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EFFECTS OF HARVESTING CYPRESS SWAMPS ON WATER QUALITY AND QUANTITY

by

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Karla Brandt supervised the field work and performed most of the data analysis. Katherine Alexander, Rickie Oliver, and Sandra Upchurch provided most of the field assistance. Eric Klein conducted the water quality analysis as an independent student project.

ABSTRACT

The responses of cypress swamps to a spectrum of harvest techniques are being studied in the Withlacoochee State Forest. Among the eleven swamps in the study area, four contain plots that were harvested experimentally in 1984. Stand improvement cuts were made in plots in two large swamps by releasing all co-dominant crop trees from competition on all sides. In two other large swamps, plots were thinned to three different levels of basal area: 16, 25, and 34 m^2 ha^{-1}. Two additional large swamps will be partially clearcut in strips, one small swamp will be partially clearcut in wedges, and another small swamp will be completely clearcut. Three swamps will serve as controls for this last group of swamps.

Measurements of tree biomass were made in all but two of the large swamps. In addition, the swamps were surveyed for cone production in the fall and regeneration in the spring. Cone production was poor in all swamps, and few seedlings were found the following spring. However, coppice was produced in all the harvested plots. These preliminary results suggest that coppice production may be a dependable regeneration method, although it may not be desirable for stand improvement cuts and thinning.

Evapotranspiration from three cypress swamps averaged 79 cm yr^{-1} over a 3-yr period. This represented 52% of rainfall at the site. This rate was 77% of the average evapotranspiration rate measured in pine flatwoods in north Florida during the same time. These data confirm earlier reports of low evapotranspiration rates in cypress swamps.

A preliminary analysis of nitrogen concentrations in harvested and control swamps suggests that harvesting may increase organic nitrogen concentrations in the water column during the harvest operation. However, these higher concentrations appear to be short-lived.

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INTRODUCTION

Swamps dominated by bald cypress (*Taxodium distichum*) and pond cypress (*T. distichum* var. *nutans*) comprise over 25% of the forested wetlands on Florida's commercial forest lands. Most of these swamps were logged by the 1950's, and many of them now contain merchantable timber. Within the last decade, however, research has demonstrated that cypress swamps may provide more than timber to society. Their importance to water quality, water quantity, and wildlife is only now beginning to be recognized (e.g., Ewel and Odum 1984).

In the past, logging in cypress swamps was exploitative and destructive, and no silvicultural techniques were developed for managing these wetlands on a sustainable basis. Improved technology, such as in chipping, has made cypress logs attractive for a variety of new uses, and more and more cypress swamps are being harvested each year. A study was initiated in 1980 to evaluate long-term silvicultural and environmental impacts of potential management practices. The purpose of this project was to determine specific impacts of harvesting on water quality and water loss rates in the study areas.

Project Background

In 1980, a Memorandum of Agreement was signed by the U.S. Forest Service, the Florida Division of Forestry, and the University of Florida to support a study of cypress management practices in the Withlacoochee State Forest. This forest is located in the Green Swamp, which is an Area of Critical Concern in Florida because of its importance to water resources. The intent was to develop information on the silvics and silviculture of pond cypress as well as on the effects of potential silvicultural practices on ecological relationships in the swamp, specifically the hydrologic cycle.

As part of this Memorandum of Agreement, information was developed on regeneration and growth following the logging of small cypress domes (Terwilliger 1983), annual variations in growth rates in swamps of different sizes (Parendes 1983), the effect of false rings on growth rate and age estimation (Ewel and Parendes in press) and the impact of thinning on growth rates and nutrient cycling in a small cypress dome (Upchurch in prep). Measurements were begun on evapotranspiration (ET) rates from three cypress domes, and studies were initiated to evaluate the effects of thinning and stand improvement cuts on growth rates in larger swamps.

Impacts of Silvicultural Practices on Cypress Trees

Growth Rates

Cypress tree growth rates are fastest in cypress-hardwood associations, such as bottomland riverine forests and sloughs (Mitsch and Ewel 1979). They are slow in shallow areas, where the trees compete with pine trees and other more mesic species, and in permanently inundated ponds where virtually no other species can survive. In large cypress domes, such as the study areas in the Withlacoochee State Forest and in cypress strands, fastest tree growth and largest trees are often in the centers of swamps, although no single environmental parameter (e.g., peat depth, water level, basal area) is a good indicator of growth rate (Parendes 1983). The most rapid growth rates in the large cypress strand at Corkscrew Swamp are found in the moist, protected, interior locations but these differences are apparent only for the first 150 yr (Duever et al. 1984). Ewel and Parendes (in press) found considerable year-to-year

Cypress trees also reproduce by producing coppice when they are burned or cut down, but this process is poorly understood (Williston et al. 1980). The effects on coppice production of season in which harvesting occurs, the degree of thinning, the height of the stump, and the removal of slabs for clock faces on the production of coppice, as well as the death rate of sprouts, are poorly understood areas that may affect regeneration in a harvested stand.

The objective of this portion of the study was to describe cone, seedling, and coppice production in both control and harvested sites in the Withlacoochee State Forest.

