SAND PINE SCRUB VEGETATION RESPONSE TO TWO BURNING AND TWO NON-BURNING TREATMENTS

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ABSTRACT

Peninsula Florida's sand pine scrub community tends to burn with a high fire intensity under sometimes extreme weather conditions, thus exhibiting uncontrollable and unpredictable fire behavior. Because of the potential hazards and risks associated with scrub burns, few representative samples of these xeric pinewoods are being perpetuated by natural or human-induced fires, often with subsequent adverse effects on the community's flora and fauna, including its many endangered and threatened species. To study the effects of burning versus not burning scrub parcels of various sizes, a combination of fire and mechanical alteration treatments was applied in May 1996 to 4.05 hectares of this community at Jonathan Dickinson State Park in southeastern Florida. Effects of the 4 treatments on the canopy, shrub understory, and ground cover were compared with each other and untreated areas. Three permanent 5 × 20-meter nested quadrats were located in 3 replicate research units for: BURN (vegetation left intact and burned), CUT&BURN (shrubs and small trees cut, dried, and burned), MULCHED (all shrubs and trees chopped, mulched, and left unburned), and UNTREATED (natural vegetation left intact). Two replicate units were also established for HAND-CUT (understory vegetation hand-cut, removed, and not burned). Preliminary results (1 year after burn) show a significant difference ($F_{(4,37)} = 10.6$, $P < 0.01$) in mean number of trees that died in the treated and untreated units. Main effects for dead trees for BURN (94%) and CUT&BURN (100%) were significantly different from HAND-CUT (5.6%), MULCHED (7.7%), and UNTREATED (21.2%). Shrub heights did not return to pre-treatment values, and an interaction between years and treatments was significant ($F_{(4,74)} = 3.7$, $P < 0.009$). The average shrub densities were significantly different between years and treatments ($F_{(4,74)} = 2.5$, $P < 0.049$). A significant increase ($F_{(4,74)} = 4.4$, $P = 0.003$) in herbaceous species in the ground layer was found between years and treatments. At the species level, the effects of the 4 treatments were observed on the flowering and fruit set of the four-petal pawpaw, *Asimina tetramera* (considered by the federal government to be an endangered plant). Preliminary results show a significant year-by-treatment interaction for an increase in flowering ($\chi^2 = 16.7$, df = 8, $P < 0.034$). The percentage of plants setting fruit was significantly higher for all 3 years 1994–1996 ($\chi^2 = 34.9$, df = 2, $P = 0.001$), but sample sizes were small and significant changes among units were difficult to detect. One-year postburn results suggest fire is an important component, even if moderated by mechanical alteration, to manage this community, and mechanical techniques were shown to have some success in mimicking natural fires.

keywords: Asimina tetramera, endangered species, live fuel moisture, mechanical treatments, pawpaw, prescribed fire, sand pine scrub, southeastern Florida, vegetation response.

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INTRODUCTION

Fire is an important force in shaping many natural environments and a natural catalyst for the diversity that provides stability in these ecosystems (Vogl 1973). Many of Florida's terrestrial communities, such as sandhills, scrub, and flatwoods, are fire-dependent and often have interesting relationships with and adaptations to fire (Myers 1990). One of the more interesting communities in regard to its relationship with fire is the sand pine scrub plant community.

Scrub occurs throughout Florida and portions of southeastern Alabama on dry, sandy ridges of relic shorelines, which contain quartz sands of low organic content. The community is usually dominated by even-aged stands of sand pine (*Pinus clausa*), a sometimes dense understory of evergreen oaks (*Quercus myrtifolia, Q. geminata, Q. chapmanii*), Florida rosemary (*Ceratiola ericoides*), and saw palmetto (*Serenoa repens*) with little or no herbaceous ground cover. As many as 40–60% of the plant species associated with scrub communities are endemic and occur nowhere else (Myers 1990).

The flora and fauna of this pyrogenic community has developed many adaptations to fire (Myers 1990). From a functional viewpoint, the sand pine of peninsular Florida is best described as a mature die response type species (T. St. John, University of California—Irvine, unpublished manuscript), where the pines are killed in the fire, but reproduce abundantly afterwards through release of seeds from serotinous cones. The aboveground portions of many shrubs are frequently killed by fire, but the plants recover by resprouting from underground rhizomes (Abrahamson 1984, Menges and Kohfeldt 1995). Many of the scrub oaks rapidly return to their preburn levels of dominance shortly after fire through vegetational regrowth. Other woody species are killed by fire and must reestablish from seeds stored in soil seed banks. Florida rosemary, a short-lived woody shrub (30–35 years) depends on fire for seed recruitment, but only after the parent plant is consumed by fire (Johnson 1982). The need for periodic fire and/or disturbance becomes a requirement for the development of a healthy scrub community (Myers 1990); however, habitat fragmentation, caused by development of homes, roads, and canals has restricted the spread of fires that historically burned vast areas. The requirements for fuel reduction and the recycling of nutrients are still necessary at both the community and species levels.

Maintenance of sand pine scrub forests depends on a high-intensity crown fire once every 20–60 years (Harper 1915, Webber 1935, Laessle 1958, 1967, Harper 1979, Christensen 1981, Menges et al. 1993). Currently, wildfires have virtually defied human control efforts (Johansen and Cooper 1965, Hough 1973); fire roads and suppression equipment have proven largely ineffective. In 1935, one of these wildfires consumed 14,170 hectares of scrub in 4 hours (Florida Department of Natural Resources 1975:104).

In 1985 a modified chaparral fuel model (#4: flame lengths of 6.0–9.0 meters) and a prescription for burning this biological community was developed (Doren et al. 1987). The resulting test burns in 1986 suggested that effective, safe methods exist to burn sand pine scrub under controlled conditions (Doren et al. 1987).

