is well documented that burning often increases plant species diversity and stimulates flowering and fruiting, especially in xeric and short hydroperiod communities (Wade et al. 1980, Robbins and Myers 1992). In long hydroperiod wetlands, however, drying events appear to be a more important influence on species diversity than fire. Several investigators have found no significant changes in species diversity after a fire in maidencane (VanArman and Goodrick 1979, Lee et al. 1995), sawgrass (Forthman 1973, Lee et al. 1995), and *Spartina* marshes (Schmalzer et al. 1991). Hydrologic variables, primarily length of hydroperiod, and not fire were found to be the major factors determining vegetation patterns and diversity in Lake Okeechobee marshes (Richardson et al. 1995).

Ground fires which burn into the peat are probably more important in determining structural diversity and creating the habitat mosaic in wetlands than surface fires that only consume above ground plant biomass. Ground fires alter vegetation communities by killing root systems, which allows for complete community shifts. For example, Lowe (1986) hypothesized deeper peat fires were responsible for creating the abrupt edge between sawgrass and maidencane (*Panicum hemitomon*) communities. Peat fires may also lower the soil surface to such an extent that deeper open water areas are created when reflooding occurs (Craighead 1971).

Unfortunately, the ecological benefits of peat burns cannot be re-created with a prescribed fire program because of liability issues and because prescribed fires are restricted with regards to intensity and duration. Attempts will also be made to extinguish any peat burns which ignite naturally.

RISKS OF PRESCRIBED FIRE

Although fire occurred historically in the marshes of the St. Johns River basin, this cannot be construed to mean that all fires are beneficial. Because of hydrologic, nutrient, and vegetation changes which have occurred throughout the basin we believe that we cannot safely assume that fire functions in the same ecological role that it did a half century ago. To responsibly use fire now we have initiated research to reassess the role of fire in the upper basin marshes in order to develop fire prescriptions which address specific, measurable resource needs. Information is also being collected which will allow us to weigh the potential ecological benefits of prescribed fire against potential risks.

Two immediate risks we have identified that we believe must be considered by our prescribed fire program include: (1) the risk of undesirable vegetation community changes, primarily increased cattail expansion; and (2) potential adverse impacts to threatened or endangered species.

Risk of Cattail Expansion

Recently, the encroachment of cattails has become an issue of concern throughout the upper St. Johns River basin as well as the Everglades (Davis 1994). Cattail proliferation is probably primarily related to increased nutrient supply and hydrology; however, disturbance by fire may play a facilitative role (Urban et al. 1993, Davis 1994). Urban et al. (1993) reported that in Water Conservation Area 2A, cattails increased following fire at both low and high nutrient sites. This increase is consistent with the role of cattail as an early colonizer following disturbance.

Cattail have increased dramatically in the upper basin during the past twenty years in conjunction with the increasing nutrient status of the marsh. Analysis of recent aerial photographs indicates that cattail is continuing to encroach into other herbaceous wetland communities throughout the basin. Once established, cattail often form dense monotypic stands. Consequently, this alters the species composition and abundance of microbial, periphyton, and macroinvertebrate communities (Davis 1994). In addition, conversion to cattail affects hydrology by increasing transpiration rates (Koch and Rawlik 1993) and increasing peat accretion rates (Reddy et al. 1993).

In addition to the fire itself, firelines constructed through the marsh may also facilitate cattail expansion if soil is disturbed or if the fire line creates a conduit for nutrient-enriched water to get into interior marshes. The occurrence of cattails in nutrient-poor areas of the

Everglades often coincides with an area of soil disturbance (Davis 1994). Cattail expansion into the interior marshes of Lake Okeechobee has been noted to occur near the lake along well maintained airboat trails (Fox, personal communication, 1996).

Potential Adverse Impacts to Listed or Endangered Species

In the upper basin marsh habitats, only three plant species are considered threatened and none are listed as endangered. Two birds found commonly in the upper basin, the Everglades snail kite (*Rostrhamus sociablis plumbeus*) and the wood stork (*Mycteria americana*) are officially listed as endangered, while the black rail (*Laterallus jamaicensis*) is a candidate for the endangered status. Of mammals, the round tail muskrat (*Neofiber alleni*) is a candidate for listing, while the American alligator (*Alligator mississippiensis*) is considered threatened. Several wading birds considered by the state as species of special concern are also common throughout the basin.