Environmental Impacts of Silvicultural Practices

Evapotranspiration

Pond cypress swamps have relatively low ET rates, which suggests that water loss may actually increase when a cypress swamp is harvested (Brown 1981, Heimburg 1984). Because cypress swamps account for such a large area in the Green Swamp area in central Florida (20% in 1973; Brown 1984), and the Green Swamp is an Area of Critical State Concern because of its water resources, the potential impact of harvesting in cypress swamps on the regional water budget should be examined. Because the study swamps could not be harvested during this project, this report describes the pattern of ET in undisturbed cypress swamps.

Water Quality

Because most large cypress swamps are hydrologically connected to other wetlands or water bodies at some time over a course of several years and could impact their trophic status during the time they are connected, the impact of harvesting on water quality in swamps is an important topic.

Baseline water quality in cypress swamps has been described by Dierberg and Brezonik (1984), who compare the chemical characteristics of a Florida cypress dome with other Florida water bodies. They suggest that dissolved organic matter predominates over inorganic constituents and that potassium, phosphate, NH_4^+-N, and NO_3^--N are limiting nutrients in cypress swamps.

One of the original objectives of this study was to examine changes that occur in concentrations of the major forms of nitrogen (ammonium (NH_4^+-N), nitrate (NO_3^--N), organic nitrogen, and total Kjeldahl nitrogen (TKN) during and after logging. This portion of the study was conducted as a student project by an undergraduate (Eric Klein) before funding from the Florida Water Resources Research Center became available. It was intended to provide baseline data for the larger study; however, a drought prevented any sampling during the period when funding was available. These results are included in this report because they comprise the only analysis of the impacts of harvesting on water quality that is available.

METHODS

Description of Swamps

The swamps in the current study are listed in Table 1, and their approximate locations are shown in Figure 1. Six of the swamps were part of Parendes' (1983) earlier analysis: the three smaller swamps listed in Table 1 were the three medium-sized swamps in her study; Billy's Pond 1 and the swamps on North Carter Pond Road and Dark Stretch Road were her large swamps. The three smaller swamps, which were logged in the late 1930's, were also part of a study analyzing structure and growth rates of swamps that had been logged in the past (Terwilliger 1983).

Table 1. Current study swamps in the Withlacoochee State Forest

Size	Management	Date	Location
Small	Clearcut		Pole Bridge Road
Small	Partial Clearcut		Boggey Road
Small	Control		Porter Gap Road
Large	Thinning	Summer '84	Billy's Pond 1
Large	Thinning	Winter '84	Billy's Pond 2
Large	Stand Improvement	Summer '84	Dark Stretch Road
Large	Stand Improvement	Winter '84	North Carter Farm Road
Large	Strip Cut		Revel Road 1
Large	Strip Cut		Pole Bridge/Boggey Roads
Large	Control		Old Rte. 50
Large	Control		Revel Road 2

Parendes (1983) demonstrated that water level was significantly deeper in the larger swamps than in the smaller swamps from March 1982 - March 1983; differences in depth of organic matter were significant within but not between the two size classes; and differences in tree basal area

