Comparison of Economic Feasibility of Chemical Control Strategies on Differing Age and Density Classes of *Schinus terebinthifolius*

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ABSTRACT: *Schinus terebinthifolius* (Brazilian pepper), which is native to Brazil has become an aggressive, woody weed in southern Florida, displacing native vegetation and rapidly invading disturbed sites. Studies on the effective use of herbicides to control *S. terebinthifolius* began in 1982. Concurrent studies on the labor, time, and costs of controlling *S. terebinthifolius* with herbicides were begun to determine the cost criteria for future implementation of *S. terebinthifolius* management programs. Comparisons were made between different age and density classes and between matricide and complete control strategies. Stand structure was also evaluated. The numbers of trees and stems and the amount of herbaceous cover varied according to age and density of the stand. The young successional sites averaged 1453 stems/ha and 44.7 cm understory height compared with the most dense sites averaging 11,355 stems/ha and less than 14 cm understory height. Costs were directly related to the numbers of trees and stems per unit area. Principal costs resulted from labor, not herbicide, and did not vary significantly between matricide or complete control treatment strategies.

INTRODUCTION

The remarkable vegetation of southern Florida has fascinated scientists and naturalists since its discovery and was a primary reason for the establishment of Everglades National Park. One cause of this fascination is the presence of a high percentage of West Indian species. Of approximately 1600 species of vascular plants in Dade, Monroe, and Collier counties, Florida (Figure 1) 60 to 70 percent have tropical affinities (Small 1904, Long 1974, Little 1978, Tomlinson 1980).

Plant communities and individual taxa of south Florida have proven extremely vulnerable to disturbance from human activities. Although the area was settled late, compared to most eastern states, and was in a near pristine condition prior to 1900, changes occurred rapidly in the early decades of the twentieth century (Small 1929). This deterioration has continued, through agriculture, urbanization, drainage, deliberate and accidental burning, and introduction of exotic plant species.

Exotic plants pose the greatest long-term threat to the integrity of Everglades' ecosystems today. Two hundred and seventeen species of introduced plants are known to occur in Everglades National Park (Whiteaker and Doren in prep.). One of the major areas of exotic plant invasion within the park is a 4000-ha area of former agricultural land known as the 'Hole-in-the-Donut' (Figure 2).

Early farming took place on existing deep marl and peat sediments. In the 1950's rock plowing (which crushes the native surficial limestone substrate) was developed to produce a soil better suited for crops than the existing substrate (Ewel et al. 1982). This pedogenesis changed the area from primarily low nutrient, anaerobic soil conditions to higher nutrient, aerobic soil conditions that are more favorable for exotic plants (Gerrish and Mueller-Dombois 1980, Bridgewater and Backshall 1981). Rock plowing continued in the 'Hole-in-the-Donut' area through 1975, by which time approximately 2000 ha of land had been rock plowed. The 2000 ha of rock plowed land formerly consisted of approximately 1600 ha of wetland prairies, 140 ha of sawgrass glade, 40 ha of ponds, and 180 ha of pineland, with the remainder in bayhead or hammocks (Krauss 1987).

The remaining 2000 ha of land that were not rock plowed had been abandoned from approximately 1930 through the early 1960's. Farming ended in July 1975 with the final acquisition of the privately held agricultural land. The majority of the farmed land that was not rock plowed has returned to essentially native vegetation, with only a small portion now dominated by *Schinus terebinthifolius* (Brazilian pepper) (Ewel et al. 1982), while the 2000 ha of rock plowed land are essen-