Prescribed fire must be used carefully to avoid causing the injury or death of an endangered species, regardless of whether or not such a fire is deemed necessary for the long-term maintenance of the habitat. This creates a dilemma for managers who must possess detailed information about the distribution of endangered species prior to initiating a burn.

ASSESSING THE RISKS

The St. Johns River Water Management District has initiated a number of research projects to collect data to guide the development and implementation of our prescribed fire program. These include investigating the short- and long-term impacts of hydrology, fire, and nutrients on vegetation community dynamics and collecting information on the spatial distribution, habitat use, and reproduction of endangered species. Vegetation studies initially focus on managing willow with fire and the responses of mixed sawgrass-cattail communities to prescribed fire.

Vegetation Experiments

On June 1, 1994 an experimental burn was conducted to investigate willow, cattail, sawgrass, and soil nutrient responses to a single fire event. Early June is the end of the dry season when water levels are typically low. At the time of the burn, average water depths were less than 0.5 centimeters. Specific research questions were: 1) how was cover of willow and other woody species affected by the burn?, 2) what was the impact of the burn on willow stem density?, 3) what was the impact of the burn on cattail and sawgrass densities? and 4) did the fire affect soil phosphorous levels?

Study Area

The experimental burn was conducted in the southwest portion of the Blue Cypress Marsh Conservation Area. The north and central portions of the site are characterized by a mosaic of sawgrass and maidencane with scattered tree islands. The southern end is dominated by willow, while the western boundary is characterized by a monoculture of cattail.

An area of approximately 265 hectares was enclosed in fire lines and designated for treatment. The adjacent marsh was considered the control area. Sampling sites were located throughout the study site, and chosen based on existing vegetation. Control sites were located near the treatment sites. Water depths were nearly identical between control and treatment sites. For willow studies, sites with visually estimated cover of 40–60% willow were selected. For questions concerning sawgrass and cattail, sites where these two species were intermixed were chosen.

Methods

All initial preburn sampling was conducted during April and May, 1994. To investigate the impacts of fire on willows, a total of 15 permanent transects were established in communities dominated by willow in the overstory and sawgrass in the understory. Of the 15 transects, 11 transects were burned and 4 remained as unburned controls. A total of 8 transects were established in communities dominated by willow in the overstory and cattail in the understory. Of these transects, 5 were burned and 3 remained as controls. Two of the sites (sites 8 and 9) originally designated as controls burned. Therefore, 2 additional sites (sites 11 and 12) were added and sampled in the unburned area in July 1994. Postburn sampling at all sites was conducted from 10 to 15 months after the fire. Water depth was measured at all sites during each sampling event.

Cover of willows and other woody species taller than 1.5 meters (canopy) and shorter than 1.5 meters (subcanopy) heights was measured using the line-intercept technique (Mueller-Dombois and Ellenberg 1974). One and one-half meters was estimated to be the height at which overstory species begin to affect establishment, growth, and survival of understory components. Percent cover of each species was calculated by dividing the canopy intercept by the total transect length. Willow mortality and shoot production was estimated by measuring stem density, diameter and condition (dead, live, sprout) at a height of approximately 0.5 meters within a 15 square meter belt transect located adjacent to the cover transects. Stems that were small and lacked woody tissue were considered to be sprouts. Understory species composition and cover within seven to eight square meter quadrats along each transect were also measured using modified Braun-Blanquet cover classes (Mueller-Dombois and Ellenberg 1974).

Responses of sawgrass and cattail to the burn were calculated along 9 transects established in mixed sawgrass/cattail communities. Of the 9 transects, 6 transects were burned and 3 were controls. Cattail and sawgrass densities were determined by counting live culms in 2 meter square quadrats positioned contiguously along 3 permanent 20 meter transects. Postburn sampling included density of both live and dead culms. Presence of other species was also noted.

The nonparametric Wilcoxon paired sample test (Zar 1984) was used because the data did not exhibit normal distributions, and variances were unequal (Zar 1984). Postburn changes in cattail and sawgrass densities were compared to initial densities using simple correlation to determine if initial density had a significant effect on burn response. Where significant correlations were found, relative densities instead of actual densities were tested using the nonparametric Mann-Whitney test. For all statistical tests the significance level was set at $\alpha = 0.05$.