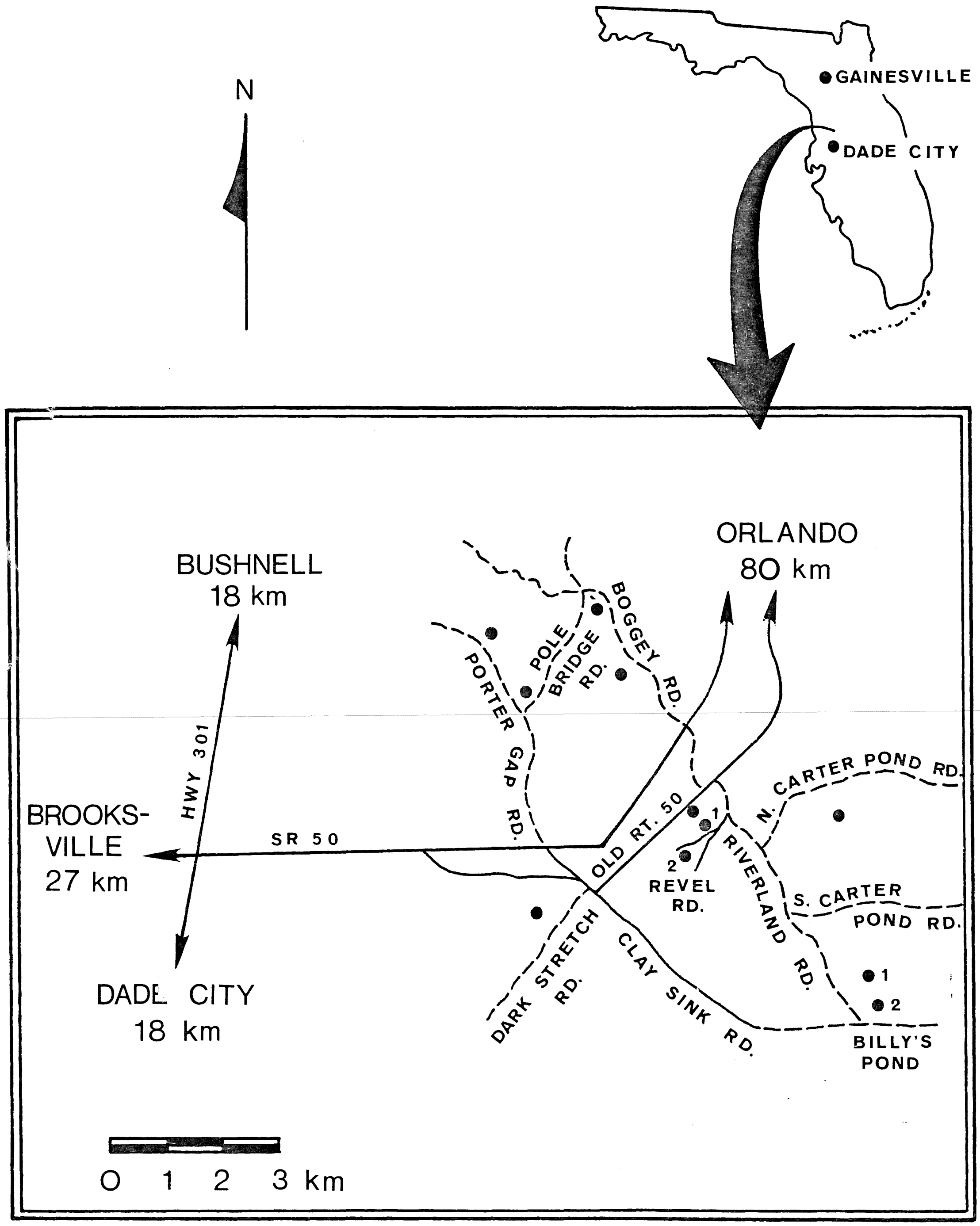

Figure 1. Study sites in the Withlacoochee State Forest.

between the two groups were not significant, but tree density was signficantly greater in the smaller than in the larger swamps. Cypress comprised 75% of the trees in the larger swamps and 59% of the trees in the smaller swamps. There were larger trees in the larger swamps than in the smaller swamps, but growth rates did not differ signficantly between or within the groups.

Silvicultural Practices

Four silvicultural practices that span a range of intensity in terms of both biomass removal and potential impact are being evaluated. The two practices that appear to be least intensive have been implemented: thinning and stand improvement. Partial clearcutting, in which logging is concentrated in only part of a swamp, is ready for implementation. The most intensive practice, clearcutting, will be evaluated on only one of our sites. A more complete evaluation of this practice is being conducted in cooperation with Division of Forestry personnel.

Because of a drought during the study year, potential contractors concentrated their harvesting operations in larger, normally inaccessible swamps, and a satisfactory bid was not submitted to the Division of Forestry for our relatively small swamps. However, baseline information has been obtained, and harvesting will commence as soon as it is feasible.

Thinning and Stand Improvement

Three plots of approximately 0.2 ha each in each of two large swamps were thinned to basal areas of 16, 25, and 34 m^2 ha^{-1}, and a fourth plot was established as a control. Tree measurements were made in an 810-m^2 plot in the center of each thinned and control area.

A stand improvement cut was conducted on two 0.2-ha plots in two other large swamps by releasing all co-dominant crop trees from competition on all sides. A control plot was also installed in each of these swamps. As before, tree measurements were made in a 810-m^2 plot in the center of each thinned and control area.

Partial and Total Clearcut

In two large (15-40 ha) swamps, 100-m-wide strips will be cut every 300 m. Two swamps will serve as controls. In addition, one small (<4 ha) swamp will be partially clearcut by cutting all the trees in two wedges, each one-quarter of the size of the swamp and opposite one another. Another small swamp will serve as a control. One small swamp will be completely clearcut. The same small swamp mentioned above will serve as a control.

Tree Measurements

Tree diameters were measured with dbh (diameter at breast height) tapes at breast height (1.2 m) or 0.9 m above the butt swell. Heights were measured in two parts: height from the ground to the original measuring point (a nail holding a metal tag), and total height. The former measurement will be useful in the event that subsequent measurements must be made in standing water. Biomass calculations used relationships reported by Mitsch and Ewel (1979).

Regeneration

Cone Production

A survey of cone production was conducted by noting whether several trees in each swamp or plot had 0, some (<15), or many (>15) cones. In each of the three small unharvested swamps, 30 trees were tallied: 10 on the edge, 10 in the middle, and 10 halfway between. In three of the four large swamps in the partial clearcut experiment that will be strip cut (the fourth had not yet been selected), 60 trees were tallied. Thirty trees were tallied in the control plots and some of the harvested plots in the thinned swamp and in the control and harvested plots in one of the swamps with stand improvement cuts. Although we tried to eliminate suppressed trees from the survey, no attempt was made to select trees randomly. In the control plots and harvested plots, the first 30 trees encountered were tallied; some of the heavily thinned plots had less than 30 trees, in which case all were tallied regardless of whether or not they were suppressed.

