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Impact of Fire Exclusion and Invasion of Schinus terebinthifolius on Limestone Rockland Pine Forests of Southeastern Florida

Everglades National Park, South Florida Research Center, P.O. Box 279, Homestead, Florida 33030

IMPACT OF FIRE EXCLUSION AND INVASION OF SCHINUS TEREBINTHIFOLIUS ON LIMESTONE ROCKLAND PINE FORESTS OF SOUTHEASTERN FLORIDA

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Lloyd L. Loope and Vicki L. Dunevitz

National Park Service
South Florida Research Center
Everglades National Park
Homestead, Florida 33030

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ABSTRACT

Exclusion of fire from stands of Pinus elliottii var. densa on limestone substrates of Dade County in southeastern Florida, results in shading of the understory by native tropical hardwood tree species and eventual elimination of a rich herbaceous, light-requiring understory flora, including endemic and/or very rare species. The exotic tree Schinus terebinthifolius has extensively invaded most remaining rockland pine forests outside Everglades National Park. Once saplings of the invading Schinus reach 1 m in height, most are able to survive fire. Aided by rapid recovery from fire, Schinus comes to dominate the understory of the stand and hastens the shading out of the herbaceous flora. Prescribed burning of pine stands at 5-year intervals within Everglades National Park has apparently largely prevented establishment of Schinus there. Eventual requirements for pine regeneration as the stands approach maturity may result in application of less frequent, more severe prescribed fires. If such a regime results in the expected accelerated Schinus invasion, use of herbicides on Schinus may be necessary to maintain the native pineland ecosystem.

INTRODUCTION

The pine forests of the Miami Rock Ridge of extreme southeastern Florida (Fig. 1) form a highly distinctive vegetation type with the following characteristics: (1) a rough limestone (Miami oolite) substrate with abundant crevices and solution holes, but very little soil development; (2) an understory including a variety of West Indian hardwood species; and (3) a rather rich herbaceous flora, including South Florida endemics. The single overstory tree of these forests is Pinus elliottii var. densa.

These pine forests, essentially confined to Dade County, once extended from near Mahogany Hammock in the present Everglades National Park northeastward to the vicinity of North Miami. Prior to the establishment of Everglades National Park, most of the pine forest of that area (a large portion of which is known as Long Pine Key) was logged in the late 1930's and early 1940's, but has since largely recovered in the sense that most of it has well-stocked stands of 30-40 year second growth. Approximately 500 hectares of Everglades National Park pine forests were obliterated by "rock plowing" and farming within the so-called "Hole-in-the-Donut," a former privately owned enclave of farmland within park boundaries. Approximately 8000 hectares of pine forest remain in the park and are maintained by a fire management program which involves periodic prescribed burning of segments of the pine forest (Hofstetter, 1973; Everglades National Park, 1979).

Outside Everglades National Park, pine forests of the Miami Rock Ridge formerly covered about 65,450 ha, but have been largely removed by farming and urban expansion between 1900 and the present (Shaw, 1975). The most rapid destruction of this forest took place between 1940 and 1970. At present, only scattered remnants persist. A 1975 inventory (Shaw, 1975) located 268 isolated stands of 2.1 ha or more, totalling 2132 ha in area. A more recent inventory in 1978 (K. Daugherty, personal communication) showed a 25% reduction in the total area remaining due to stand destruction during the three-year period.

Most of the rockland pine stands outside Everglades National Park are being invaded by the exotic tree Schinus terebinthifolius Raddi, locally known as "Brazilian pepper" or "Florida holly." Schinus, a native of Brazil, was introduced to Florida as an ornamental in 1898, but did not become widely naturalized until much later (Austin, 1978). It probably entered the park in the 1940's (Bancroft, 1973). A report by Dr. Frank Craighead (1961) cited the presence of Schinus at several locations in the park and the possibility that it might become a serious problem.