To investigate the impact of the fire on soil phosphorous levels, soil samples were collected from 7 sites located in the burn area and 5 sites located outside the burn area. Samples were taken one month prior to the burn and then monthly for approximately 18 months following the burn. Two months after the experimental fire, four of the control sites burned as a result of arson. These sites were relocated to similar communities in the marsh which had not burned. Approximately 12 months after the fire, the number of burn and control sites sampled were reduced to three of each type. Soil samples were collected using a post hole digger which was inserted from 18 to 20 centimeters into the substrate. The soil plug was removed and placed in a large pan. A sample was then taken from the center of the plug at a depth of 5 to 8 centimeters. Samples were stored in glass jars and transported to the lab for analysis. Samples were analyzed for total phosphorous (TP) following standard EPA procedures (Plumb 1981). Sample means of TP and 95% confidence intervals were plotted.

Results

Fire reduced the cover of canopy willows along the burn transects an average of 65% ($P<0.05$; Figure 2). Prior to the burn, willows taller than 1.5 meters covered an average of 46% of the length of the transects. One year postburn this value was reduced to 16%. In comparison, willow cover did not change significantly at the control sites, although one year postburn values were an average of 14% less than preburn cover scores (Figure 2). Cover of willows less than 1.5 meters in height did not change significantly at either the burned or control sites, however, cover scores did show an increase at 5 of the 6 burn sites (Figure 2).

The reduction in willow cover was a result of mortality of mature stems at the burn sites (Table 1). The average number of mature willow stems declined significantly from 62 preburn to 9 postburn . The number of mature stems at the control sites did not change. Fire stimulated willow sprouting at all burn sites. The average number of willow sprouts significantly increased from 5 stems preburn to 156 stems postburn, whereas sprout density at the control site remained unchanged (Table 1). Concomitant with the decrease in the number of large, mature stems and the increase in number of sprouts at the burn sites was a reduction of average live willow stem diameter from 23 millimeters to 7 millimeters. Willow stem diameters at the control sites increased slightly from 20 to 21 millimeters.

Within the understory, wax myrtle, red maple, and saltbush (*Baccharis haemilifolia*) appeared to be eliminated by fire. New species which appeared most frequently after the burn at all sites were bladderwort (*Utricularia spp.*), lemon bacopa (*Bacopa caroliniana*), pickerelweed (*Pontedaria lanceolata*), and mosquito fern (*Azolla spp.*). The most evident species abundance changes at the burn sites were the substantial decrease of buttonbush and the increase of bladderwort. The increase of bladderwort cover was most likely stimulated by increased light penetration through the newly opened canopy. At control sites, none of these changes were observed.

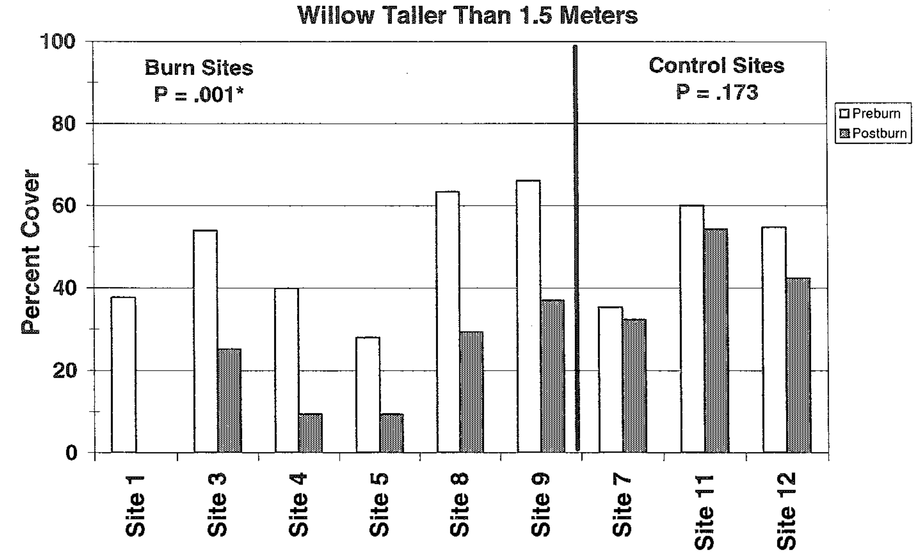
At the cattail-sawgrass sites there was an average increase in the density of cattails of 78% from 2.47 stems per square meter preburn to 4.40 stems per square meter postburn (Figure 3). This increase is attributed directly to the effects of the fire since no changes in cattail densities were noted at the control sites (Figure 3). In comparison, sawgrass density significantly decreased at one burn site, but showed no significant change at the second burn site (Figure 3). A significant negative correlation was found between initial cattail density and cattail density increase at burn sites (Figure 4). Analysis of relative density indicated that cattail increased significantly as a result of the burn. No effect of the fire could be demonstrated on sawgrass densities.