Seedling Production

Fifty circular 3-m^2 subplots were randomly located in each swamp, control plot, or harvested plot, and the number of live and dead cypress seedlings in each subplot was recorded. Subplots were located by selecting sets of three numbers from a random numbers table. The first number determined whether the sampler would turn left (even number) or right (odd number) from the starting point (the center of a swamp or a plot). The next two numbers were summed to determine the number of paces to be taken to reach the center of the next subplot. Zeroes in the random numbers table were skipped at this stage. The point reached was the center of a circular subplot with a radius of 1 m. If one subplot overlapped another, it was rejected and a new set of numbers was selected. If the sampler reached the boundary of a plot while pacing, he/she turned 120° toward the plot center and continued pacing.

Coppice Production

In each plot that had been harvested, all cypress stumps were surveyed for sprouts. The average height of each stump was measured and the levels of abundance of sprouts (live and dead) on the top, middle, and lower thirds of each stump were recorded. In two plots, all sprouts were counted; in the rest, three categories were used to record numbers of sprouts: 0, 1 - 10, and >10.

Evapotranspiration Rates

Measurements of ET and infiltration rates began in spring 1982. A 10 m X 10 m grid was established in each of the three swamps, and water depths were measured at each point. The volume equations listed in Table 2 were formulated from these data.

Table 2. Volume equations for three cypress domes in the Withlacoochee State Forest. Maximum values refer to the depths and surface areas that were measured when the equations were formulated. V = volume in m^3 and S = depth in cm.

BOGGEY ROAD

$$V = 458.0 - 43.6*S + 0.674*S^2$$

Maximum Stage = 125 cm
Maximum Surface Area = 13,400 m^2

POLE BRIDGE ROAD

$$V = -12.8 + 30.02*S - 1.12*S^2 + 0.0109*S^3$$

Maximum Stage = 120 cm
Maximum Surface Area = 19,100 m^2

PORTER GAP ROAD

$$V = 12.1 + 2.38*S - 0.301*S^2 + 0.00827*S^3$$

Maximum Stage = 105 cm
Maximum Surface Area = 17,900 m^2

Water level recorders were placed in the centers of the swamps. These have 1:1 gage scales that make them sensitive enough to allow nighttime reductions in water level (due to infiltration) to be distinguished from daytime reductions (due to ET plus infiltration). Charts were collected each week, and water depths at the beginning and end of each record were read from staff gauges mounted on the water level recorder stands. Although many of the hydrographs had been read before the beginning of this project, all were read again in order to ensure consistency.

On a typical rainless day, the trace on a hydrograph decreases more rapidly during the day, when both ET and infiltration cause water loss, and less rapidly at night, when only infiltration is in effect. To determine these rates, the number of hours between each change of slope was noted, along with the water level at the beginning of each period of consistent slope. These values allowed a rate of loss to be calculated; the position on the hydrograph indicated whether it was a daytime or a nighttime loss. Then, the change in volume of water in the swamps was calculated using the equations in Table 2. Infiltration was calculated from the nighttime water loss rate and then converted to a 24-hour basis. Water loss rates calculated for daytime hours were converted to ET rates by subtracting the subsequent infiltration rate.

Several factors prevented complete data sets from being collected for each month. In some summer months, for instance, when rainfall confounded most hydrographs, only one day's measurement could be obtained. On the other hand, in the spring and fall, when very little rain fell, nearly an entire month's data were obtained. Unusually deep water, which exceeded the predictive capability of the volume equations, persisted virtually the entire first year of the study; this reduced the amount of data that could be collected in the swamp on Porter Gap Road and limited the amount of data that was available in the other two swamps. Lack of personnel at that time prevented us from enlarging the grid and measuring the depths in order to take these high volumes into account. Finally, the drought during the study year eliminated estimates from September 1984 through June 1985.

Water Quality

Four swamps were used in this study. The two swamps that were harvested in Winter 1984 (Table 1) were sampled once before and three times after harvesting, and the two swamps scheduled for harvesting in Summer 1984 were used as controls.

Ten 200-ml water samples were taken from just below the surface of the water at a variety of sites in each of the four swamps at each sampling period (pre-harvest in January and post-harvest twice in February and again in May). Samples were stored at 4° C until analyzed.

All samples were analyzed unfiltered for NH_4^+-N, NO_3^--N, and total Kjeldahl nitrogen. Organic nitrogen was determined by subtracting NH_4^+-N from TKN. NH_4^+-N was determined by steam distillation with CaO and titration with weak H_2SO_4. NO_3^--N was determined by steam distillation with CaO and Devardo's alloy after ammonium was determined and subsequent titration with weak sulfuric acid. Total Kjeldahl nitrogen was determined by sample digestion with concentrated H_2SO_4 (Black et al. 1965).

RESULTS

Tree Biomass and Diameter Distribution

The percentages of biomass removed in the stand improvement harvests at Carter Pond Road and Dark Stretch Road, as well as in each of the thinnings at Billy's Pond 1 and 2, were roughly proportional to the percentages of basal area removed (Figures 2-4). Basal areas in the control plots of the two control swamps for the strip cuts, Old Route 50 and Revel Road 2, were somewhat lower than at the harvested swamps: 41 and 28 $m^2\ ha^{-1}$, respectively. Trees have not yet been marked at the two swamps to be partially clearcut. Basal areas of the three smaller swamps ranged between the two groups of swamps: 44 $m^2\ ha^{-1}$ at Pole Bridge Road, 59 $m^2\ ha^{-1}$ at Porter Gap Road, and 56 $m^2\ ha^{-1}$ at Boggey Road (Parendes 1983).