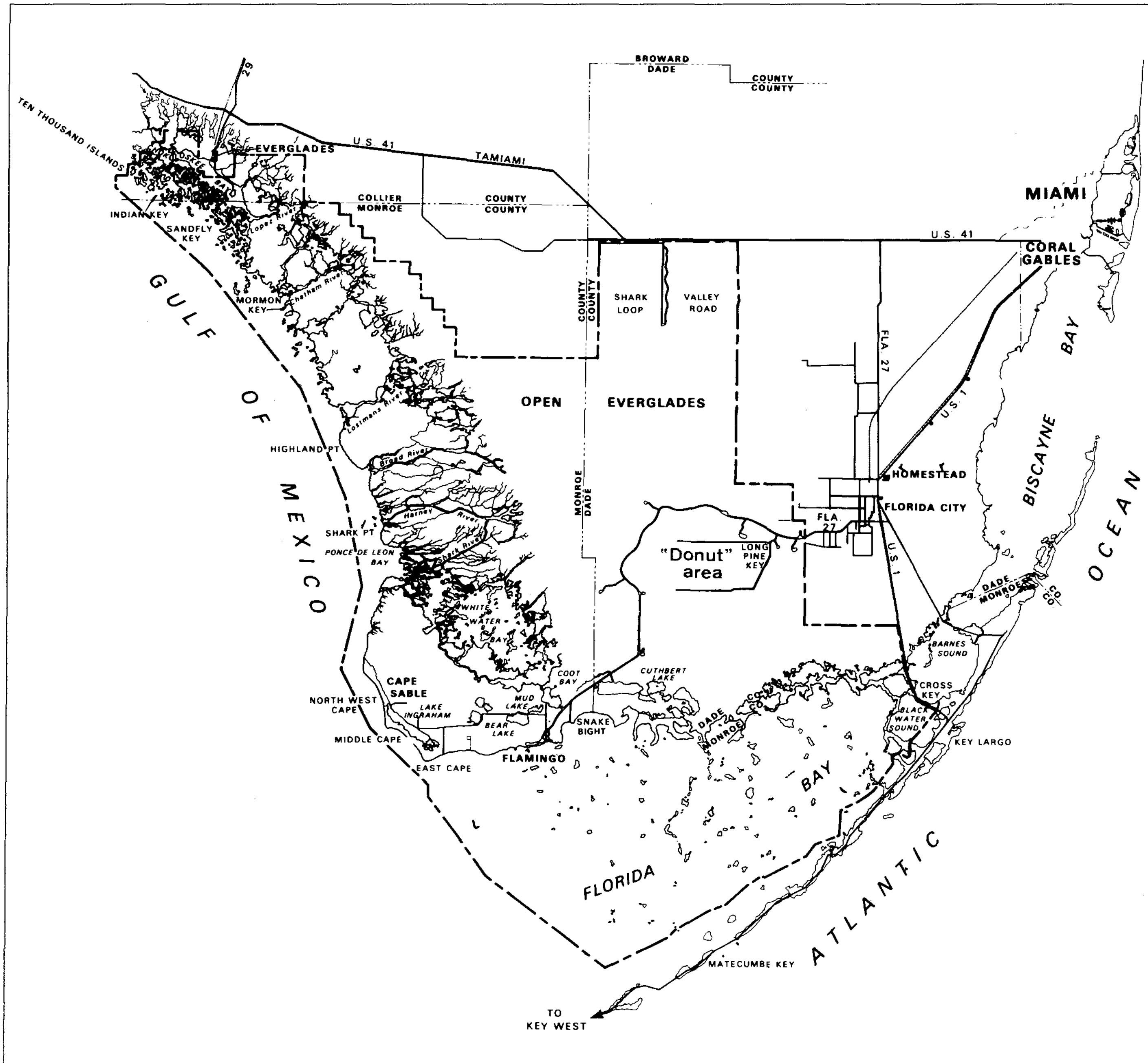

FIGURE 1. Map of southern Florida and Everglades National Park indicating 'Hole-in-the-Donut' area.

tially dominated by *S. terebinthifolius* (Doren et al. in prep.).

S. terebinthifolius is a tree or shrub that grows as tall as 12 m, with multiple arching branches. The plants are generally wider than they are tall. It is usually dioecious with alternate odd-pinnate compound leaves developing dense clusters of bright red, holly-like fruit during the winter months of November to January.

This study is based on field work conducted from 1982 through 1985. The objectives of this study were to (1) determine and compare the costs involved with control of *S. terebinthifolius* using basal bark treatment with Garlon 4 (Triclopyr) on different age and density classes, and between matricide and complete stand treatment, and (2) evaluate the successional characteristics of *S. terebinthifolius* on abandoned farm land.

STUDY AREA

The study area is located in the southern everglades in Everglades National Park, Ranges 36 and 37 East, Township 58 South in Dade County, Florida (Figure 1). The natural features and vegetation of the area have been described by Davis (1943), Egler (1952), Robertson (1955), Craighead (1971), Alexander and Crook (1973), Hilsenbeck (1976), Wade et al.