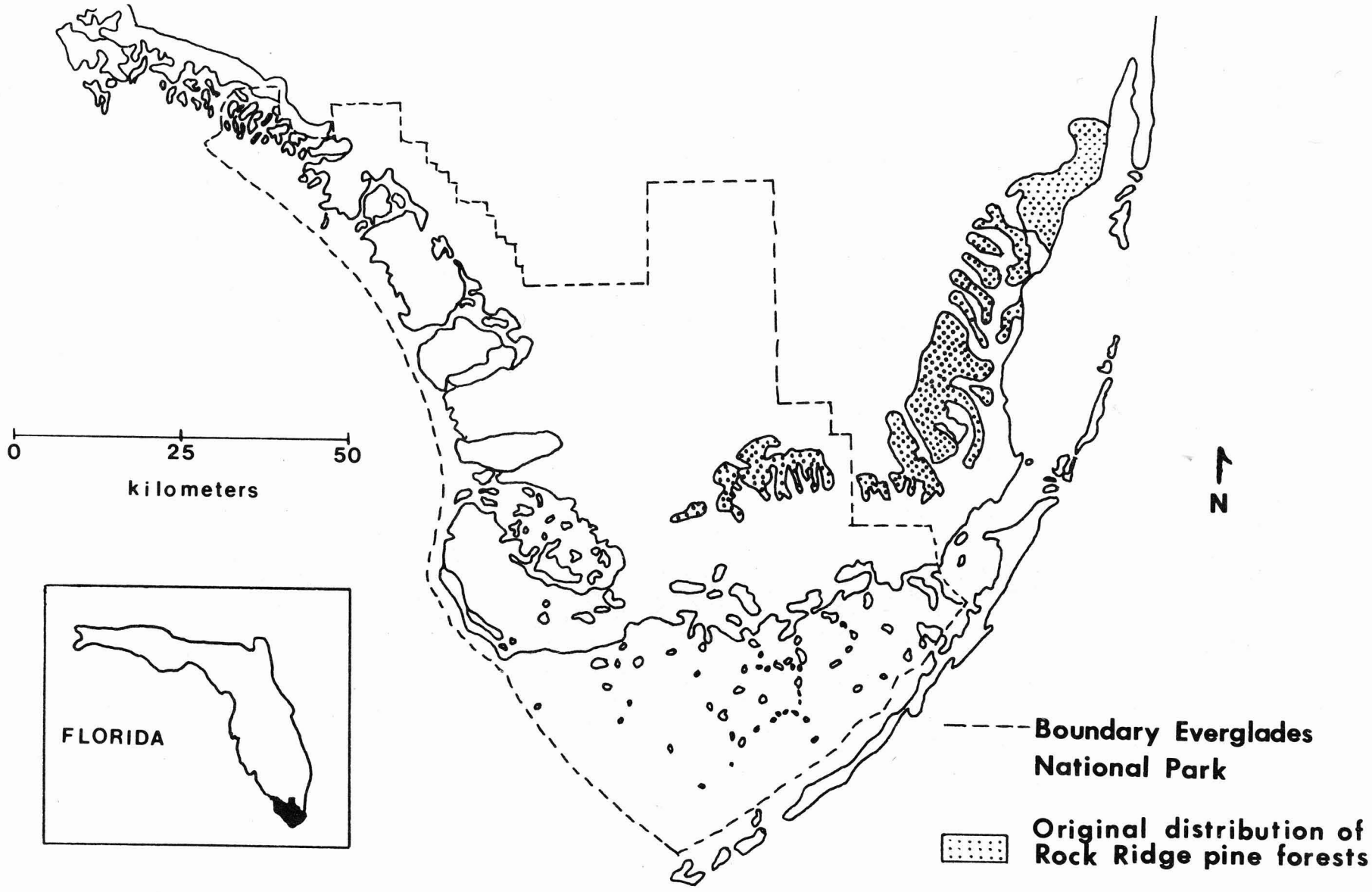

Figure 1. Distribution of rock ridge pine forests in South Florida.

Schinus is currently widely recognized as a menace to natural ecosystems of South Florida as well as to human health (Morton, 1979). It becomes dominant on abandoned farmlands or other disturbed sites throughout Dade County within 5-15 years of abandonment. These stands on disturbed sites provide an abundant seed source for invasion of nearby rockland pine forests.

Ewel, Ojima, and DeBusk (1979) have characterized the ecology of Schinus in southern Florida as follows:

> ". . . Schinus has many characteristics typical of other weedy pioneer species. It grows rapidly, it is a prolific seed producer, its foliage flushes nearly continuously, it coppices vigorously, and it tolerates a wide range of sites. As a weed tree, however, it is nearly unique in terms of the broad spectrum of characteristics that it possesses which are more typical of mature ecosystem species. It produces large, animal-dispersed seeds, its large cotyledons aid seedling survival, it is dioecious and insect-pollinated, its seedlings are remarkably shade tolerant, and its reproductive activity is synchronous and compressed into an extremely short period."

A related factor threatening rockland pine forests outside Everglades National Park is a sporadic fire regime which often allows native hardwoods and Schinus to shade out the herbaceous understory. Within Everglades National Park, prescribed burning has maintained favorable conditions for pine forest understory and is believed to be the factor suppressing establishment of Schinus.

This paper reviews the nature of Miami rockland pine forest vegetation, quantifies the impact of Schinus invasion and fire exclusion on representative stands of this vegetation type, and explores future prospects for preservation of pine forest vegetation and flora. Nomenclature used follows Avery and Loope (1980a) and Long and Lakela (1971) in most instances.

PAST WORK ON MIAMI ROCKLAND PINE FORESTS

Robertson (1955) reviewed early accounts of South Florida pine forests, citing writings by Bessey (1911, p. 268), Harshberger (1914, pp. 87-98), Simpson (1920, Chapter 8), Harper (1927, pp. 90-92, 176-179), Davis (1943, pp. 160-166), and the many writings of Small (1911, p. 151), who made one of the earliest assessments of fire effects in South Florida pinelands, stating that "the vegetation of the burned areas is restored after the rains begin again and all the plants that grew there before seem to re-appear." Small (1929 and other writings) strongly felt, however, that South Florida vegetation, pine forests included, was being rapidly destroyed by repeated fires set first by Indians, later by white men, and that fire effects were becoming increasingly severe following installation of drainage canals. Beard (1938) believed it likely that before the introduction of fires to South Florida by man's activity, "the Everglades Keys were once all hammock growth with intervening sawgrass glade lands."

Robertson (1953, 1955) described South Florida pine forest vegetation in much greater detail than has been provided before or since and articulated the essential ecological role of fire in maintaining these forests. Robertson's work eventually led to implementation of prescribed burning of pine forests in Everglades National Park. Robertson recognized the presence of a considerable number of endemic taxa in the flora of South Florida pine forests as well as the strong similarities between the pine forest vegetation of the larger islands of the Bahamas and that of South Florida.

Craighead (1971, 1974) provided descriptions of pine forest vegetation and of the dynamics of the hardwood hammock/pine forest ecotone. Hofstetter (1973) made management recommendations for implementation of prescribed burning in Everglades National Park pine forests, including the recommendation that a burning frequency of three to seven years be utilized. The Everglades National Park Fire Management Plan (Everglades National Park, 1979) provides background on fire history and management and details the current fire management program, which involves prescribed burning, surveillance of certain lightning and man-caused fires, and suppression of all fires under specified drought conditions.

Loope et al. (1979) recorded 186 taxa in eleven 40 m x 40 m quadrats scattered throughout the rockland pine forest both within and outside Everglades National Park. They found that of the 76 major pineland species (with mean frequency of .05 or greater in 1 m^2 quadrats), 17% are endemic to southern Florida with an additional 7% endemic to Florida; 47% have West Indian distributions; and 33% have northward (temperate) distributions. They found that substantial variation occurs from site to site within the rockland pine forests and that numerous rare species are not found within Everglades National Park.

Avery and Loope (1980b) determined that Miami rockland pine forest provides habitat for 32 endemic taxa, one-half of the endemic taxa of southern Florida. Of these 32, 17 are confined to this vegetation type. Only 8 of these 17 local endemics have fairly secure populations within Everglades National Park.