Phosphorous is probably the limiting nutrient in the upper basin marshes as it is the Everglades marshes (Craft et al. 1995) and was the only nutrient considered for this paper. Total soil phosphorous levels between burned and unburned sites were similar prior to the burn and averaged between 800 and 1000 milligrams per kilogram (Figure 5). Fifteen days after the burn, TP dropped to around 500 milligrams per kilogram at control sites but remained elevated in the burn area. TP levels at the burn sites remained consistently above those at the unburned sites for 18 months after the burn although 95% confidence intervals overlapped in all but three of the monthly samples.

Discussion and Management Implications

Prescribed fire was effective at reducing willow stature for at least one year postburn, although fire appeared to stimulate willow sprouting. The variability of willow sprouting between sample sites may reflect intensity of the fire. Site 3, where willow sprouting was the greatest after the fire, (Figure 2) burned incompletely and probably with less intensity than the other sites. Others studies have reported that burning graminoid wetlands does not eradicate willows but merely prunes them (Hofstetter 1974, Johnson and Crossett 1991).

Although willows are generally grouped with other woody shrubs, references presenting data that specifically describe the response of willow to fire are lacking, and where observations are presented, results appear to indicate willows are stimulated by fire. Love-



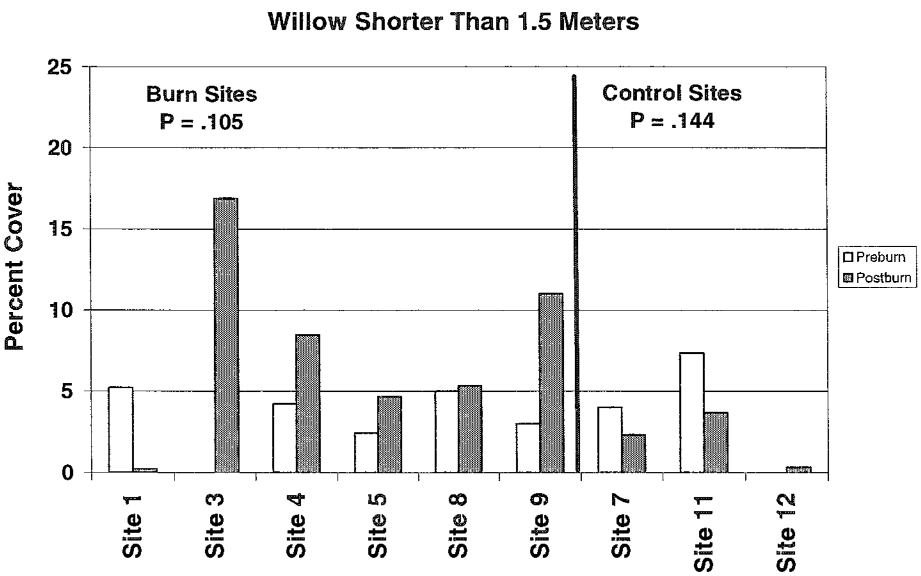


Figure 2. Line intercept cover for willow taller than and willow shorter than 1.5 meters preburn (1994) and one year postburn (1995). * indicates a significant difference between pre-and postburn samples (P<0.05).

less (1959) stated that willows appeared to be "fire followers," and invaded freshly burned areas or areas where the soil had been disturbed. He further stated that willows appeared to be unaffected by fire unless the peat burned or the fire was immediately followed by high water. He also observed that willows occurred most abundantly adjacent to peripheral levees and canals and, as a result of repeated fires, "willows have now replaced much of the original vegetation on some tree islands in the Everglades." Craighead (1971) attributes the formation of willow heads in the Everglades to soil disturbance caused by either agricultural activity or fires. He credits both of these factors for causing a tremendous increase in willow in the Shark Valley Slough in the 1950's, where willow replaced sawgrass. Scientists working on Lake Okeechobee have been concerned with the recent loss of willow from the littoral zone of the lake since the 1970's (Richardson et al. 1995) because of its importance to nesting wading birds. Extensive analysis of plant communities along environmental gradients indicates willow loss in Lake Okeechobee resulted from prolonged hydroperiods (Richardson et al. 1995). Recent willow expansion in the littoral zone has been attributed to a dry period and fire (Richardson and Harris 1995).