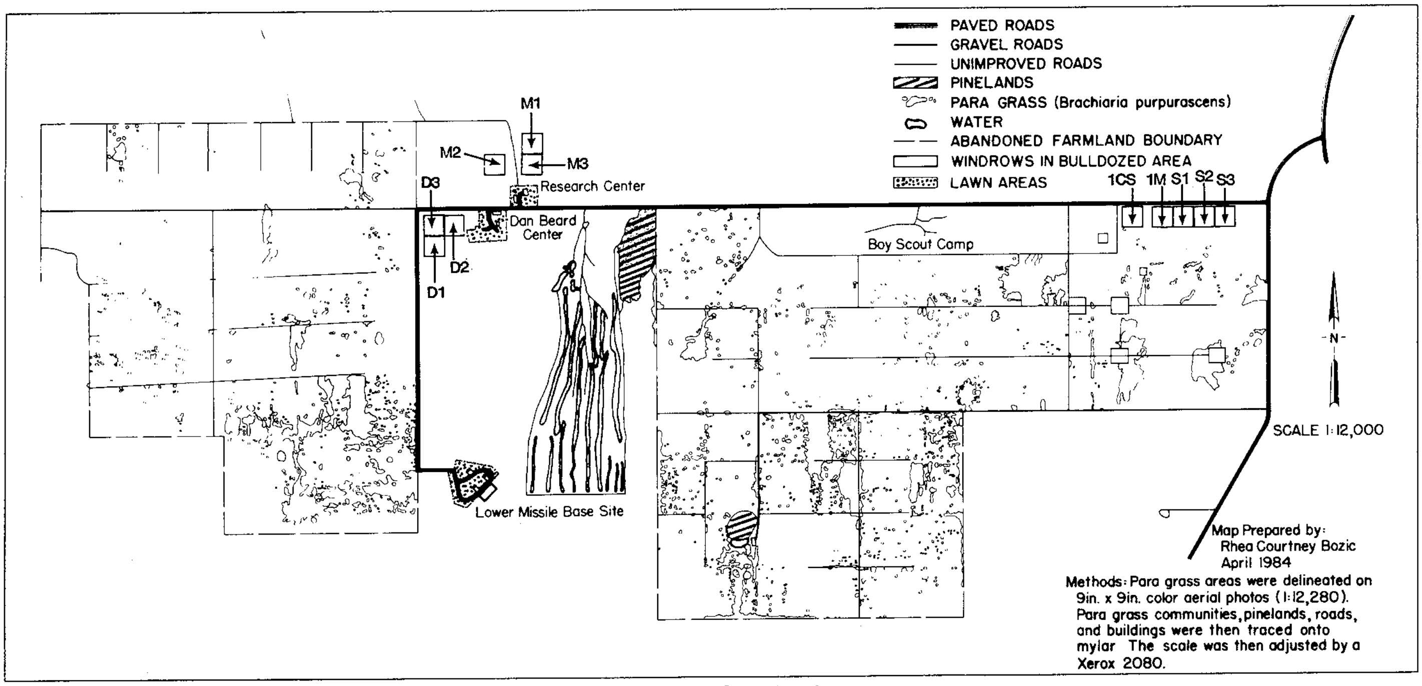

FIGURE 2. Map of the 'Hole-in-the-Donut' indicating locations of study plots.

(1980), and Krauss (1987). Soils were mapped and described by the USDA (1958). The study sites are within the 'Hole-in-the-Donut' (Figure 2). Earlier post-farming successional associations have been described by Hilsenbeck (1976), Ewel et al. (1982), and Krauss (1987).

METHODS

This study involved the basal bark treatment (application of herbicide to the bark of the tree usually within 0.5 m above the ground) of *S. terebinthifolius* with Triclopyr (Garlon 4). The study was proposed to establish cost criteria for consideration of future implementation of this method of control in the exotic plant management program of Everglades National Park. Garlon 4 basal bark treatment was chosen as a result of previous herbicide evaluations by Ewel et al. (1982), which compared several basal and foliar application methods and chemicals.

The feasibility treatment study on *S. terebinthifolius* was conducted using seven 50 x 50 m permanent plots (2500 m^2 area) and a 5-m-wide buffer strip around each plot for a total of 3600 m^2. The plots were established in three different age and density classes of *S. terebinthifolius* by site: young successional plots S1, S2, 1CS (10 years or less since abandonment); old successional plots D1, D2 (11 to 20 years since abandonment); and mature successional plots M1, M2 (more than 20 years since abandonment). These classifications are similar to categories of Ewel et al. (1982) but have been adjusted to take into account time elapsed since that work was done.