ECOLOGICAL ROLE OF FIRE IN ROCKLAND PINE FOREST AND RELATION TO TROPICAL HARDWOOD HAMMOCK VEGETATION

As pointed out above, largely based on Robertson's work, the rockland pine forests have been intensively managed by the National Park Service for the past 20 years utilizing prescribed fire at 3-7 year intervals. Fire maintains a diverse understory, preventing shading out of the numerous herbaceous species which resprout from underground parts following fire. Most individuals of hardwood tree species are killed back to the ground by each fire. In the 3 to 7 years between prescribed fires, they attain heights of 2-4 m. Virtually all species, both herbaceous and woody, normally resprout following fire. Numbers of individuals before and after fire are typically similar. We have observed little evidence of regeneration of pine forest species (with the notable exception of the exotic Schinus) from seed after prescribed fires, although many species quickly come into flower and fruit after fire. The mature pines, which regenerated after logging in the 1940's and currently

have attained diameters of 20-30 cm and heights of 15-20 m, are only rarely killed by prescribed fires, even though needle fall due to crown scorch is common. A possible problem with the existing prescribed fire regime is that young pines may not attain a large enough size in 3-7 years to survive fire. Less frequent but more severe fires, resulting in localized death of the pine overstory, may be required to obtain pine reproduction and perpetuation of this forest type. Lack of seedling establishment under the current fire regime may occur because all available favorable sites (with sufficient soil and/or crevices for root development) are held by mature plants which are able to survive intact or coppice following light fires.

Disjunct units of tropical hardwood forest, locally referred to as "hammocks," ranging from less than 1 ha to nearly 100 ha in size occur scattered within the matrix of pine forest vegetation. The underlying bedrock of hammocks is superficially very similar to that of the pine forest, but typically has larger solution holes and may be harder, perhaps due to solution and reprecipitation of calcium carbonate (Craighead, 1974). These hammocks normally have a 5-20 cm deep organic layer composed of litter in various stages of decomposition (Olmsted, Loope, and Hilsenbeck, 1980).

Hammocks of Long Pine Key are dominated by 5-7 tree species. Quercus virginiana and Lysiloma latisiliquum have the greatest basal area, whereas Nectandra coriacea, Coccoloba diversifolia, Bumelia salicifolia, Eugenia axillaris, and Metopium toxiferum have the greatest density and frequency (Olmsted, Loope, and Hilsenbeck, 1980). A total of about 40 tree species are present in the hammocks collectively. Most of these species have primarily West Indian distributions, with the live oak (Quercus virginiana) the only temperate species among the dominants. These include many of the same species which occur in the pine forest as fire-pruned shrubs as well as additional less fire-resistant species not found in the pineland. Relatively mature hammocks have a closed canopy at 6-10 m, with emergents to 17 m. The understory is rather open and ground cover is sparse, with few species.

The hammock canopy acts to modify the microclimate of the hammock interior. Compared to the adjacent pine forest, the hammock interior has low solar radiation, higher humidity, higher soil moisture, and more moderate temperatures (with extremes of 1-3^{o}C less than in pine forest, according to Robertson (1955) and Olmsted (unpublished)). Hammock-pine forest margins, characterized by a dense tangle of vegetation, are typically abrupt. Examination of aerial photography at intervals over the past 40 years shows that these margins have been remarkably stable. Frequent fire serves to maintain a stable hammock-pine forest ecotone and to counteract succession of pine forest vegetation to hammock-like vegetation. Fire rarely affects hammocks because of their high humidity and soil moisture and sparseness of combustible vegetative fuels. In the absence of fire for 15-25 years (Robertson, 1953), pineland vegetation develops into hammock-like vegetation with a 4-6 m canopy of hardwood trees under the emergent pines.

Table 1. Comparison of frequency and density values for understory species of a Schinus-invaded pine stand with those reported by Loope et al. (1979) for the nearby "Navy Wells" stand and mean values for species with .05 frequency or greater in 11 pineland sites in southeastern Florida. (F = forb or forb-like; G = graminoid; S = fire-pruned shrub or tree).

	Frequency (fraction of plots in which species is recorded)					Density (plants/100m^2)				
Species	Mean 11 Sites	Rank	Value for Schinus-dominated pineland	Value for Navy Wells pineland	Value for pineland without fire for 35 years	Mean 11 Sites	Rank	Value for Schinus-dominated pineland	Value for Navy Wells pineland	Value for pineland without fire for 35 years
Chiococca parvifolia (F)	.67	1	.55	1.00	-	1029	1	90	3655	-
*Dyschoriste oblongifolia (F)	.65	2	-	.10	-	338	2	-	10	-
*Phyllanthus pentaphyllus (F) var. floridanus	.65	3	.10	.30	-	314	5	10	40	-
Morinda royoc (F)	.47	4	.20	.35	.35	238	7	20	150	50
Andropogon cabanisii (G)	.44	5	-	.05	-	280	6	-	5	-
Anemia adiantifolia (F)	.42	6	.80	.35	.10	214	9	145	85	10
Borreria terminalis (F)	.40	7	-	.20	-	332	3	-	40	-
Guettarda scabra (S)	.39	8	.70	.85	.35	320	4	205	980	45
*Tragia saxicola (F)	.36	9	-	.85	-	128	14	-	175	-
Schizachyrium sanguineum (G)	.35	10	-	.35	-	184	11	-	135	-
*Chamaesyce porteriana (F)	.31	11	-	.05	-	126	15	-	10	-
*Dichromena floridensis (G)	.30	12	.05	.35	-	145	12	5	150	-
*Schizachyrium rhizomatum (G)	.30	12	-	-	-	232	8	-	-	-

Species	Frequency (fraction of plots in which species is recorded)					Density (plants/100m^2)				
	Mean 11 Sites	Rank	Value for Schinus-dominated pineland	Value for Navy Wells pineland	Value for pineland without fire for 35 years	Mean 11 Sites	Rank	Value for Schinus-dominated pineland	Value for Navy Wells pineland	Value for pineland without fire for 35 years
Paspalum setaceum (G)	.30	14	0	.20	-	76	21	-	25	-
Acalypha chamaedrifolia (F)	.29	15	-	.95	-	70	22	-	300	-
Passiflora suberosa (F)	.29	15	-	.15	-	52	31	P	20	-
Muhlenbergia filipes (G)	.28	17	-	-	-	140	13	-	-	-
Sorghastrum secundum (G)	.26	18	-	.25	-	99	19	-	35	-
Randia aculeata (S)	.25	19	.05	.15	-	100	18	5	145	P
Piriqueta caroliniana (F)	.25	20	-	.15	-	64	24	-	25	-
Solidago stricta (F)	.24	21	-	-	-	55	29	-	-	-
Hedyotis nigricans (F)	.21	22	.10	-	-	198	10	10	P	-
Physalis viscosa (F)	.21	22	-	.10	-	52	31	-	10	-
Mikania scandens (F)	.21	24	-	-	-	111	16	-	-	-
Myrsine floridana (S)	.21	24	.95	-	.20	52	31	310	-	25
Angadenia sagraei (F)	.21	24	-	.25	-	44	37	-	40	-
Ayenia euphrasiifolia (F)	.20	27	.10	.55	-	102	17	15	160	-
Serenoa repens (S)	.18	28	.25	.10	.05	31	43	5	25	10