As with this burn and ensuing scrub burns since 1987 conducted at Jonathan Dickinson State Park (JDSP), Florida, mechanical treatment was part of the burn prescription to reduce maximum spotting distance and the probability of ignition. Because scrub communities that have not been burned for 25 years require more active management, the Kennedy Space Center in Florida has been using various cutting and burning techniques since 1992 for restoration (Schmalzer et al. 1994). As part of our reserve, the JDSP site preparation methods (mechanical and burn) were further assessed in conjunction with only mechanical techniques. Two burning and 2 non-burning treatments were applied to an area of scrub where the previous 50-year land use history was known and long-term monitoring would be assured. This research focused on the need to evaluate non-burn approaches for both large and small scrub sites and for sites where urban burning is not an option due to liability, smoke management, or cost.

At the species level, the primary focus was to quantify the flowering and fruiting response of four-petal pawpaw to a combination of burning and mechanical management techniques. This species was selected due to its current federal- and state-protected status and its rare occurrence in southern Florida. Many scrub species are endemic and severely restricted in their range, possibly due to habitat fragmentation, lack of burning, and disappearance of pollinators (Christman and Judd 1990).

The results presented in this paper are from the first year after treatment and should be considered preliminary. This research focused on several important questions: (1) How can we safely burn sand pine scrub habitat that historically burned under catastrophic conditions? (2) Does the mechanical removal of the woody and herbaceous understory in scrub accomplish the same results as burning? Or do pines, understory shrubs, and herbaceous species show dissimilar responses (regeneration) to the burning and non-burning treatments? (3) Does the four-petal pawpaw show similar flowering and fruiting responses to burning and non-burning treatments, which may affect natural recruitment within the existing population?

STUDY AREA

The study site is located in JDSP (27°00′ N; 80°06′ W) in southeastern Florida. The park is near the southern terminus of the existing sand pine scrub community on the Atlantic Coastal Ridge. Before 1940 the northern portion of the study site was used for agriculture, possibly for pineapple production (Alexander and Crook 1975). Then between 1942–1944, the land that would become JDSP in 1947 was used as a U.S. Army Military Base (Camp Murphy). During the Army's tenure there were 12 temporary barracks (approximately 10 × 60 meters) constructed within the study area, but they were later removed before the land was transferred to the state. The park now contains 4,600 hectares and 13 plant communities (Florida Natural Areas Inventory and Department of National Resources 1990). Sand pine scrub covers 852 hectares (Department of Environmental Protection, unpublished data).

Habitat

The study site was dominated by a closed canopy of mature sand pine scrub, a dense scrub oak understory, and a sparse herbaceous ground layer. Large, downed pines scattered throughout the area created gaps in the canopy. Understory shrubs included scrub oaks, Florida rosemary, staggerbush (*Lyonia fruticosa*), wax myrtle (*Myrica cerifera*), saw palmetto (*Serenoa repens*), and pawpaw (*Asimina reticulata* and *A. tetramera*). Florida rosemary-dominated patches occurred at lower elevations. Though scarce, the common herbaceous species in the ground layer included lichens (*Cladonia* spp.), beak rush (*Rhynchospora megalocarpa*), capillary hairsedge (*Bulbostylis ciliatifolia*), and narrowleaf silkgrass (*Pityopsis graminifolia*).

Study Species

The four-petal pawpaw, listed by the federal government as an endangered species (U.S. Fish and Wildlife Service [USFWS] 1988), is endemic to scrub habitat in southern Florida. This small shrub, in the predominantly tropical Annonaceae, is restricted to the sands of Pleistocene dunes in Martin and Palm Beach counties (Kral 1960). The JDSP population was inventoried in 1988 and then from 1993–1998. Extensive surveys found the population consisted of 230 mature plants and an undetermined number of seed-

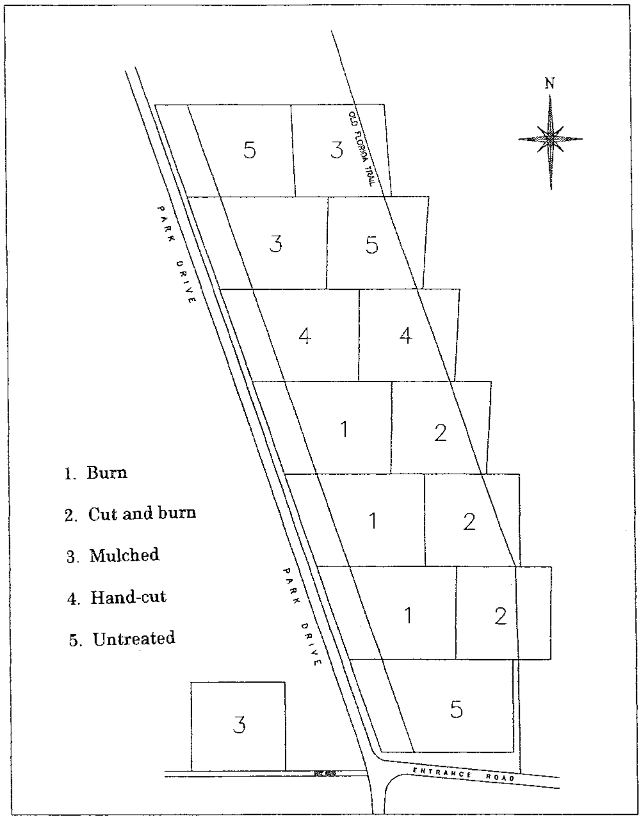

Fig. 1. Jonathan Dickinson State Park (JDSP) research site and location of treatment units at JDSP. 1 = BURN, 2 = CUT&BURN, 3 = MULCHED, 4 = HAND-CUT, 5 = UNTREATED.

lings and saplings. In 1995, a second population of 18 plants was found south of the main concentration of plants (A.C. Cox and R.E. Roberts, unpublished data).

Both reduced flowering and fruiting in four-petal pawpaw was observed under the closed canopy of mature sand pines at JDSP, which had not been burned for ≥50 years. Although reproductive response is best in clearings and open stands (Austin and Tatje 1979), occasional flowers and fruit occur in shady sites. In dense oak scrub, this aromatic shrub responds vegetatively, growing ≥2 meters high from a root crown and root system that extends several meters into the sand. Observations by Kral (1960, 1983), Austin and Tatje (1979), and USFWS (1988) indicated that both cutting and burning stimulated shoot development, and plants produced vigorous new shoots. However, these observations were not documented by quantitative studies.