Tree and stem inventories were conducted on all plots using the following methods. Individual trees were categorized into two size classes: less than 2 cm basal diameter and greater than 2 cm basal diameter. Trees less than 2 cm basal diameter, but greater than 12 cm high were considered as single-stemmed trees (saplings). All *S. terebinthifolius* less than 12 cm high were counted as seedlings. For each tree greater than 2 cm basal diameter, individual stems greater than 2 cm that originated 60 cm or less above ground level were counted. These individual stems were tallied in two size categories; stems between 2 and 10 cm and stems 10 cm or larger. Tree and stem tallies were made only within the 50 x 50 m plot and not within the buffer zone.

Each 50 x 50 m plot was subdivided into 50, 5 x 10 m subplots. The nodes at each 5 x 10 m subplot intersection were numbered, and 0.1-m^2 understory samples were made at each node. Seedlings (less than 12 cm high) were counted. Each subplot also was monitored for the following understory vegetation characteristics: percent cover of native grasses; percent cover of paragrass (*Brachiaria mutica*); and percent cover of all other herbaceous plants. Daubenmire's (1959, 1968) cover classes were used for percent-cover classification (1 = 0 to 5 percent; 2 = 5 to 25 percent; 3 = 25 to 50 percent; 4 = 50 to 75 percent; 5 = 75 to 95 percent; 6 = 95 to 100 percent). An average height (cm) of the understory vegetation was estimated for each subplot using a meter stick and taking four estimates of height. The subplots were not permanently marked.

Each tree in each plot and in the buffer zone was then treated, using the basal bark method of application, with a 2 percent Garlon 4/diesel mixture. In the mature plot seedlings in each subsample were treated by foliar application using a 1:64 mixture of Glyphosate (Roundup) and water. Prescribed burning was also used in plot D1 in an attempt to control seedlings. The *S. terebinthifolius* leaves had been allowed to drop and cure after herbicide treatment to provide a source of fine fuels.

In addition to the complete stand treatment plots outlined above, four 50 x 50 m plots (S3, D3, 1M, and M3) were established (one in young successional, one in old successional, and two in mature successional, Figure 2) for basal bark treatment of female trees only. This matricide method established by Ewel et al. (1982) kills only reproductive trees in an attempt to (1) eventually remove *S. terebinthifolius* from the canopy and (2) reduce treatment costs by treating fewer trees. Tabulation of trees and stems was identical to the previously described sites.

Female trees in fruit were marked using spray paint marks on the branches. All female and male trees were counted. Surveys on matricide plots were conducted using the same methods as applied in the complete stand treatment plots. Amounts of herbicide solution(s) and work hours (excluding data collection time) were noted for each plot. Herbicide amount and work hours for seedling treatment were not tracked.

Basal bark treatment included a thorough application on all trunk and branch surfaces within 0.5 m above root crown. Diesel fuel was the diluent in a 1:50 Garlon 4 to diesel (2 percent) mixture. Foliar applications of Glyphosate were made according to label directions for farmland weed control. All chemical applications were made using 1.5-gallon low pressure garden sprayers. Sprayer pressure was maintained at a low level to avoid overspray from fine spray droplets.

RESULTS

Tree and stem inventories for each stand type were converted to density per ha for comparison of stand types (Figure 3). Trees and stems on young successional sites are not as dense (355 trees with 61 stems/ha greater than 10 cm in diameter out of a total of 1453 stems/ha). Old successional sites have large numbers of trees (6055/ha) but still have few stems greater than 10 cm in diameter (58) although they contain huge numbers of stems (11,355/ha). Mature successional sites have fewer trees (892/ha) than old successional sites, with 396 stems/ha greater than 10 cm in diameter out of a total of 1915 stems/ha.

In young successional sites, native grasses and the exotic paragrass had the largest number of samples in cover class 1 (0 to 5 percent) (Figure 4). The largest percentage of plots (34 percent) were in cover class 3 for other herbaceous species, but 74 percent of the samples had cover values of 3 or less for this understory category. However, some samples had cover classes 4, 5, or 6 for two of the understory categories (other herbaceous species and native grasses).