In all control plots in the large swamps except Revel Road 2, the largest group of trees were those that were approximately 30 m tall (Figures 5-10). No trees less than 20 m were left in any of the harvests. There was more variability in diameter distribution among the swamps, however. Most of the trees were in the 20- to 40-cm diameter groups except at Revel Road 2, where the largest group of trees was in the 15 cm category (Figures 11-16).

Regeneration

Cone and Seedling Production

In all swamps surveyed, at least 63% of the trees bore no cones during the 1985 cone survey (Figure 17). In only four of the plots surveyed were there any trees with more than 15 cones; none of these were in the harvested plots.

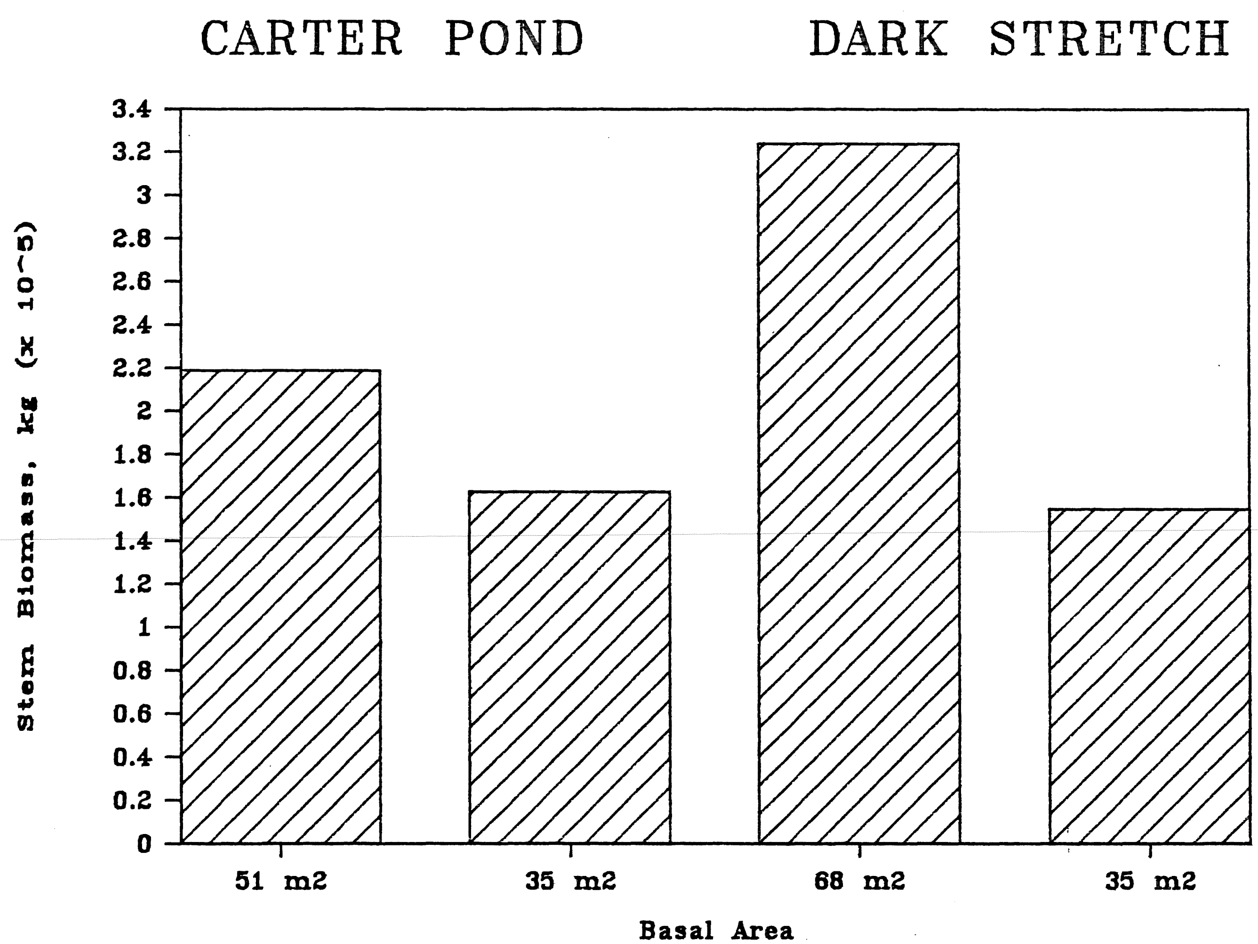

Figure 2. Stem biomass in control and harvested plots at swamps on Carter Pond Road and Dark Stretch Road.