METHODS

Site Preparation

We conducted this research using a combination of fire and mechanical treatments in 4.05 hectares of mature sand pine scrub. The site was divided into 14 units (0.25 hectares each) in 1995 (Figure 1). Three units were assigned per treatment, except for the HAND-CUT treatment (2 units) originally designed as a firebreak. The units were assigned the following treatments: (1) vegetation left intact and burned [BURN]; (2) shrubs and small trees cut to 40 centimeters with a mechanical cutter, allowed to dry, and burned [CUT&BURN]; (3) all shrubs and small trees chopped and left as mulched biomass and not burned [MULCHED]; (4) understory vegetation hand cut, removed, and not burned [HAND-CUT]; and (5) natural vegetation left intact [UNTREATED]. The BURN and CUT&BURN units were placed adjacent to each other for fire control purposes, and the other 3 treatments were randomly assigned.

Units to be cut (CUT&BURN, MULCHED, and HAND-CUT) were prepared in mid-April 1996. Approximately 10–15 days were required without rain for the cut fuels to dry out and reduce the fuel moisture for burning. Local weather conditions (wind speed, wind direction, relative humidity, cloud cover, state of weather) and fuel moisture levels (1-, 10-, and 100-hour dead fuel and live fuel moisture) were monitored for the prescribed conditions for burning. The fire was set on 17 May 1996, the first day that the local weather conditions were within the prescribed range. The BURN units were started first using backing fires; then flank fires were set into the prevailing wind at the north and south ends. The CUT&BURN units were ignited last using head and strip head fires. This pattern resulted in first burning out the fuels around the fire and then burning out the designated area. This process reduced the overall intensity, spotting distance, and rate of spread.

Live Fuel Moisture.—Because the development of the Rothermel fire spread model (Rothermel 1972) had only limited live fuel moisture inputs and the Fuel Model #4 used for scrub burns was largely dominated by this information, a live fuel moisture sampling effort was established in February 1996 for this research and to assist in future prescribed burn planning. Samples of myrtle oak, sand live oak, saw palmetto, sand pine, and litter were collected and dried in a convection oven to determine percent moisture. Sample methodology and procedures were followed according to Countryman and Dean (1979) and Norum and Miller (1984).

Vegetation Sampling

In 1995 a nested plot design was used to quantify vegetation in 3 strata: canopy, shrubs, and ground layer. Three 5 × 20-meter quadrats were randomly placed within in each treatment area. In the canopy layer, trees taller than 4 meters were sampled within the 5 × 20-meter quadrats to determine density. A spherical densiometer placed in the center of each quadrat was used to measure the percent of light in the canopy reaching the ground and the average canopy coverage for each treatment unit. The status of trees, living or dead, was recorded, and 1 live tree in each quadrat was randomly selected for coring with increment borers to determine age. In quadrats with no trees, the tree nearest the quadrat was cored.

The quadrats were further divided into 4 5 × 5-

Table 1. Weather parameters during the time of the burn of 17 May 1996 at Jonathan Dickinson State Park, FL.

Time	Dry temp. (°C)	RH[a] (%)	6-m. wind speed (km./hr.)	Wind direction	State of weather[b]	10-hr. fuel sticks (sun)	10-hr. fuel sticks (shade)
1100	28	62	11.1	E	0	13.0	15.5
1200	29	62	10.5	ESE	1	12.5	14.75
1300	29	59	11.9	ESE	1	12.0	14.25
1400	29	60	10.9	ESE	0	12.0	12.5
1500	29	60	10.0	ESE	1	11.25	12.5
1600	28	62	11.9	E	1	11.0	11.75
1700	28	62	10.0	ENE	1	11.25	11.5
1800	27	64	10.5	E	2	11.5	11.5

[a] Relative humidity.
[b] State of weather: 0 = Clear (10% cloud cover); 1 = Scattered (10–50% cloud cover); 2 = Broken (60–90% cloud cover). The predicted Dispersion Index was 51, the Keetch/Byram Drought Index was 461, and Days Since Rain was 1 (0.84 centimeters).

meter sections, and the northern quadrat was sampled to measure understory shrub height and determine density. Using a 1-meter square at the northeast corner of each 5 × 5-meter section, the herbaceous species were sampled to determine density and species composition in the ground layer.

Vegetation height and density were sampled for all strata in 1997, 1 year after the treatments, using the same methodology. Seedling sand pine trees were counted in the 5 × 5-meter quadrats to determine germination and establishment. Trees were assessed for damage from fire, mechanical injury, and insects.

Study Species

In 1994, 157 four-petal pawpaw plants were tagged and mapped in the 4.05-hectare site. After the site was divided into units, 114 plants were in the treatment units: 28 in BURN, 49 in CUT&BURN, 14 in MULCHED, and 23 in HAND-CUT; 43 plants remained in the UNTREATED units. Flowering and fruit-set for each adult plant were recorded weekly from 1994–1996 before treatments and for the remainder of 1996 after burning and non-burning treatments.

Statistical Analysis

Data for seedlings were analyzed using one-way analysis of variance (ANOVA). Comparisons between years 1995 (baseline data) and 1997 (1 year after treatments) for shrubs and herbs for average height and density were analyzed using 2-way ANOVA's. Significant results ($P < 0.05$) were further tested using the Tukey HSD post hoc test (Spjotvoll and Stoline 1973) for multiple comparisons of unequal sample sizes.

Multi-way contingency table analyses were used to test for comparisons between years and the treatments for continuous variable data when sample distributions did not meet the tests for normality. Data for the four-petal pawpaw were analyzed using multidimensional contingency table analysis. Weighted least squares analyses (4 treatment areas and the untreated area times 3 years) were run using Pearson chi-square tests. All tests were considered significant at the $P < 0.05$ level. Data for fruit were transformed by adding 0.5 to all values because of the large number of zeros in the data set (Tabachnick and Fidel 1989).

Table 2. Live fuel moisture content (%) for 4 common species collected in April and May 1996 at Jonathan Dickinson State Park, FL.

Species	New fuels		Old fuels	
	April	May	April	May
Pinus clausa	170[a]	170	131	134
Serenoa repens	134	129	106	105
Quercus myrtifolia	150	121	107	93
Quercus geminata	243	104	85	92
Average	174	131	107	106

[a] % moisture content is expressed as sample weight loss divided by sample dry weight.