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Pteridium aquilinum var. caudatum (F)	.18	29	-	35	.05	69	23	P	50	5
Metopium toxiferum (S)	.17	30	.30	.45	.40	63	26	30	45	70
Hyptis alata var. stenophylla (F)	.17	30	-	-	-	39	30	-	-	-
Aristida spp. (G)	.17	-	-	-	-	45	-	-	-	-
Rhus copallina (S)	.16	32	-	-	-	47	36	-	-	-
Cassia deeringiana (F)	.15	33	-	.20	-	49	35	-	30	-
Dodonea viscosa (S)	.15	34	-	-	-	94	20	-	-	-
*Chamaesyce pinetorum (F)	.15	34	-	.20	-	40	38	-	55	-
Cassytha filiformis (F)	.15	34	-	-	-	37	40	-	-	-
Ruellia caroliniensis (F)	.15	34	-	.05	-	33	41	-	5	-
Galactia (F) (incl. G. pinetorum)	.15	-	-	-	-	46	-	-	-	-
Cynoctonum sessifolium (F)	.14	38	-	-	-	33	41	-	-	-
Sachsia polycephala (F)	.14	38	-	-	-	59	26	-	P	-
Agalinis fasciculata (F)	.14	40	-	-	-	22	50	-	-	-
*Tripsacum floridanum (G)	.13	41	-	.05	-	31	43	-	10	-

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Bumelia salicifolia (S)	.12	42	-	-	.15	20	54	P	-	15
Cladium jamaicense (G)	.12	42	-	-	-	55	29	-	-	-
*Jacquemontia curtissii (F)	.12	44	-	-	-	21	52	-	-	-
Polygala grandiflora (F)	.11	45	-	-	-	17	62	-	-	-
Pteris longifolia (F)	.11	45	.10	-	-	31	43	15	P	-
Croton linearis (F)	.11	45	-	.10	-	15	65	-	25	-
Pinus elliottii var. densa (S)	.11	45	-	.05	-	12	69	P	5	P
Sabal palmetto (S)	.10	49	-	-	.05	13	68	-	P	5
Crotalaria pumila (F)	.10	49	-	.10	-	20	54	-	20	-
Smilax auriculata (F)	.10	49	-	-	-	27	46	-	-	-
Samolus ebracteatus (F)	.10	52	-	-	-	50	34	-	-	-
Heterotheca graminifolia var. tracyi (F)	.10	53	-	-	-	64	24	-	-	-
*Poinsettia pinetorum (F)	.09	54	-	.05	-	20	54	-	5	-
Coccothrinax argentata (S)	.09	55	.10	.10	-	20	54	10	10	-
Aster dumosus (F)	.09	55	-	-	-	22	50	-	-	-

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Coreopsis leavenworthii (F)	.08	57	-	-	-	57	28	-	-	-
Guettarda elliptica (S)	.08	57	-	-	-	21	52	P	-	-
*Melanthera parvifolia (F)	.08	57	-	.10	-	23	48	-	15	-
Heliotropium polyphyllum (F)	.08	57	-	-	-	20	54	-	-	-
Evolvulus sericeus (F)	.08	57	-	-	-	25	47	-	-	-
Eupatorium villosum (F)	.07	62	-	.05	-	23	48	-	5	-
Ardisia escallonioides (S)	.07	63	.05	-	-	20	54	5	P	P
Aster adnatus (F)	.07	63	-	.10	-	11	70	-	15	-
Rhynchosia reniformis (F)	.07	63	-	.15	-	16	63	-	20	-
Rhynchospora spp. (G)	.07	-	-	-	-	23	-	-	-	-
Sporobolus junceus (G)	.06	66	-	-	-	18	60	-	-	-
Echites umbellata (F)	.06	66	-	-	-	9	71	-	-	-
Ipomoea tenuissima (F)	.06	66	-	-	-	16	63	-	-	-
Crossopetalum ilicifolium (S)	.06	69	-	.10	-	15	65	-	15	-
Zamia pumila (F)	.05	70	.35	.05	.30	9	71	20	5	35
Liatris gracilis (F)	.05	70	-	-	-	18	60	-	-	-

Species	Frequency (fraction of plots in which species is recorded) Mean 11 Sites	Rank	Value for Schinus-dominated pineland	Value for Navy Wells pineland	Value for pineland without fire for 35 years	Density (plants/100m^2) Mean 11 Sites	Rank	Value for Schinus-dominated pineland	Value for Navy Wells pineland	Value for pineland without fire for 35 years
Liatris gracilis (F)	.05	70	-	-	-	18	60	-	-	-
Phyllanthus caroliniensis (F)	.05	70	-	-	-	7	73	-	-	-
*Lantana depressa (F)	.05	73	-	.05	-	7	73	-	5	-
Psidium longipes (S)	.05	74	-	-	-	7	73	-	-	-
Byrsonima lucida (S)	.05	74	-	-	-	6	76	-	P	-
Pluchea rosea (F)	.05	74	-	-	-	15	65	-	-	-

* = these species are considered endemic to South Florida by Avery and Loope (1980b).

P = recorded present within the 40m x 40m macroplot

Additional species for Schinus-invaded pineland: Baccharis glomeruliflora (S, frequency-.25, density/100m^2-40), Chiococca alba (F,.10,15), Eugenia axillaris (S,.05,15), Ficus aurea (S,P), Galium hispidulum (F,.05, 5), Ilex krugiana (S,.05, 5), Lantana camara (S,P), Lantana involucrata (S,P), Myrica cerifera (S,P), Parthenocissus quinquefolia (F,.40, 55), Psychotria nervosa (S,.10, 10), Rhus copallina (S,.05, 5), Schinus terebinthifolius (S,.85, 245), Smilax havanensis (F,.10, 10), Tetrazygia bicolor (S,.35, 45), Toxicodendron radicans (F,.80, 165), Vitis munsoniana (F,.10, 10).