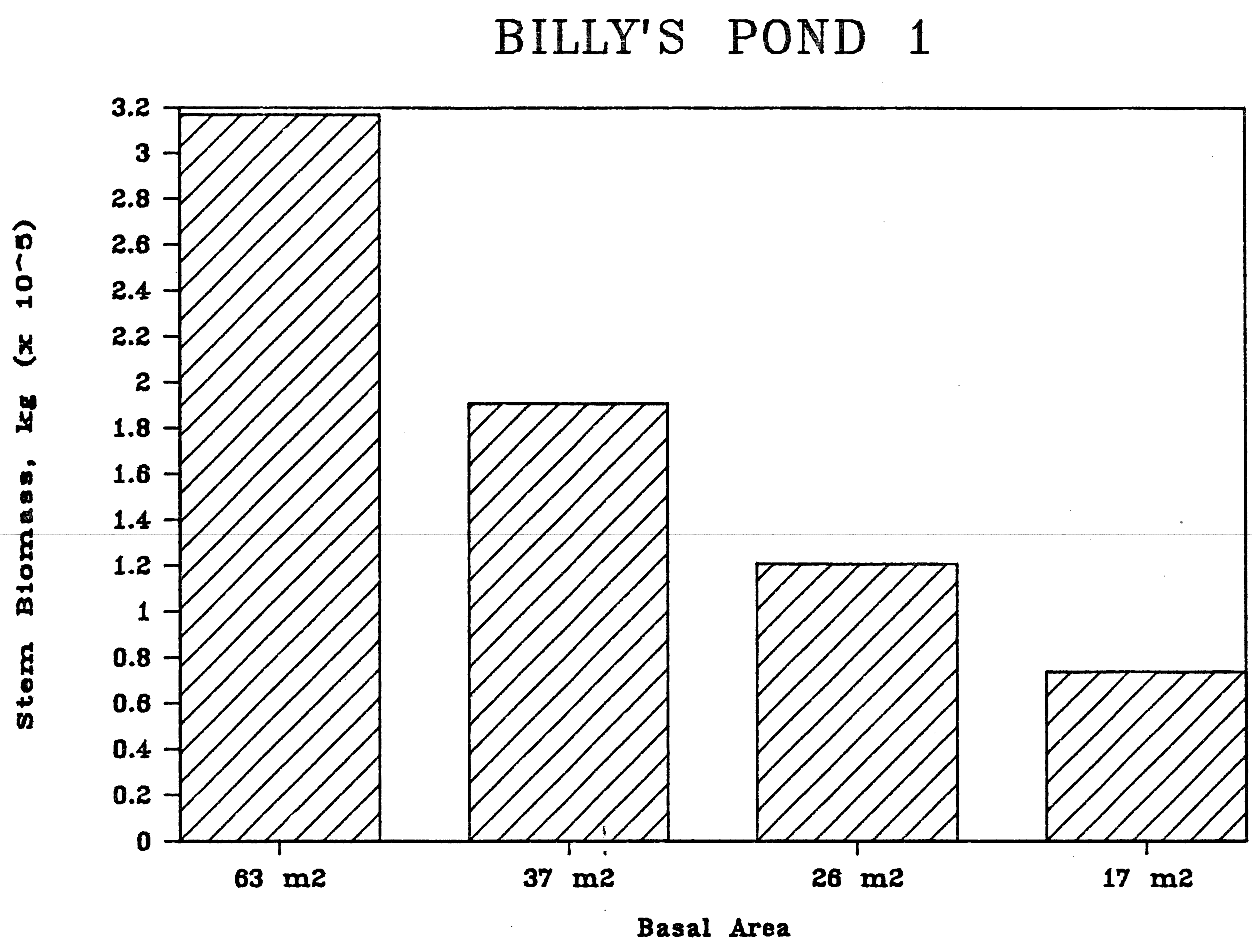

Figure 3. Stem biomass in control and harvested plots at Billy's Pond 1.