RESULTS

Prescribed Burn

The predicted weather for 17 May 1996 indicated that all conditions were within the established prescription ranges. After the test fire was completed, the firing pattern commenced at 1405 hours by torching the downwind (west) edge of the mulched fuels next to the park drive. Fires on the south and north flanks were then initiated at 1515 hours, followed by a head fire at 1605 hours. However, as the flame length and torching of pines increased, the head fire was changed to a strip head fire at 1628 hours. Three small spot fires (<2 meters in circumference) occurred west of the park drive at 1430, 1642, and 1645 hours but were quickly suppressed by fire fighters. Weather conditions for the burn day were recorded from 1100–1880 hours (Table 1). The existing live fuel moisture levels were collected and measured for 4 representative species (Table 2).

The backing fire behaved like a Fuel Model #8 (flame lengths of 0.6–1.2 meters), head fire in cut fuels like a Fuel Model #11 (flame lengths of 0.6–0.9 meters), and the head fire in standing vegetation like a Fuel Model #4 (flame lengths of 6.0–9.0 meters) (Anderson 1982). The change to a more conservative firing pattern left a few small islands of intact vegetation, and all quadrants were ignited.

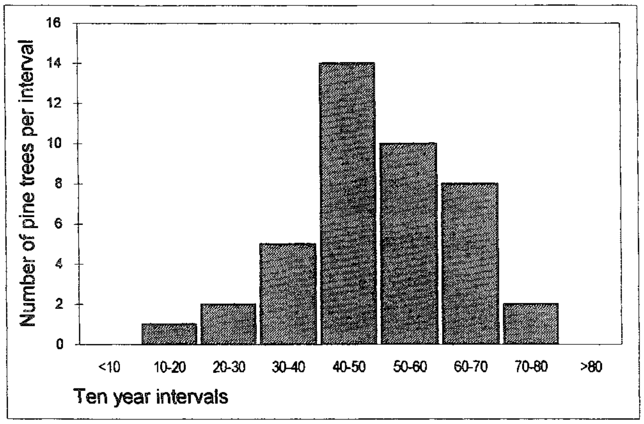

Fig. 2. Age distribution of sand pine (*Pinus clausa*) trees in the research area at Jonathan Dickinson State Park, FL, in 1995 before resource management applications.

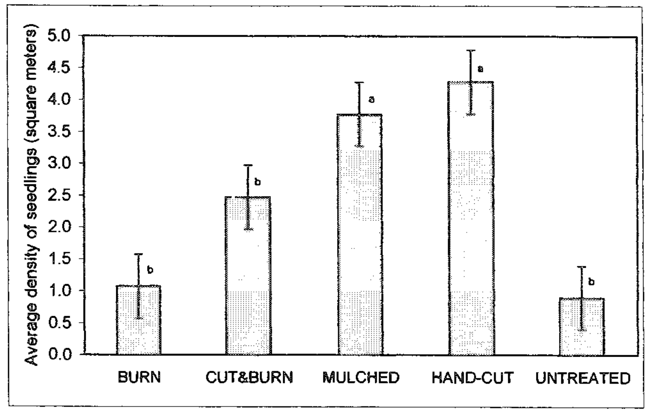

Fig. 3. Average (SE) number of sand pine (*Pinus clausa*) seedlings (per square meter) in 4 treatment units and untreated units in 1997, 1 year after management applications at Jonathan Dickinson State Park, FL. For BURN, CUT&BURN, MULCHED, and UNTREATED units, n = 9; for hand-cut, n = 6. Means with the same letter are not different. $F_{(4,37)} = 4.2$, $P = 0.005$.

Response of Sand Pine to Fire

At the beginning of the study in 1995, 11% (n = 16/145) of the sand pine in the permanent quadrats were dead, but there were no significant differences in the mean number of dead trees between the treatments, BURN (n = 7), CUT&BURN (n = 4), MULCHED, (n = 9), HAND-CUT (n = 0), and the UNTREATED units (n = 3). One year after treatments the difference in the mean number of dead trees across all units was significant ($F_{(4,37)} = 10.6$, $P < 0.01$). Further analysis of dead trees showed the treatment main effects for BURN (31/33 trees, 94%) and CUT&BURN (18/18 trees, 100%) were significantly different from HAND-CUT (1/18 tree, 5.6%), MULCHED (2/26 trees, 7.7%), and UNTREATED (7/33 trees, 21.2%). Trees in the units adjacent to the BURN and CUT&BURN died from heat, or indirectly from beetle damage. No adult sand pines (>12 centimeters diameter at breast height [DBH]) were killed by the mechanical or hand-clearing operations.

Although trees in all units sustained some beetle infestations after the treatments, 45 of the 59 trees that died (76%) showed signs of beetle damage. A comparison of the percentage of trees affected by the beetles showed significant differences between the units ($\chi^2 = 43.7$, df = 4, $P < 0.01$). Two trees that survived the fire in the BURN units escaped beetle infestation in the small patches of unburned vegetation, but 23 of the 31 dead trees (74%) showed signs of beetles. Of the 18 trees in the CUT&BURN units that died, only 14 trees (78%) showed signs of beetle infestation. Beetle damage in the other units was observed in 3 trees still alive after 1 year.

Vegetation

Sand Pines

Within the 4.05-hectare study site, the sand pines consisted of an uneven-aged stand of trees, based on ring counts from 42 tree cores (Figure 2). The average age of sand pines was 48.3 years (SD = 14.2); ages ranged from 22–78 years. Mean DBH was 19.3 centimeters (SD = 10.3, n = 198). The tree density for the site calculated from the mean number of trees in the 100 square meter quadrats was 338 (SD = 225, n = 42) stems per hectare. Mean sand pine canopy coverage calculated from the densiometer measurements was 86.5% (SD = 11.7), indicating a closed canopy forest with the percent pine canopy cover ranging from 61–89%. No significant difference in percent canopy coverage between units was found in 1995 prior to the treatments. However, in 1997, the canopy coverage was reduced in all units and ranged from 0% in the CUT&BURN to 83% in the HAND-CUT units. The difference in percent canopy coverage between units was significant ($F_{(4,37)} = 24.4$, $P < 0.01$). Percent canopy coverage in the BURN and CUT&BURN was significantly different from that in the mechanically treated and UNTREATED units.