Additional species for pineland without fire for 35 years: Bursera simaruba (S, frequency-.05, density/100m^2-5), Chiococca alba (F,.05, 10), Citharexylum fruticosum (S,.05, 5), Eugenia axillaris (S,.20, 20), Exothea paniculata (S,P), Ficus citrifolia (S,P), Galium hispidulum (F,.05, 5), Ilex cassine (S,P), Myrica cerifera (S,.15, 30), Nectandra coriacea (S,P), Parthenocissus quinquefolia (F,.10, 10), Persea borbonia (S,.40, 70), Psychotria nervosa (S,.35, 50), Psychotria sulzneri (S,P), Quercus virginiana (S,.15, 20), Simarouba glauca (S,.05, 5), Smilax bona-nox (F,.50, 65), Tetrazygia bicolor (S,P), Tillandsia flexuosa (P), Toxicodendron radicans (F,P), Vitis munsoniana (F,.15, 20).

Table 2. Height structure within 300m^2 of Schinus-dominated pine forest site near Homestead, Florida. Heights are given for all individuals of all species 2m tall or taller.

SPECIES	HEIGHT CLASS (meters)																			TOTAL
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Ardisia escallonioides	3	1		2																6
Baccharis glomeruliflora	1																			1
Bumelia salicifolia			1	1	1	1	3													7
Bursera simaruba																				0
Eugenia axillaris																				0
Ficus citrifolia						3														3
Guettarda elliptica	1																			1
Guettarda scabra	23	6	5	1																35
Ilex cassine																				0
Ilex krugiana	1																			1
Lantana involucrata	1																			1
Lysiloma latisiliquum																				0
Metopium toxiferum	1																			1
Myrica cerifera																				0
Myrsine floridana	13	14	20	4	3	3														57

SPECIES	HEIGHT CLASS (meters)																			TOTAL
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Pinus elliottii var. densa	1	1	1	2		4	3	1	1	1	2	1	2	4	3	1				28
Quercus virginiana																				0
Rhus copallina		1																		1
Sabal palmetto																				0
Schinus terebinthifolius	3	13	30	29	13	5														93
Serenoa repens	4																			4
Tetrazygia bicolor	6	10	9	1	1															27
Total																				266

Table 3. Height structure within 300m^2 of pine forest site within Everglades National Park unburned for 35 years. Heights are given for all individuals of all species 2m tall or taller.

SPECIES	HEIGHT CLASS (meters)																			TOTAL
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Ardisia escallonioides		1																		1
Baccharis glomeruliflora																				0
Bumelia salicifolia	2	3	5	4	2	3	5	3			1									28
Bursera simaruba											1									1
Eugenia axillaris	1	3	4	9	2															19
Ficus citrifolia		2	1	2																5
Guettarda elliptica																				0
Guettarda scabra	10	17	6																	33
Ilex cassine		1			2	1														4
Ilex krugiana			1	2		1	1													5
Lantana involucrata																				0
Lysiloma latisiliquum						1	1			2		1								5
Metopium toxiferum		2	6	3	7	8	12	9	4		1									52
Myrica cerifera	1	1	1	1																4
Myrsine floridana	1	7	5	5		2	1													21

SPECIES	HEIGHT CLASS (meters)																			TOTAL
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Pinus elliottii var. densa												3	1	1	2	3	1		1	12
Quercus virginiana		1	3		1	2	1		1											9
Rhus copallina																				0
Sabal palmetto	3	3																		6
Schinus terebinthifolius																				0
Serenoa repens																				0
Tetrazygia bicolor		1	3	2	5	1														12
Total																				217

METHODS AND RESULTS

Potential impacts of Schinus invasion and fire exclusion

After a reconnaissance of pine stands outside Everglades National Park, a study site was selected which was easily accessible, had as dense a growth of Schinus as observed anywhere, and was located near a pine forest without Schinus invasion in the state-owned Navy Wells stand, in which understory data had been collected in a previous study. This study site was located within the central portion of a pine stand located in the southwest quadrant of T57S R36E Section 35. This is the only remaining pine stand in this quadrant and covers about 4 ha. For convenience, we refer to this stand below as the "Schinus-invaded pine stand."

Sampling of the understory and pines was carried out using methods identical to those of Loope et al. (1979), which had been applied to pine forest within Navy Wells Pineland Preserve, under the jurisdiction of the Metropolitan Dade County Parks Department. That stand was located in the southwest quadrant of T57 R38E Section 26. In both instances, one 40 m x 40 m macroplot was used, within which a complete list of vascular plant species was compiled. Along opposite margins of the 40 m x 40 m macroplot, ten 1 m^2 quadrats were placed at 4 m intervals, making a total of twenty 1 m^2 quadrats, in which all individuals of all vascular plant species were counted.

Table 1 compares frequency and density values for understory species of the Schinus-invaded pine stand with those reported from the nearby Navy Wells stand and mean values for the 76 most frequent species at 11 pineland sites (including Navy Wells) in southeastern Florida reported by Loope et al. (1979). Of the 76 most frequent pineland species in Dade County, the Schinus-invaded stand had only 20, whereas the nearby Navy Wells stand had 45. Total species numbers for the 40 m x 40 m macroplots were as follows: Schinus-invaded stand, 39; Navy Wells stand, 70; 10 other stands in Dade County sampled by Loope et al. (1979), 69-91.

Sampling of the height structure of the tree vegetation was carried out using methods comparable to those used in tropical hardwood hammock vegetation by Olmsted, Loope, and Hilsenbeck (1980). Three 5 m x 20 m plots were established at representative locations within the 40 m x 40 m macroplot. Within the 5 m x 20 m plots, all specimens of all species taller than 2 m were recorded, and their height was measured.

Table 2 gives the height structure of the Schinus-dominated pine stand. Note that Schinus comprises 40% of the trees 2 m and over and 66% of the trees 5 m tall and over.

Impact of fire exclusion without Schinus

For comparison of height structure of tree vegetation of a long-unburned pine stand without Schinus with the Schinus-invaded stand, a site was chosen within the most extensive area (about 3 hectares) of Long Pine Key in Everglades National Park which has escaped fire for about 35 years. This site is located just east of a road intersection at the NW corner of the NW quadrant of T58S R38E Sect. 22, just west of the hammock known as "Palma Vista" (Craighead, 1974) (Fig. 2). According

Table 4. Mean numbers of Schinus individuals present by height class per $100m^2$ recorded in transects 50m long and 5m wide. Blocks designated plot locations within fire management units shown in Figure 1. Numbers of transects per block given in parentheses.