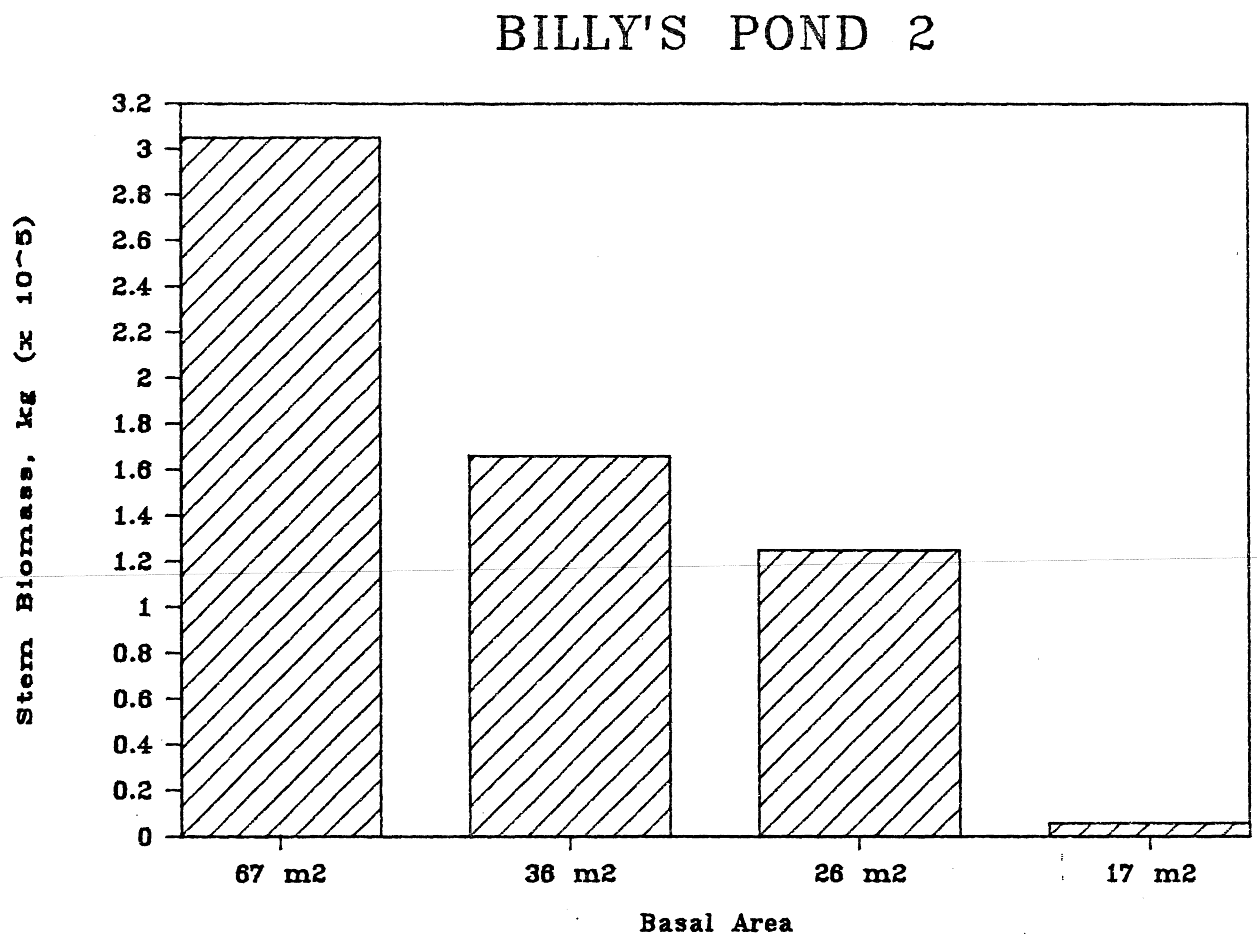

Figure 4. Stem biomass in control and harvested plots at Billy's Pond 2.