Other studies also suggest that hydrology may be a more important regulating factor for willows than fire. Lowe et al. (1984) noted a significant increase in willows in the marsh near Lake Hell'n Blazes in the upper St. Johns basin and attributed this increase primarily to a reduction in the inundation of the marsh. Hall (1987) reached the same conclusion regarding substantial increases of willows around Lake Washington. Willows have also been expanding in the Blue Cypress Marsh Conservation Area in the past 25 years, mainly along the southern and eastern areas of the marsh. One hypothesis is that expansion has occurred because of fire exclusion. This contention, however, is

Table 1. Total number of mature stems and basal spouts of willow counted preburn versus the number counted one year postburn. Letters denote significant differences (α = 0.05) between pre- and postburn values as determined by a Wilcoxon Sign Rank test.

Site no.	Mature stems		Sprouts	
	Preburn	Postburn	Preburn	Postburn
Burn sites				
1	79	0	3	53
3	53	3	1	477
4	66	4	9	182
5	53	0	7	37
8	71	16	0	49
9	51	49	7	77
Weighted average	62[a]	9[b]	5[a]	156[b]
Control sites				
7	50	51	1	0
11	39	29	33	39
12	120	96	10	4
Weighted average	70[a]	59[a]	15[a]	15[a]

not necessarily supported by fire records, since they are incomplete, nor by spatial analysis of the encroachment which suggests willows are expanding in a south to north direction away from a major roadway and project levee. In addition, expansion of the willows around Lake Hell'n Blazes occurred despite the fact that this area was burned annually during the 1970's and early 1980's (Cox, personal communication, 1996).

The expansion of cattail in the burned area documented in this study is consistent with the results reported by other authors. Urban et al. (1993) reported that cattails increased following burning at both high and low nutrient sites, although the increase was temporary as cattail densities declined the next year following a drought. Cattail is viewed as an early colonizer following disturbance in the oligotrophic Everglades, however, they must be replaced by other species or they would, by now, be dominant in the area (Davis 1994). Cattail's role as an early colonizer apparently changes with increased nutrients as they have been found to become the long-term dominant in oligotrophic marshes that have become eutrophic (Davis 1994).

Nutrients, primarily phosphorous, appear to be the primary factor regulating the distribution of cattails in the Everglades (Davis 1991, DeBusk et al. 1994, David 1996). DeBusk et al. (1994) conducted an extensive analysis in July 1994 of soil nutrients versus vegetation community structure in Water Conservation Area 2A. Their results indicate that at soil TP levels above 450 milligrams per kilogram cattail began replacing sawgrass as the dominant community type. Above 800 milligrams per kilogram the sawgrass community was completely replaced by dense cattail monocultures. Soil TP levels measured at burn and control sites in this study (Figure 5) were well within the range at which cattail has been shown to expand.

The results of this study suggest that the prescribed burn increased soil phosphorous levels in the burn area. Schmalzer and Hinkle (1992) reported that available phosphorous levels following a fire in *Juncus* and *Spartina* marshes were elevated for up to 12 months.

The results of this study have important management implications for the use of fire to control willows, and to understand how fire influences cattail expansion. Under wet soil or flooded conditions, fire appears to stimulate willow sprouting, although the long-term effects on willow cover are unknown. Repeated fires in this habitat may continue to control the stature of willow but at the same time further facilitate cattail expansion. Thus we may be trading off one habitat monoculture for another.