Old successional sites had the majority of samples for all three understory catego-

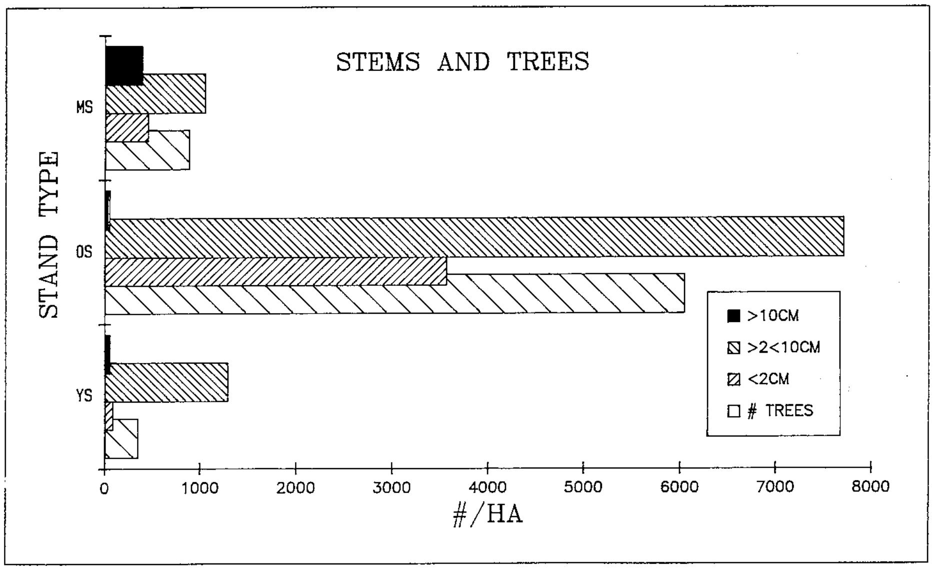

FIGURE 3. Bar graph of numbers of *S. terebinthifolius* stems (by size class) and trees by stand type per hectare. YS = young successional; OS = old successional; and MS = mature successional.

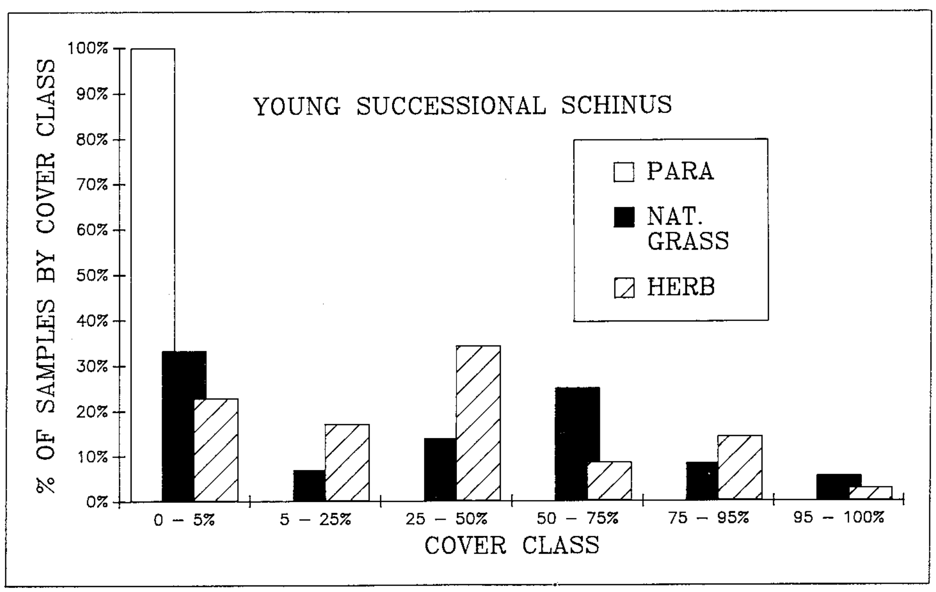

FIGURE 4. Bar graph of herbaceous cover by category. PARA = paragrass, NAT. GRASS = native grasses, and HERB = other herbaceous cover by cover class in young successional *S. terebinthifolius*.

ries in the lowest cover class, and 100 percent of the samples in cover class 3 or less for other herbaceous species and paragrass (Figure 5). There were no samples in cover class 6 for any understory category.