Sand pine seedlings monitored in March 1997, 10 months after treatment, were present in the highest densities in the HAND-CUT units; the lowest densities were in the UNTREATED units. Seedlings per square meter in the MULCHED (x = 3.8, SD = 3.2, n = 9) and HAND-CUT (x = 4.3, SD = 3.1, n = 6) units were significantly higher ($F_{(4,37)} = 4.4$, $P < 0.005$) than in the BURN (x = 1.1, SD = 0.9, n = 9), CUT&BURN (x = 2.5, SD = 0.9, n = 9), and UNTREATED (x = 0.8, SD = 1.1, n = 9) units (Figure 3).

Shrubs

The pretreatment (1995) heights in the treatment units ranged from 0.95 meter in HAND-CUT to 0.82 meter in CUT&BURN. One year after treatment the shrubs in the treatment units had not attained pre-treatment heights, but shrub heights in UNTREATED units increased from 0.85–0.89 meters in the 2 years (Figure 4). Analysis of variance showed a significant interaction ($F_{(4,74)} = 3.7$, $P < 0.009$) between years (1995 and 1997) and the 4 treatments and UNTREATED units for mean height of shrubs.

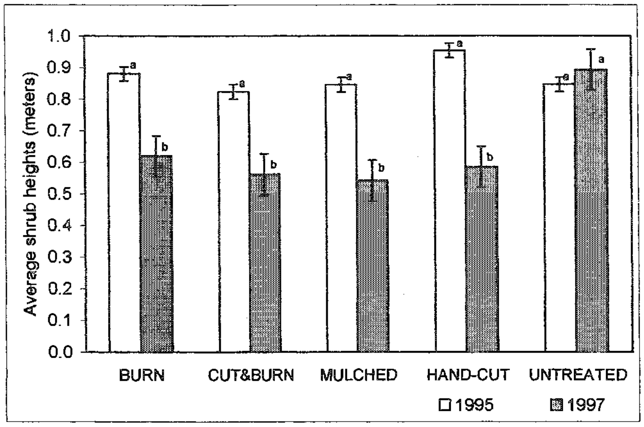

Fig. 4. Average (SE) shrub heights (meters) in 4 treatment units and UNTREATED units at Jonathan Dickinson State Park, FL, in 1995 (before treatments) and 1997 (1 year after management applications). For BURN, CUT&BURN, MULCHED, and UNTREATED units, n = 9; for HAND-CUT, n = 6. Means with the same letter are not different. Year × treatment interaction, $F_{(4,74)} = 3.7$, $P = 0.009$.

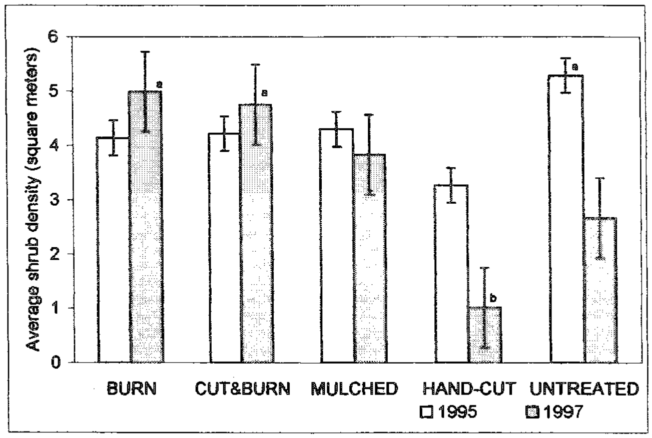

Fig. 5. Average (SE) shrub density (stems per square meter) in 4 treatment units and UNTREATED units at Jonathan Dickinson State Park, FL, in 1995 (before treatments) and in 1997 (1 year after management treatments). For BURN, CUT&BURN, MULCHED, and UNTREATED units, n = 9; for HAND-CUT, n = 6. Means with the same letter are not different. Year × treatment interaction, $F_{(4,74)} = 2.5$, $P = 0.049$.

The shrub densities (number of stems) increased in 1997, compared with densities in 1995 in the BURN and CUT&BURN units, but decreased in the MULCHED, HAND-CUT, and UNTREATED units (Figure 5). The interaction between years (1995 and 1997) and 4 treatments and UNTREATED units was significant ($F_{(4,74)} = 2.5$, $P < 0.049$). In 1995, before management applications, the mean density of shrubs was not significantly different among the 4 treatment units and the UNTREATED units. In 1997, the mean density of shrubs was significantly higher in the BURN and CUT&BURN units compared with the HAND-CUT units, but not significantly higher than in MULCHED or UNTREATED units or than the density in 1995 in the UNTREATED units.

Herbs

Herbaceous species, including grasses, sedges, vine seedlings, and ferns, almost doubled, from 23 to 45 species (Table 3). Eleven additional herbs and 8 grasses were recorded in the 1-meter plots after treatments. The year (1995 and 1997) times treatment (4 treatments plus the UNTREATED units) effects were significantly higher ($F_{(4,74)} = 4.4$, $P = 0.003$) in 1997 than in 1995 (Figure 6). The Tukey post hoc test showed that BURN, CUT&BURN, and HAND-CUT treatments had significantly higher numbers of species in 1997 after treatments than in 1995 before the treatments. However, a comparison of the number of species per square meter in the MULCHED and UNTREATED units was not significantly different from 1995 to 1997.