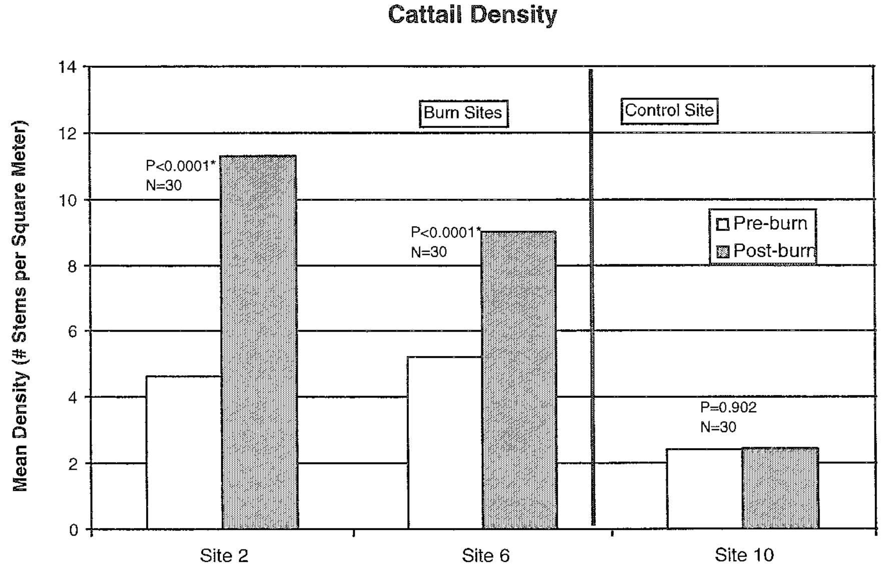
Cattail expansion is a major concern and as with the willows we will continue to monitor these sites for three years. In the meantime, we are initiating a survey to measure soil nutrient levels throughout the basin in order to identify areas where the threat of cattail expansion after a fire may be greatest. Additional studies are needed to quantify nutrient levels at which cattails gain a competitive edge.

Endangered Species

One goal of the St. Johns River Water Management District prescribed fire program is to protect and enhance wildlife habitat without adversely impacting the individual animals themselves. To responsibly use fire in habitats occupied by listed species requires a knowledge of their habitat requirements, distribution, and life history. Our program to monitor the endangered Everglades snail kite is a good example of how we are collecting information that is essential to making informed management decisions. The Everglades snail kite is an endangered bird which is found only in South Florida wetlands, including the upper St. Johns River basin (Nicholson 1926, Sykes 1983, Toland 1993). Because the snail kite feeds exclusively on one species of aquatic snail, the apple snail (*Pomacea paludosa*), their survival is completely dependent upon the maintenance of wetland habitats, which they use for both foraging and nesting (Bennetts et al. 1996). The impacts of fire on either snail kites or apple snails have not been studied.

Since 1990, the St. Johns River Water Management District has been collecting snail kite data through contracts with other state agencies and the University of Florida (Toland 1993, Bennetts et al. 1996). The information obtained so far has proved invaluable for making informed management decisions, both in relation to fire and hydrology (Miller et al. 1996b).

Snail kite nesting in the upper basin occurs primarily in the Blue Cypress Water Management Area (Figure 1). While the snail kite nesting in the Everglades may begin as early as December (Snyder et al. 1989), the earliest nesting documented in the upper basin was in late January (Toland 1993). Nesting continued most years through July and into August. The primary substrates used for snail kite nest construction



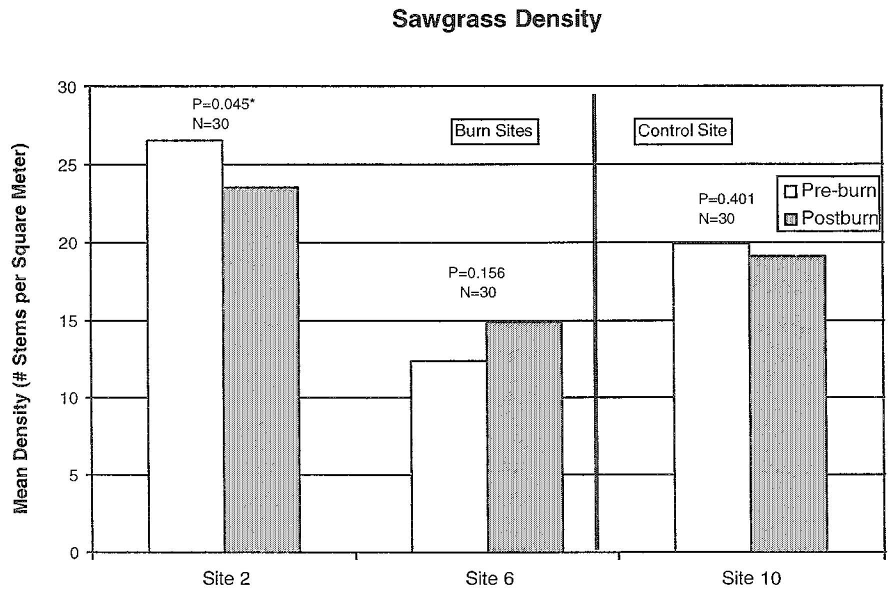


Figure 3. Cattail and sawgrass density preburn (1994) and one year postburn (1995).