	Sampling Location Block						
Size Class	M(5)	A(2)	B(1)	I(4)	T2(2)	J(3)	F(2)
0.5-2.0m	2.7	2.8	2.0	0.8	1.0	0	0
2.1-5.0m	0.4	0.6	1.2	0.2	0.8	0	0.2
5.0m	0	0.4	0	0	0.2	0	0
TOTAL	3.1	3.2	3.2	1.0	2.0	0	0.2

Table 5. Percentage of Schinus trees resprouting six months after the fire of November 5, 1979. Block Y, Everglades National Park.

Prefire size class (measured on 11/17/78).	Total Schinus surveyed, pre-fire	Schinus Resprouting	
		Number	Percentage of total surveyed
0-.9m	10	3	30%
1.0-1.9m	16	14	88%
2.0-2.9m	13	11	85%
3.0-4.0m	11	11	100%
TOTAL	50	39	78%

Table 6. Growth rates of post-fire sprouts of selected hardwood species in pineland understory, 11/5/79 - 6/11/80, Block Y, Everglades National Park.

Species	Mean height (cm)	N	Mean growth per 30 days (cm)	% of plants with multiple sprouts
Ardisia escallonioides	54.3	6	7.4	100
Baccharis glomeruliflora	79.7	9	10.9	89
Guettarda scabra	36.0	2	4.9	100
Metopium toxiferum	43.2	9	5.9	78
Myrica cerifera	130.4	8	17.9	100
Myrsine floridana	48.5	6	6.6	50
Persea borbonia	54.6	5	7.5	80
Rhus copallina	91.9	19	12.6	63
Tetrazygia bicolor	43.5	11	6.0	100
Trema micranthum	94.7	3	13.0	100

Table 7. Recovery of Schinus (absolute numbers of individuals) after fire by size classes, 1/11/80, Long Pine Key Campground, Everglades National Park. Fire occurred on 10/29/79.

Size Class	# of plants in sample	# with no green leaves	# with some branches not fire-killed	#top sprouting only	# sprouting only at base	# with both top and base sprouting
L 2m	7	2	1	0	4	1
2-5m	35		7	1	22	8
5m	13	2	3	1	5	5
TOTAL	55	4	11	2	31	14

to W. B. Robertson (personal communication), this pine stand probably last burned in 1945.

Sampling methods were identical to those used for the Schinus-invaded pine stand. Results are given in Tables 1 and 3.

Table 1 shows that only 34 species were present in the 40 m x 40 m macroplot. Of these, only 13 are among the 75 most characteristic species of Miami rockland pine forests. Virtually all the characteristic herbaceous pine forest understory species have been lost after 35 years without fire. Table 3 shows that the population structure of the stand is approaching that of tropical hardwood forests of this part of Everglades National Park, as described by Olmsted, Loope, and Hilsenbeck (1980).

Schinus occurrence in pine forests of Everglades National Park

Although Schinus is locally abundant in remnant pine stands of Dade County outside Everglades National Park, this exotic species is not present in large numbers in pine stands of the park in spite of the presence of adjacent seed sources. We conducted a survey of Schinus abundance in pine stands of the Long Pine Key area of Everglades National Park in January 1980. In a preliminary broad survey, we concluded that negligible Schinus numbers were present away from margins of pine forests adjoining successional vegetation on abandoned farmland which included fruiting Schinus. In order to quantify maximum current densities and establish baseline data for future comparisions, we established nineteen 5 m x 50 m transects perpendicular to pine forest margins at locations along the southern and eastern edge of the pine forest area of Everglades National Park. Within these 5 m x 50 m transects, all individuals of Schinus over 0.5 m tall were mapped using three size classes: 0.5 m-2.0 m; 2.1 m-5.0 m; and > 5.1 m. Seedlings (< 0.5 m tall) were counted.

Baseline data and exact plot locations are recorded in plant ecology files at the South Florida Research Center, Everglades National Park. Summary data for Schinus numbers per 100 m^2 for the areas sampled are given in Table 4. Mean densities range from 0 to 3.2/100 m^2. Note that the Schinus dominated pine stand sampled outside the park had 31 Schinus plants/100 m^2 in 2 m or greater size classes.

Effect of fire on Schinus in pine forests

In order to assess the effects of fire on Schinus in pine forests of southeastern Florida, we took advantage of prescribed burns carried out by Everglades National Park personnel in October and November of 1979. Three separate opportunities for evaluation of fire effects were utilized, as follows:

1. On November 17, 1978, 55 Schinus trees up to nearly 4 m in height were identified and labelled in a pine forest (Block Y, Fig. 2), at the east boundary