Pawpaws

All 114 plants in the research plots (and 43 plants in the UNTREATED units) were accounted for after the treatments, and no plants were lost because of cutting or burning. Preliminary results after 1 year (Figure 7a) show the unit (4 treatment units and the UNTREATED units) by year (1994–1996) interaction was significant for an increase in flowering ($\chi^2 = 16.7$, df = 8, $P < 0.034$). More plants flowered across all units in 1996 ($\chi^2 = 18.87$, df = 4, $P < 0.001$) than in either of the previous 2 years (1994 and 1995). The percentage of plants flowering in 1996 after treatments was significantly higher in the BURN units (53.6%) ($\chi^2 = 5.29$, df = 2, $P < 0.05$) and CUT&BURN units (65.3%) ($\chi^2 = 30.58$, df = 2, $P < 0.001$). Although the percentage of plants flowering also increased in 1996 in the MULCHED, HAND-CUT, and UNTREATED units, the increases were not significantly higher than in 1994 or 1995.

The percentage of plants setting fruit (Figure 7b) was significantly higher for all 3 years 1994–1996 ($\chi^2 = 34.9$, df = 2, $P = 0.001$). Although the number of plants setting fruit increased in all units (4 treatments and UNTREATED), the increase was not significant ($\chi^2 = 3.2$, df = 4, $P = 0.52$) as the sample sizes were small and significant changes were difficult to detect. No significant interaction occurred between units and years. The highest percentages of plants setting fruit were in BURN (39.3%) and CUT&BURN (34.7%) units, followed by the HAND-CUT (30.4%), MULCHED (28.6), and UNTREATED (27.9%) units.

DISCUSSION

Prescribed Burn

Even though various land managers are burning sand pine scrub (Roberts, unpublished data), there are few documented prescribed burns (Doren et al. 1987, Custer and Thorsen 1996, Outcalt and Greenberg 1998), as well as little research on conditions for the start and spread of scrub crown fires (Van Wagner 1993). Our successful burn serves to refine the previous work (Doren et al. 1987) for managing sand pine

Table 3. Herbaceous species in 1-meter square quadrats in Jonathan Dickinson State Park, FL, in 1995 before management and in 1997 after management.

Species[a]	Common name	Category	1995	1997
Ageratum conyzoides	Tropical whiteweed	herb	1	1
Ambrosia artemisiifolia	Common ragweed	herb		1
Andropogon floridanus	Florida broomsedge	grass		1
Andropogon virginicus	Broomsedge bluestem	grass	1	1
Bulbostylis ciliatifolia	Capillary hairsedge	sedge		1
Cassytha filifornis	Love vine	vine		1
Catharanthus roseus	Madagascar periwinkle	herb		1
Cenchrus incertus	Coastal sandbur	grass		1
Chamaesyce sp.	Spurge	herb	1	1
Cnidooscolus stimulosus	Stinging nettle	herb	1	1
Conyza canadensis	Canadian horseweed	herb		1
Crotalaria pumila	Low rattlebox	herb		1
Cyperus croceus	Baldwin's flatsedge	sedge	1	1
Cyperus retrorsus	Pinebarrens flatsedge	sedge		1
Dalea feavi	Feay's prairieclover	herb		1
Dicanthelium aciculare	Needleleaf witchgrass	grass	1	1
Emilia fosbergii	Tassel flower	herb		1
Erechtites hieracifolia	Fireweed	herb		1
Eupatorium leptophyllum	False fennel	herb		1
Eustachys petraea	Pinewoods finger grass	grass		1
Galactia volubilis	Downy milk pea	vine	1	1
Galium hispidulum	Coastal bedstraw	herb	1	1
Galium uniflorum	One-flower bedstraw	herb	1	1
Helianthemum nashii	Florida scrub frostweed	herb	1	1
Lupinus diffusus	Sky-blue lupine	herb		1
Lydogium microphyluum	Small-leaf climbing fern	fern		1
Opuntia humifusa	Prickly-pear	herb	1	1
Panicum sp. 1	Panic grass	grass		1
Panicum sp. 2	Panic grass	grass		1
Parthenocisus quinquefolia	Virginia creeper	vine	1	1
Paspalum monostachyum	Gulfdune paspalum	grass		1
Paspalum setaceum	Thin paspalum	grass	1	1
Pectis glaucenscens	Sanddune cinchweed	herb	1	1
Phyllanthus abnormis	Abnormal phyllanthus	herb	1	1
Pityopsis graminfolia	Narrowleaf silkgrass	herb	1	1
Polygronella polygama	Racemed milkwort	herb	1	1
Rynchelytrum repens	Rose natalgrass	grass	1	1
Rynchospora megalocarpa	Sandyfield beaksedge	sedge	1	1
Sisyrinchium xerophyllum	Jeweled blue-eyed grass	herb		1
Smilax auriculata	Earleaf greenbrier	vine	1	1
Solidago odorata var. *chapmanii*	Chapman's goldenrod	herb	1	1
Spoorobolus domingensis	Coral dropseed	grass		1
Thelypteris kunthii	Southern shield fern	fern	1	1
Vitis rotundifolia	Muscadine grape	vine	1	1
Total			23	45

[a] Nomenclature from Wunderlin (1998).

scrub. Some spotting did occur, but the spots were easily controlled, thus demonstrating the continuing need for sharing and testing fire management data for this community. For a typical old growth sand pine scrub forest, the fire behavior should have been more similar to Fuel Model #7, but even without the torching of sand pines, the head fire acted like a Fuel Model #4.

To better model future prescribed burns within sand pine scrub, we emphasized live fuel moisture collection. Although this information alone does not indicate fire behavior, it is important for fire planning and wildfire preparedness (Weise and Saveland 1996). Measurements of weather conditions or dead fuels are not always indicative of the moisture content of living plants. Living plants may either suppress combustion or contribute to it, depending on their moisture content and the flammability of the chemical compounds contained in the plants (Norum and Miller 1984). Typically, 55–75% of the total standing fuel in mature chaparral is living material (Countryman and Dean 1979), as compared to 84% for 9-year-old sand pine scrub (I.J. Stout, University of Central Florida, unpublished data).

At the time of the prescribed burn, both fuel moisture and the Keetch/Byram Drought Index were in a drying trend, but in our research (R.E. Roberts and A.C. Cox, unpublished data) the phenological stages of growth did not always correspond to weather conditions, especially drought (Table 2).