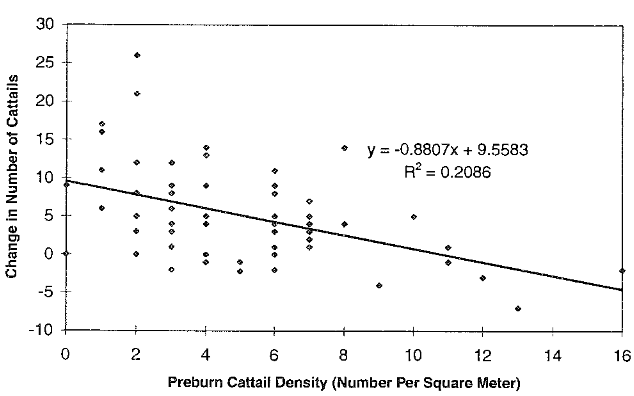


Figure 4. Change in cattail density one year postburn at burn sites as a function of initial cattail density. * indicates significance at $P<0.05$.

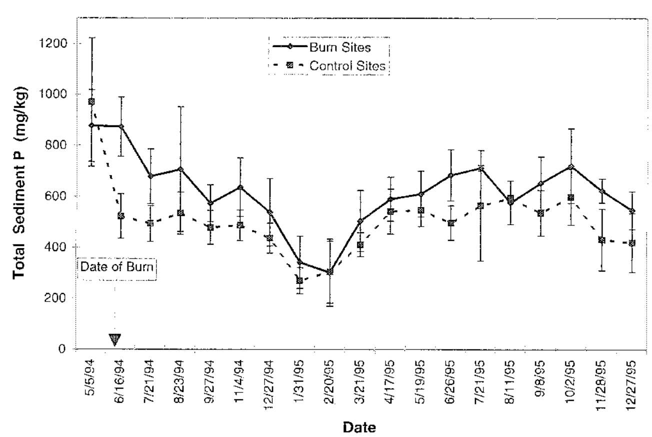


Figure 5. Total soil phosphorous measured at burn and control sites in the Blue Cypress Marsh Conservation Area from May 1994 to December 1995. Values represent the mean and vertical bars represent 95% confidence intervals.

Table 2. Snail kite nest substrate plant species composition and nesting success by substrate species from 1990–1993 in the St. Johns River upper basin. Nesting success is described as successfully fledging at least one young. Data taken from Toland (1993).

Plant species	Total number	Percent composition	Percent of nests successful
Willow	88	38%	24%
Cattail	28	12%	39%
Wax Myrtle	20	9%	6%
Cabbage Palm	20	9%	25%
Sawgrass	17	7%	33%
Red Bay	14	6%	58%
Red Maple	12	5%	64%
Cypress	14	6%	8%

were woody species, primarily willow, but dense cattail and sawgrass were also frequently used (Table 2). Nests were usually constructed in single or small clumps of woody shrubs surrounded by herbaceous vegetation and over standing water. Snail kites also were found to nest throughout the Water Management Area (Figure 6), probably in response to hydrologic conditions during an individual year (Toland 1993, Bennetts et al. 1996).

These studies reveal that snail kites begin nesting during the late dry season, which is an optimal time for burning. They often nest in association with herbaceous fire prone communities, and they may be found nesting almost anywhere in the Water Management Area during an individual year. Management implications are that without complete nest survey data we should conduct only winter burns in this area. Burns to control woody shrubs should be conducted only in small patches to ensure nesting habitat is available at all water levels. Finally, burning after January 15 should only be conducted after an intensive nest survey within the targeted burn area.

We plan to initiate similar studies to collect information on the black rail and the round-tailed muskrat. Preliminary information suggests these two species occupy similar habitats in the upper basin (Hill, personal communication, 1996). Aerial photography is being used to delimit potentially suitable habitats before population surveys are initiated. The impacts of fire on black rails is unknown, but there is some evidence they are reluctant to cross fire lines and as a result may be susceptible to fire-induced mortality. Tilmant (1975) studied the round-tailed muskrat in the Everglades and found that prescribed fires conducted over flooded areas reduced muskrat numbers and even destroyed entire colonies. Burns conducted when water levels were at or below the water surface were least damaging. Obviously, further information is needed before fire can be responsibly prescribed in habitats preferred by these species.