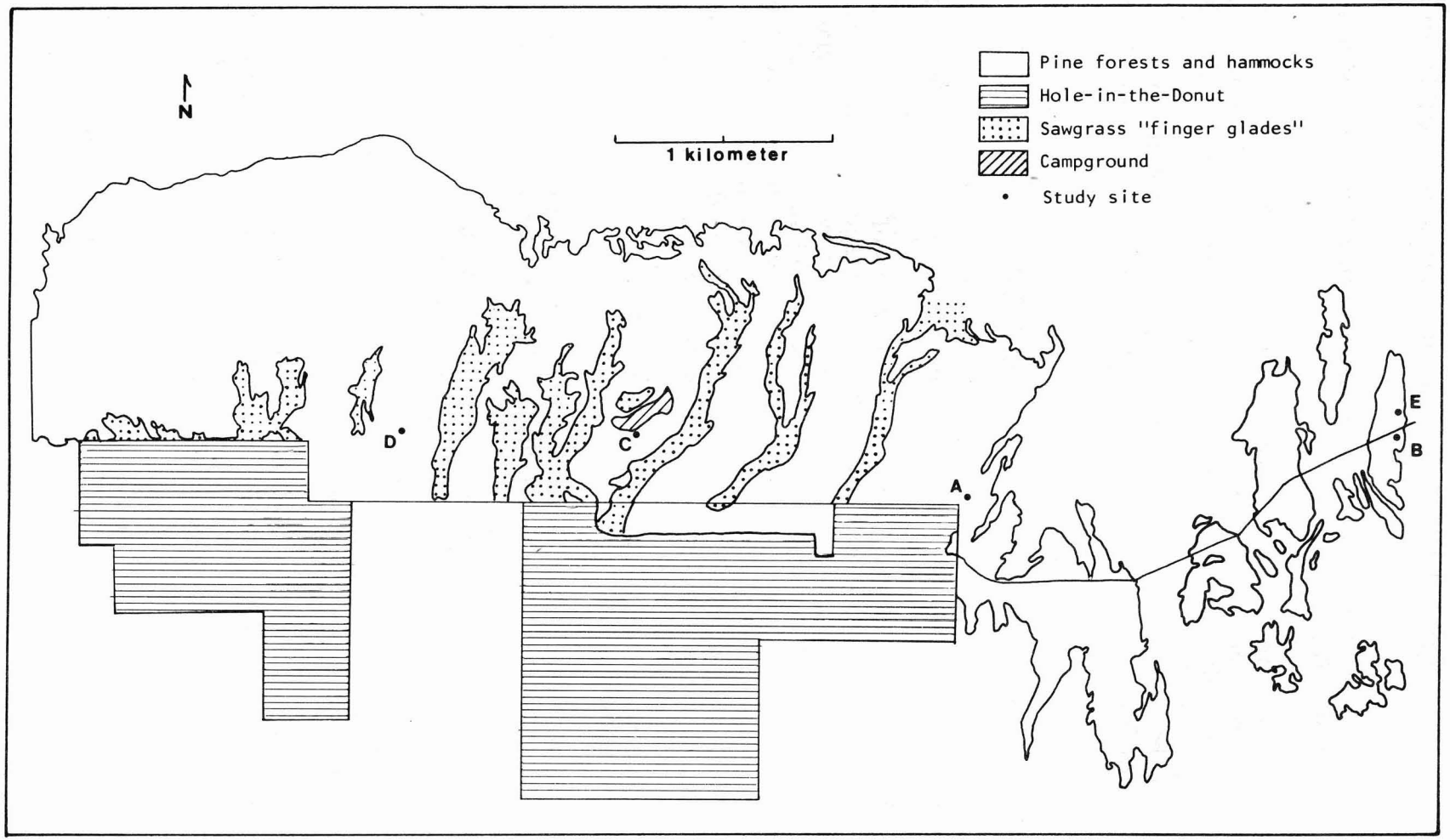

Figure 2. Location of study areas in Everglades National Park pine forests. The two study areas outside the park are not shown. Sites correspond to studies as follows: A, impact of fire exclusion without Schinus; B, C, and D, effect of fire on Schinus in pine forests, parts 1,2, and 3, respectively; and E, growth rates of Schinus seedlings.

of Everglades National Park, where the greatest amount of Schinus invasion within pinelands of the park occurs. The number of stems originating from the base of each tree and its height were recorded. The area was burned on November 5, 1979, killing the aerial portions of all Schinus plants. Fifty of the trees were relocated on December 10. The number of new sprouts at the base of each plant and the height of the tallest sprout per plant were recorded. Two additional surveys of the 50 trees were made on January 9 and May 5, 1980.

All Schinus plants were initially killed back to the ground, but 78% eventually resprouted. Percentage recovery by size classes is shown in Table 5. The pre-burn height of the smallest tree not completely killed by the fire was 0.58 m. Only 30% of plants less than 1 m tall a year before the fire survived. Within 6 months after the fire, sprouts on 6 of the surviving trees exceeded 1 m in height. Shoot growth of resprouting Schinus averaged 14.3 cm per month. Although height of Schinus was temporarily reduced, the number of stems increased, since multiple sprouting frequently occurred from the base of single stems killed by fire.

Heights of the new sprouts of fire-killed individuals of the major native tree species at the same site were measured on June 11, 1980, and growth rates were calculated. These are given in Table 6. Myrica cerifera is the only species with a growth rate exceeding that of Schinus. Weedy species--Baccharis glomeruliflora, Rhus copallina, and Trema micranthum--also had high growth rates, but some of the normal dominant fire-pruned trees of native pineland understories (Guettarda, Metopium, Myrsine, Persea, Tetrazygia, Ardisia) had shoot growth rates between one-third and one-half that of Schinus.

2. Prescribed fire was applied to the pine forest southeast of Long Pine Key Campground (Fig. 2) on October 29, 1979. According to personnel observing this fire, it burned exceptionally hot up to the ecotone with the campground where numerous large Schinus trees grew. Fifty-five of these Schinus trees along the ecotone were assessed on December 12 and January 11 for recovery from the fire.

   Results of the January 11 survey are presented in Table 7. Although 80% of the trees were completely defoliated by the fire, only 13% were apparently dead in January. Resprouting from aerial portions of the tree occurred in 29% of the individuals.

3. On November 29, 1979, prescribed fire burned an area of pine forest where experimental plantings of Schinus seedlings had been made the previous year (Fig. 2) as part of a 3-year study of Schinus ecology being carried out by Dr. Jack Ewel and colleagues, of the University of Florida. Dr. Ewel made his data available to us. The seedlings had been germinated and grown in small tubes to a height of 12 to 44 cm. Between September, 1978, and August, 1979, 48 seedlings were planted at the pine forest site. On October 22, 1979, 35 seedlings survived, with heights of 12-57 cm. On January 4, 1980, 36 days after the fire, mortality appeared complete.

Table 8. Numbers of Schinus seedlings by pre-fire height classes before and after a prescribed fire. Fire occurred on November 29, 1979. Data courtesy Dr. J. Ewel.

Height Class on Oct. 22	# Individuals on Oct. 22 (before fire)	# Individuals resprouting on April 7 (127 days after fire)
0-10 cm	0	0
10-20 cm	10	0
20-30 cm	7	0
30-40 cm	11	5
40-50 cm	3	1
50-60 cm	4	1

Table 9. Summary of data on growth rates of Schinus seedlings monitored over an 11-month period from 12/13/79 to 11/25/80 (N = 64).

87% showed positive growth

13% showed no height growth, negative growth, or died

mean height growth for all seedlings = 0.41 cm/month

mean height growth for seedlings showing gain in height = .56 cm/month (N = 52)

% of seedlings with height growth of 1.0 cm/month or greater = 6%

% of seedlings with height growth of 1.5 cm/month or greater = 3%

maximum growth rate recorded = 2.0 cm/month

However, on April 7, 7 seedlings (20%) were found to have resprouted. Results by height classes are shown in Table 8. The smallest seedling which resprouted was 30 cm tall prior to the fire.