Mature successional sites had 100 percent of the samples in cover class 1 for all three understory categories (Figure 5).

Mean height of the understory vegetation decreased with increasing age of the site (Table 1) and ranged from 44.7 cm on young successional sites to 12.7 cm on mature successional sites.

Mean densities of *S. terebinthifolius* seedlings increased from a low value ($0.9/m^2$) on young successional sites to $291/m^2$ on old successional sites, but mean density on mature successional sites decreased slightly to $205/m^2$ (Table 1).

After treatment with herbicide, recolonization of treated areas by *S. terebinthifolius* seedlings occurred within two months. This rapid recolonization may be due in part to applicator error through incomplete herbicide coverage. Control of seedlings by burning was unsuccessful due to insufficient fuels and high fuel moisture.

Work hours by stand type and treatment type are presented in Table 2. Work hours varied from 72 hours/ha on old successional sites to 12.5 hours/ha on young successional sites, but varied by a maximum of only 2 hours/ha between complete treatment and matricide treatment within a stand type.

The amount of herbicide (not including diluent) used per ha for complete treatments varied considerably between stand types from a high of 66.0 ounces/ha on old successional sites to a low of 8.5 ounces/ha on young successional sites (Table 3). The mean amount of herbicide used was 39.1 ounces/ha on complete treatment sites and 18.3 ounces/ha on matricide sites (Table 3).

Of the 5547 trees sampled, 3133 were males and 2414 were females. Therefore, there was a 1.3:1 ratio of male to female trees sampled in this study.

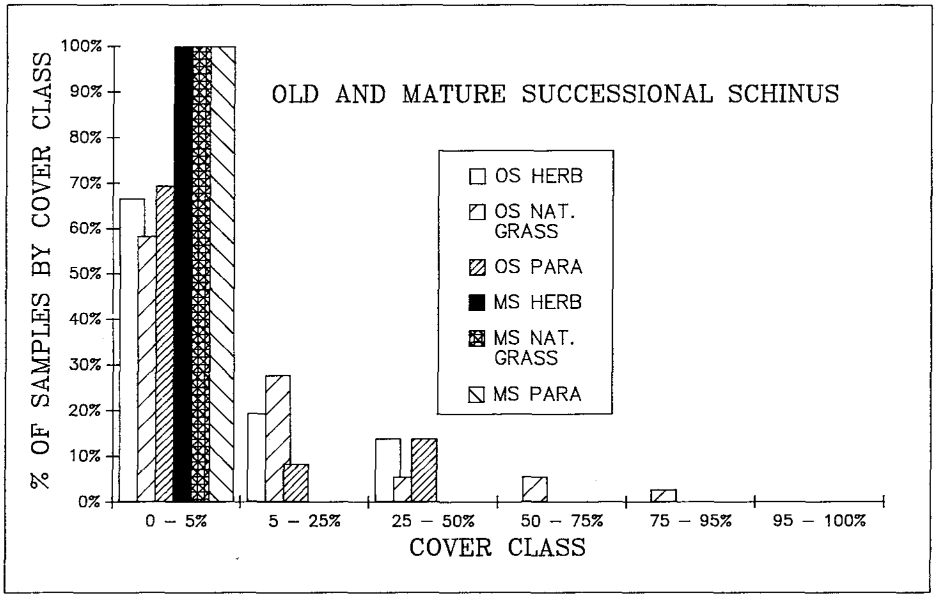

FIGURE 5. Bar graph of herbaceous cover by category. PARA = paragrass, NAT. GRASS = native grasses, and HERB = other herbaceous cover by cover class in old (OS) and mature (MS) successional *S. terebinthifolius*.

TABLE 1. Comparison of the average height of the understory and number of *S. terebinthifolius* seedlings per m² by age class category. YS = young successional, OS = old successional, and MS = mature successional.

Age Class	Avg. Height Understory (cm)	Avg. No. *S. terebinthifolius* Seedlings/m²
YS	44.7	0.9
OS	14.0	291.1
MS	12.7	204.7

TABLE 2. Total work hours per hectare (ha) comparing complete treatment sites with matricide treatments sites by age class category. YS = young successional, OS = old successional, and MS = mature successional.