SUMMARY AND RECOMMENDATIONS

1. Given the anthropogenic impacts which have occurred to the hydrology and nutrient loadings within the Upper St. Johns River basin we recommend reassessing the ecological role of fire in this wetland system.
2. We suggest defining more specifically what constitutes an unacceptable level of ecological fire damage, whether it occurs as a result of wildfire or prescribed fire. The issue of unacceptable fire damage needs to be addressed for individual project areas or habitats since management goals for areas may vary (e.g., wildlife management, restoration, etc.). Defining what constitutes an unacceptable level of

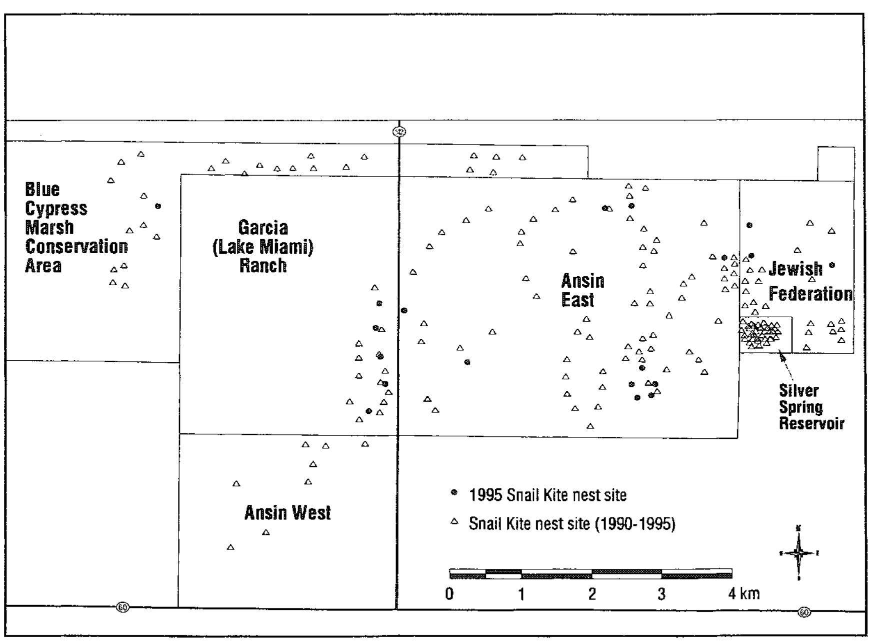


Figure 6. Locations of active snail kite nests in the upper basin of the St. Johns River documented from 1990 to 1995. The area shown is approximately 2,300 hectares.

fire harm will help more firmly establish what constitutes a hazardous fuel load and, therefore, provide an objective basis to set yearly priorities for a burn program.

3. A spring fire reduced cover of mature willows by 65% although the total number of willow stems at the burn sites increased by greater than 240%. Long-term impacts of this increase on willow cover will continue to be monitored.
4. The most frequently documented understory plant species change which followed fire was an increase in bladderwort. The woody overstory species such as wax myrtle, red maple, and saltbush appeared to be eliminated by fire.
5. Cattail density increased 78% after one year post-burn. This increase is attributed directly to the effects of the fire since no changes in cattail densities were noted at the control sites. Sawgrass densities did not change as a result of the fire. Cattail expansion is apparently facilitated by fire although nutrient levels are probably the dominant factor regulating cattail abundance. Fire should be used cautiously in areas where soil TP levels exceed 450 milligrams per kilogram.
6. To responsibly use fire in habitats occupied by listed species requires a thorough knowledge of their habitat requirements, distribution, and life history. In the upper St. Johns basin, endangered snail kites begin nesting during the late dry season. They often nest in association with herbaceous, fire-prone communities, and they may nest almost anywhere in the Water Management Area during an individual year. Management implications are that without complete nest survey data we should conduct only winter burns in this area. Burns to control woody shrubs should be conducted only in small patches to ensure nesting habitat is available at all water levels. Finally, burning after January 15 should only be conducted after an intensive nest survey within the targeted burn area.

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