Growth rates and densities of Schinus seedlings

The data presented above suggest that Schinus seedlings as small as 30 cm tall may survive fire in some instances. For seedlings 30-100 cm tall, mortality was 30-40% in the instances for which we have data. Once a height of 1 m is attained, probability of survival of fire appears to be very high--perhaps 80-90%. In order to determine how long it might take Schinus seedlings to reach this height in the relatively nutrient-poor pineland environment, we monitored tagged Schinus seedlings from December 13, 1979 to November 25, 1980. These seedlings were growing in a moderately open pine understory (Fig. 2) last burned in December 1976, under fruiting individuals of Schinus. Most seedlings were under 30 cm in height and their ages were unknown.

A summary of results is given in Table 9. Growth rates averaged 0.41 cm/month for all seedlings and 0.56 cm/month for the 87% of the seedlings which showed positive growth. The latter growth rate is equivalent to about 7 cm per year if growth rates can be assumed to be similar throughout the year. However, growth rates were markedly greater in some instances, presumably in extremely favorable sites. For 1 of the 64 seedlings, a growth rate of 2 cm/month, equivalent to 24 cm/year, was obtained.

In order to obtain an impression of short-term population trends of Schinus seedlings, their densities under fruiting "parent" trees at the same site were monitored on the same dates as seedling heights were measured. Circular plots with a 1.8 m radius around the central stem of each fruiting Schinus were utilized to count number of Schinus individuals 50 cm in height (seedlings) and those 50 cm in height (samplings). Results are given in Table 10.

DISCUSSION

Fire exclusion alone results in establishment of a tropical hardwood hammock-like understory in rockland pine forest. In a pine forest burned at intervals of about 5 years, hardwood shrubs rarely exceed 3 m in height. In the pine stand unburned for 35 years, tropical hardwoods have established a dense growth at 3-8 m, with emergents reaching as high as 12-13 m (in the case of Metopium, Bumelia, and Lysiloma). Shading by hardwoods, as well as the effects of accumulation of pine litter 20-70 cm thick, has resulted in the loss of virtually all herbaceous species characteristic of rockland pine forest vegetation.

When Schinus is able to establish in rockland pine stands, it has the potential for coming to dominate the understory, since it grows more rapidly than competing native hardwood species. This is well-illustrated by the stand sampled in which Schinus comprises 40% of the trees 2 m tall and over and 66% of the trees 5 m tall

Table 10. Schinus seedling densities (number of individuals in 10.2 m^2 plots) under ten fruiting "parent" trees in a pine forest. The first number in each pair represents the number of seedlings < 50 cm tall and the second number of seedlings ≥ 50 cm tall. The data were collected in 1979-1980.

Tree Designation	Date Dec. 13	March 18	June 10	Nov. 25
A	33/3	45/5	38/3	46/3
B	92/0	95/1	105/0	126/0
C	28/5	29/4	33/4	40/5
D	44/0	61/0	40/1	59/0
E	55/0	67/0	58/0	60/0
F	46/7	53/5	54/2	52/2
G	6/2	9/3	6/2	7/2
H	18/2	18/2	19/0	11/1
I	10/2	11/1	9/2	5/1
J	39/2	35/1	42/1	42/2
Total	371/23	423/22	404/15	448/16

and over. Once Schinus saplings attain a height of 1 m, most are able to survive fire by coppicing and, through more rapid growth than competing native hardwoods, increase dominance of the stand. Once Schinus becomes dominant, it is doubtful that pine regeneration will be possible and that a species-rich herbaceous understory can be maintained.

The rockland pine forests of Everglades National Park are largely free of Schinus, even though an abundant seed source is present nearby on abandoned agricultural land. This may be because Schinus seedlings require several years after germination in rockland pine forest to reach a size capable of surviving fire. As is illustrated by our Schinus seedling density site (Table 10), seedlings may become established abundantly in a pineland between fires in the immediate vicinity of a seed source. This site, unburned since December 1976, supported up to 126 seedlings per 10 m^2 under the relatively few female Schinus trees which have been established in the area since at least the early 1970's (c.f., Hilsenbeck, 1972). We predict that these young Schinus plants will be largely eliminated in the next prescribed fire (scheduled for late 1981).

With a regime of prescribed burning at about 5 year intervals, it may be possible to largely exclude Schinus from pine forests of Everglades National Park. The fire regime which may eventually be required to allow pine regeneration, involving less frequent but more severe fires as the pine stand approaches old age, may result in accelerated Schinus invasion. If so, use of herbicides on Schinus may be necessary during this phase. Much additional research is needed to fine tune management of fire and Schinus in Everglades pinelands.

The importance of maintenance of pine forests to preservation of numerous rare plant species within Everglades National Park has been emphasized by Loope and Avery (1979). Some of these rare species have been classified as "Endangered" or "Threatened" within Florida (Ward, 1979).

As documented by Loope et al. (1979) substantial variation occurs from site to site within the limestone rockland pine forests of southeastern Florida. Much of this variation has already undoubtedly been lost through the destruction of about 80% of the original habitat. The islands of pineland that remain in Dade County outside Everglades National Park, both with rockland substrate and sandy soil over rockland, are extremely important to efforts aimed at preservation of biological diversity in South Florida. Survival of the following endemic plant taxa is entirely dependent upon preservation of this habitat: Amorpha crenulata, Aster concolor var. simulatus, Brickellia mosieri, Chamaesyce deltoidea var. deltoidea, Chamaesyce deltoidea var. adhaerens, Galactia prostrata, Polygala smallii, and Tephrosia angustissima. In addition, a major segment of the remaining United States populations of the following species are found in these pinelands: Alvaradoa amorphoides, Argythamnia blodgettii, Bourreria cassinifolia, Ernodea littoralis var. angusta, and Verbena maritima.

Loope et al. (1979) found that in most of the few remnant pine stands in Dade County, Florida, lack of adequate fire management seriously threatens long-term viabi. ty of the pineland habitat. Invasion of the exotic Schinus adds substantially to this threat. Within Everglades National Park, the pinelands are presumably safe

from development, but require continual refining of fire management, giving special attention to eventually ensuring pine regeneration and to excluding Schinus.

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