Vegetation

Sand Pine

Sand pine tree densities of 338 trees per hectare were higher than the 292 trees per hectare found by

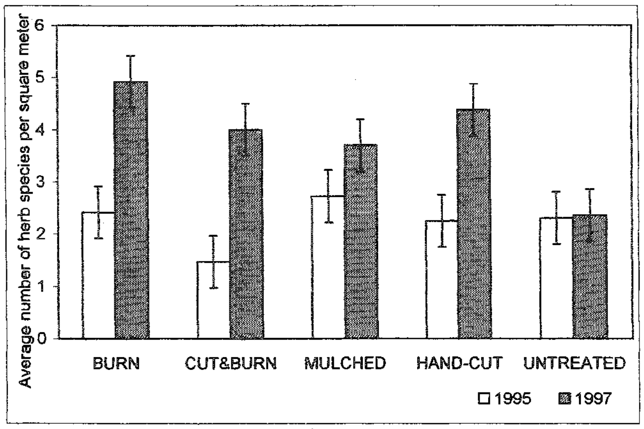

Fig. 6. Average (SE) number herbaceous species (per square meter) in the 4 treatment units and UNTREATED units at Jonathan Dickinson State Park, FL. For BURN, CUT&BURN, MULCHED, and UNTREATED units, n = 9; for HAND-CUT, n = 6. Year × treatment interaction $F_{(4,74)} = 2.5$, $P = 0.049$.

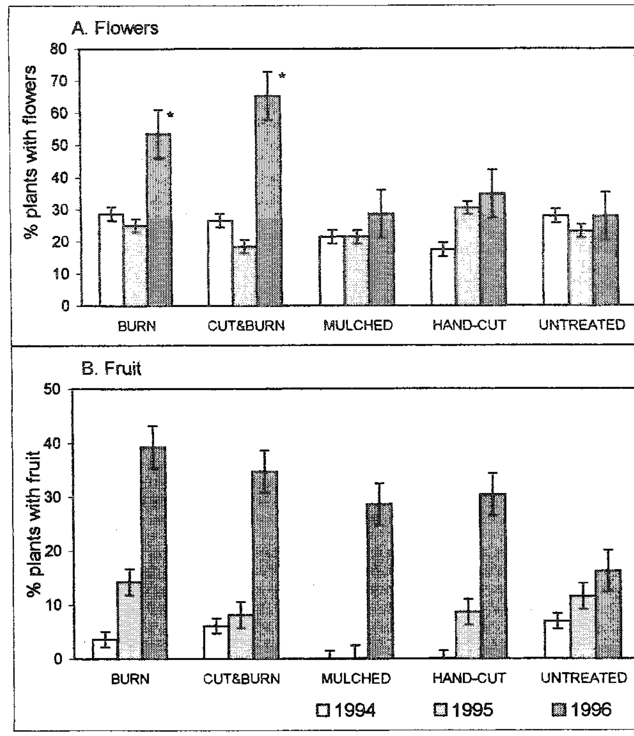

Fig. 7. Percent (SE) *Asimina tetramera* plants with (A) flowers and (B) fruit from 1994–1996 at Jonathan Dickinson State Park, FL. Data in 1996 were collected after management treatments except in UNTREATED area. Number of plants sampled: BURN = 28, CUT&BURN = 49, MULCHED = 15, HAND-CUT = 23, UNTREATED = 43. * indicates significance at $P < 0.5$.

Parker et al. (1997) in another stand of sand pines in the park that also had not burned since before 1947. However, higher densities can be attributed to approximately 75% of this area (3.0 hectares), which was cleared before 1940. Aerial photos interpreted in the Alexander and Crook (1975) study show a closed canopy of sand pines on approximately 25% or 1.0 hectares of the study site. The mean age, 48.3 years (SD = 14.3), of living trees was less than the mean of 62 years found by Parker et al. (1997). However, the oldest tree in our study was 78 years old, compared to 71 years as determined by Parker et al. (1997). Fifty percent of the trees in our study were >50 years old and 81% were >40 years old, near the median fire return interval for scrub. In 1995 before treatments, 11% of the pines were dead. Many pines in the research plot and the area studied by Parker et al. (1997) are senescent, which has led to gaps in the mature forest canopy.

Predictably, the spring (May 17) prescribed burn killed most (96%) of the sand pines within the BURN and CUT&BURN units, although 2 trees survived in the BURN units. The fire killed 100% of the trees in the CUT&BURN units, as the shrub biomass was spread more uniformly over the area and fewer small areas escaped burning. Although beetles attacked the dying pine trees within days of the fire, they were primarily limited to the BURN and CUT&BURN units and to the stressed trees in adjacent areas. By December, 7 months after the burn, the beetle infestation had ceased. In contrast, Abrahamson and Abrahamson (1996) found 45% of the sand pines were killed in a cool winter burn (February) at Archbold Biological Station, Lake Placid, Florida.

Within 2 weeks of the May 17 burn, summer rains started, promoting sand pine seed germination. Germinating seeds and seedling densities were highest in the HAND-CUT and MULCHED units (Figure 3). Both of these treatment units had intact sand pine canopies and no understory shrubs, providing shade for seed germination. The estimated 37,000–42,000 seedlings per hectare was considerable higher than the 3,000 ramets per hectare found by Abrahamson and Abrahamson (1996), but their estimates were made 3 years following fire, not during the first year. Sapling growth usually follows the sprouting understory shrub growth after fire, thus protecting saplings from the potentially lethal hot soil surface temperatures (Cooper et al. 1959). Since most seedlings rarely become established in the shade of mature sand pines (Myers 1990), it will be interesting to follow the recruitment level in this study site over the next 5–10 years.

Shrubs

Shrubs in the treatment units did not reach pretreatment heights within the first year after fire or cutting (Figure 4). Studies of infrequently (20–60 years) burned sand pine scrub and oak scrub indicate that species composition of resprouting shrubs remains relatively stable, but that structural differences occur with sand pine mortality (Schmalzer and Hinkle 1992*a*, *b*, Menges et al. 1993).