Age Class	Complete Treatment	Matricide Treatment
YS	13.3/ha	12.5/ha
OS	71.0/ha	72.0/ha
MS	24.0/ha	22.0/ha

DISCUSSION AND CONCLUSIONS

The results of the tree and stem inventories, data on understory characteristics, and data on *S. terebinthifolius* seedling densities of the three age and density classes of sites suggest a general course for secondary succession on the rock plowed farmland in the 'Hole-in-the-Donut.' On young successional sites (less than 10 years old) *S. terebinthifolius* has

TABLE 3. Comparison of the amount of herbicide (ounces) used per hectare by age class category. YS = young successional, OS = old successional, and MS = mature successional, and treatment type (matricide, complete).

Age Class/Treatment Type	Amount herbicide (ounces)/ha
YS	8.5
OS	66.0
MS	24.2
Matricide	18.3
Complete	39.1

become established in relatively low densities with a low percentage (4 percent) of large stems (greater than 10 cm diameter) in a mosaic of relatively tall herbaceous cover that can be dense and contains few *S. terebinthifolius* seedlings.

On old successional sites (between 10 and 20 years old), invasion of *S. terebinthifolius* has developed to a point where *S. terebinthifolius* is dense but still has a low percentage (0.5 percent) of large stems. A much lower stature herbaceous cover is not dense anywhere, but *S. terebinthifolius* seedlings are quite dense.

On mature successional sites (older than 20 years) *S. terebinthifolius* dominates. Considerable stand thinning has occurred, with a relatively large percentage of the stems greater than 10 cm in diameter (21 percent) and a decrease in herbaceous cover in all three understory categories (less than 5 percent cover). *S. terebinthifolius* seedling densities are still relatively high but have decreased by 30 percent from old successional sites.

Thus, *S. terebinthifolius* invasion proceeds from an early stage of low density and low reproduction in a mosaic of herbaceous species, through a period of rapid reproduction and site domination with a high density that suppresses associated herbaceous species, to a mature stand of relatively moderate stem density with a significant percentage of larger stems that have virtually eliminated herbaceous species, presumably by an almost complete canopy cover. *S. terebinthifolius* will continue to maintain its position on the site through abundant reproduction. These results support the conclusions of Ewel et al. (1982), Loope and Dunevitz (1981), and Krauss (1987) regarding recolonization and self-maintenance by *S. terebinthifolius* in this area.

Experimental treatments of seedlings growing under dense canopy of the old and mature successional sites showed that burning is not an effective method of treatment simply because the area will not burn adequately due to a lack of fine fuels and to the high fuel moisture. The rapid recolonization of the treated areas by seedlings illustrates the ability of *S. terebinthifolius* to maintain itself through reproduction by fresh seed-fall from adjacent sites or from stock within the soil seed bank, on even the mature successional sites.

The amount of herbicide used is directly related to the number of stems treated (Table 3). Treatment of sites with the highest stem densities (old successional) used the most herbicide, while the treatment of sites with the lowest stem densities (young successional) used the least amount of herbicide. Similarly, matricide treatments used slightly less than half of the amount of herbicide as complete stand treatments because female trees comprised slightly less than half of the *S. terebinthifolius* population (Table 3).

The difference in labor hours required for treatment between types of sites is principally determined by the number of stems treated. Old successional sites required the most treatment time because of the large number of stems to be treated, and young successional sites required the least treatment time because these sites had the least amount of stems. These differences in work hours between site types were not directly proportional to differences in amounts of stems because in all cases an equal area of land had to be covered on foot to treat all plants, and larger stems take longer to treat than smaller stems.

However, labor hours did not vary significantly between complete stand treatments and matricide treatments within a stand type because of the time required to mark the female trees while they were fruiting. Additionally, every tree in the matricide treatments also had to be visited to determine the sex of the tree, regardless of whether or not the tree was treated. Thus, treatment time was increased for females and not totally eliminated for males in the matricide treatments.

Although matricide treatments used less than half the amount of herbicide than complete stand treatments, labor hours required were not significantly different between types of treatment. However, labor costs are a much larger component of the total cost of treatment because labor costs per hour are high and relatively small amounts of concentrated herbicides are used. We therefore conclude that matricide treatment of *S. terebinthifolius* is not less expensive than complete stand treatment. Additionally, with the risk of missing female trees and because even male *S. terebinthifolius* trees regularly bear female flowers and viable fruit (Ewel et al. 1982), the use of matricide is not an effective strategy for controlling the spread of *S. terebinthifolius* through stand conversion.

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