As Givens et al. (1984) and Menges et al. (1993) noted, height and cover increased between fires with a few species (oaks and saw palmettos) dominating. We also expected average shrub densities (Figure 5) to increase in the units that were burned. Schmalzer and Hinkle (1992*a*) also found that oak cover took >3 years to return to preburn values. We expected similar results with shrub density in the MULCHED and

HAND-CUT units, but the densities decreased. The closed canopy of pine and environmental and structural conditions associated with the understory may contribute to these results. We expected no change in the UNTREATED units, but between the initial sampling (1995) and posttreatment sampling (1997), densities decreased as the mature pines died and fell in the UNTREATED units. We may find that shrub height and density in areas burned and those treated mechanically recover at different rates.

Herbs

A significant increase in species in the herbaceous or ground layer occurred after the management treatments (Table 3). The increases in the herb strata were as expected, since many herbaceous species establish immediately after fire in open ground associated with the removal of the canopy (Johnson and Abrahamson 1990). *Lupinus diffusa,* a small semi-woody perennial, germinated from seeds in all the treatment units except in the UNTREATED units. Other examples that recruited into the site, but are not listed in Table 3, included *Paronychia americana,* a sprawling herb, and *Lechea deckertii* and *L. cernua,* both suffrutescent species. Many of the herbs present after treatment were early colonizers that do not persist after the shrubs regain dominance. These species include such weedy herbs as common ragweed (*Ambrosia artemisiifolia*), rattlebox (*Crotalaria pumila*), and false fennel (*Eupatorium leptophyllum*), and such grasses as Florida broomsedge (*Andropogon floridanus*), rose natalgrass (*Rhynchelytrum repens*), and coastal sandbur (*Cenchrus incertus*). One particularly disturbing invader was the small-leaf climbing fern (*Lygodium microphyllum*), representing the first recorded occurrence of this invasive non-native species in scrub habitat.

Pawpaws

Fire is known to stimulate flowering in scrub species (Abrahamson 1984, Ostertag and Menges 1994, Lambert and Menges 1996). Four-petal pawpaw in the BURN and CUT&BURN units increased flowering significantly compared to flowering in 1994 and 1995 prior to management (Figure 7a). This finding was expected since this species was previously observed to respond both vegetatively and reproductively with new growth after fire (Kral 1960, 1983, Austin and Tatje 1979, USFWS 1988). *Asimina longifolia* and *A. pygmaea* seldom flower unless the longleaf pine forest they inhabit is burned. In central Florida, fire stimulated flowering the first year after burning in a closely related endangered species, *Deeringothamnus rugelii,* but plants that were clipped at ground level did not show significant differences in flowering from untreated plants (Helkowski and Norman 1997).

The lower percentages of four-petal pawpaw plants flowering in the MULCHED and HAND-CUT units (not significantly different from 1994 and 1995) were not expected, as cutting was reported to stimulate shoot development and flowering (Kral 1960, 1983). Many plants produced renewal shoots in response to the cutting treatments, but did not flower. It is possible that non-reproductive plants were young and may have had underground storage reserves sufficient only for sprouting, not for flowering. Fewer flowers per plant and the low number of individuals flowering in the UNTREATED units may have limited pollinator movement between plants. In the absence of fire or major disturbance, diminished flowering and fruit-set may cause a shift from sexual reproduction to vegetative reproduction (Lambert and Menges 1996).

The slight increases in flowering in the 4 treatment units before management and in the UNTREATED units after management could be attributed to sand pine senescence and tree falls. As sand pines reach maturity at 50–70 years, gaps form in the canopy from fallen pines, creating small disturbances in the understory. Between 1995–1996 several mature pines fell on the four-petal pawpaw plants, stimulating renewal shoots and promoting flowering.

Before implementation of management applications, few four-petal pawpaw plants in the mature scrub habitat produced fruit in 1994 and 1995 (Figure 7b). The increase in fruit production after management may be attributed to the removal of competition from dense shrubs, increase in flower production, and an increase in pollinator activity as a result of more flowers per plant and more plants flowering. The increase in flowering may also attract insects from adjacent open habitats. Though not significantly different from the MULCHED, HAND-CUT, or UNTREATED units, the percent of plants setting fruit was highest in the BURN and CUT&BURN units.

Four-petal pawpaw response to fire is similar to the "fire-persister" species in California chaparral that exhibit resilience to fire (Keeley 1989). In response to previous observations that these plants are intolerant of heavy shade (Austin and Tatje 1979) and do not persist under dense oaks in the understory, four-petal pawpaw plants remain in the habitat, although they may not reproduce in closed canopy scrub. These plants may live for hundreds of years or at least persist vegetatively for the lifetime (fire return interval) of the scrub, similar to many sprouting shrubs that owe their longevity to extensive underground parts (Abrahamson 1984). When the scrub is burned, either under natural conditions from wildfires, or more recently, through prescribed burning, these plants respond through renewal shoots. They flower and fruit in the first few years following fire and recruit new plants into the populations (A.C. Cox, unpublished data).

MANAGEMENT IMPLICATIONS

Fire is a natural force in the sand pine scrub community and should be permitted to play its role in both wildfires and prescribed fires whenever possible. Where fire is difficult to control, the modification of fire through mechanical techniques may be required to achieve management objectives. These objectives may include fuel reduction, seed bed preparation, disease control, thinning, suppression of shrubs, removal of litter, increased herbage yields, increased availability of forage, and increased wildlife (Wright and Bailey 1982). To maintain the desired diversity and structural variation, prescribed burns of scrub have been aided by mechanical preparation. However, where burning is not an option, the evaluation of strictly non-burn techniques, will require a long-term research commitment.

The results 1 year after management indicate that scrub vegetation composition is returning to pretreatment status with no loss of species. Along with weedy species, the number of herbaceous species has increased. In time, however, sand pine growth and canopy closure, plus more shrub competition, will lead to a decrease in these species.

The species make-up, structure, and age of scrub vegetation have a profound effect on both the flora and fauna of this community. These characteristics are especially important to the population levels of many endangered and threatened species that are adapted to this community, such as the four-petal pawpaw. As the scrub strata recover, the comparison of the four-petal pawpaw in all management units will extend beyond flowering and fruit-set to the recruitment of new plants into the population.

In a habitat with a fire return interval of 20–60 years, 10 years may elapse before we can say for certain that one treatment is more effective than another. We know that without the intervention of proper management and control of unwanted species, the remaining parcels of this endangered community will not persist.

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