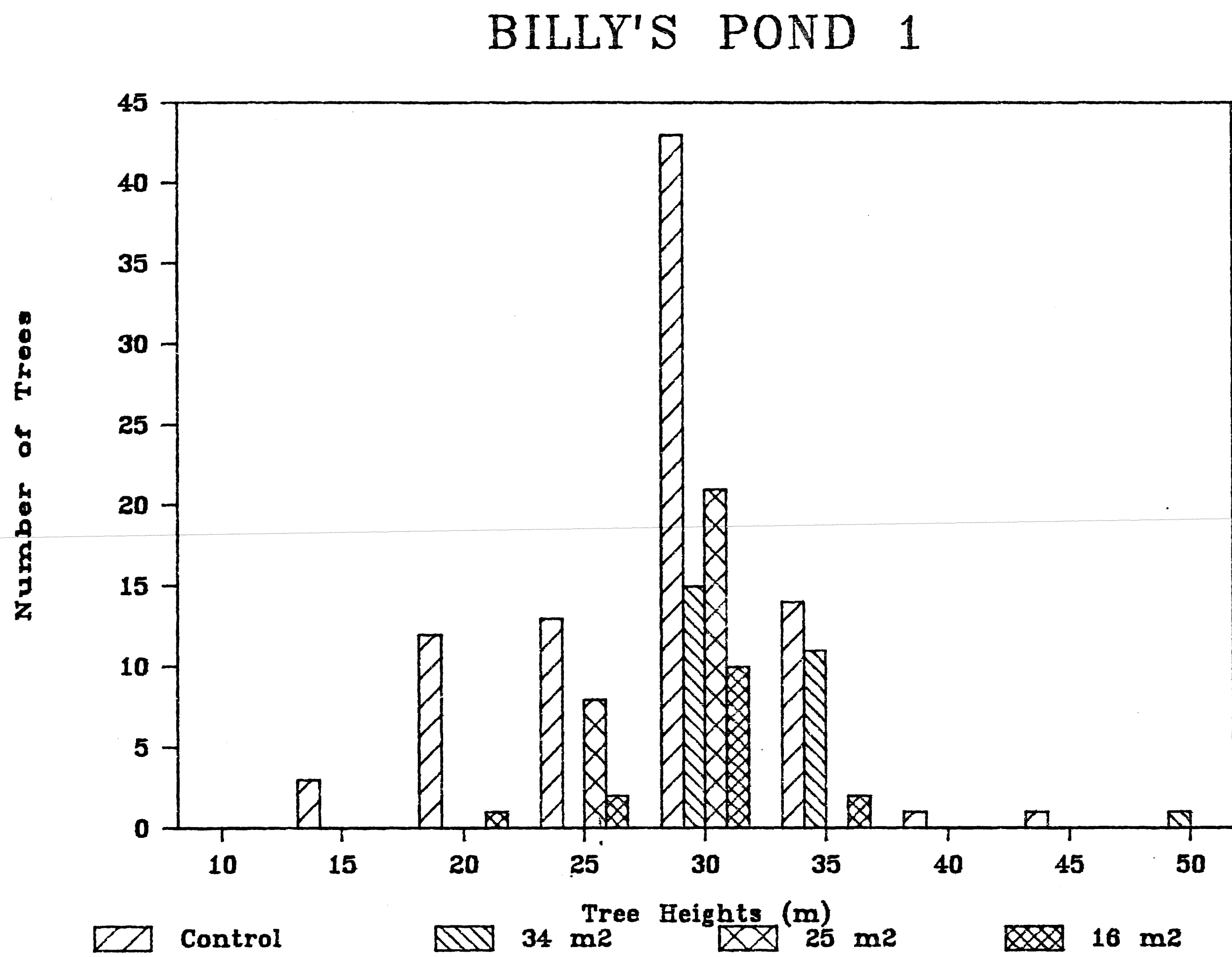

Figure 5. Distribution of tree heights in control and harvested plots at Billy's Pond 1.

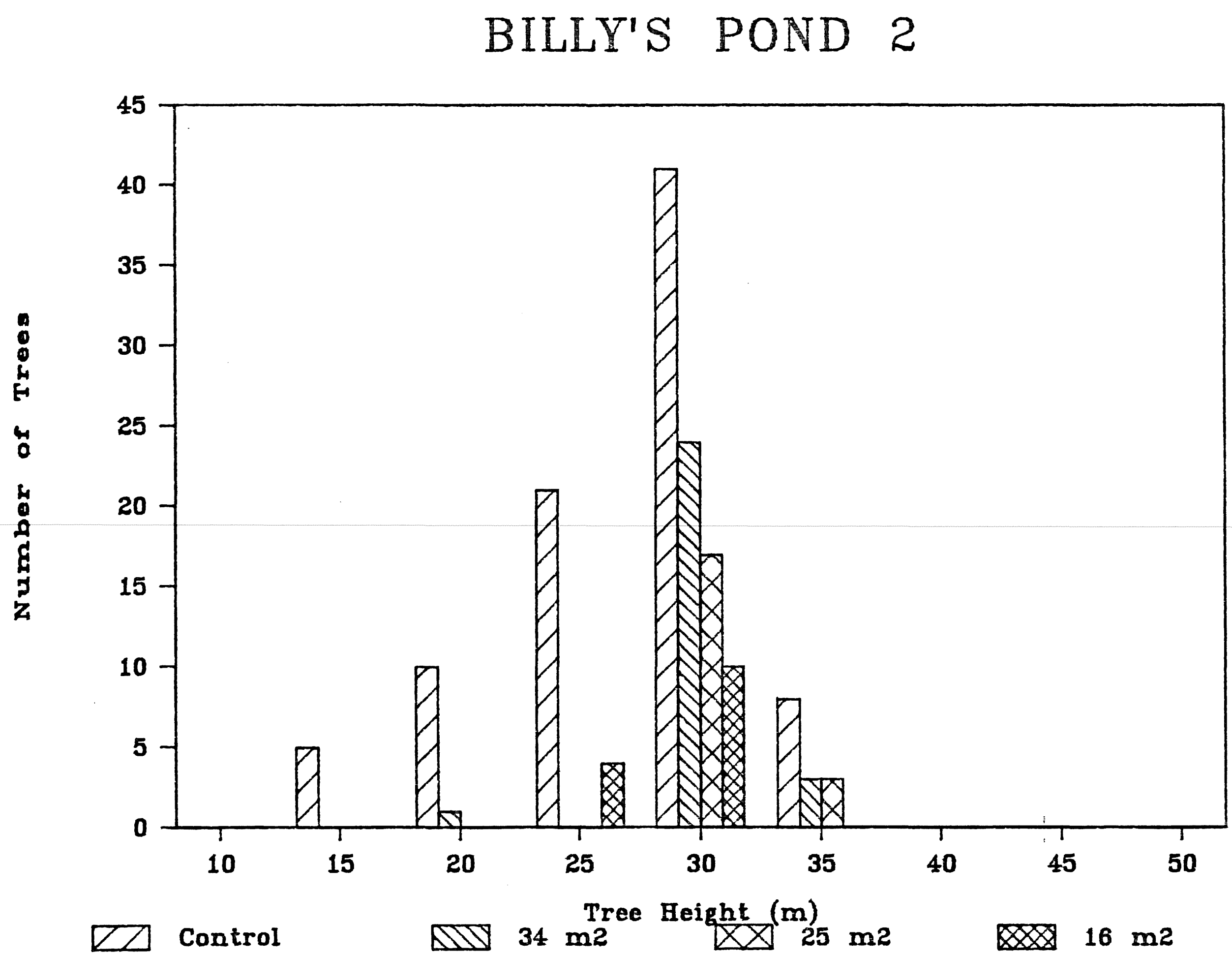

Figure 6. Distribution of tree heights in control and harvested plots at Billy's Pond 2.

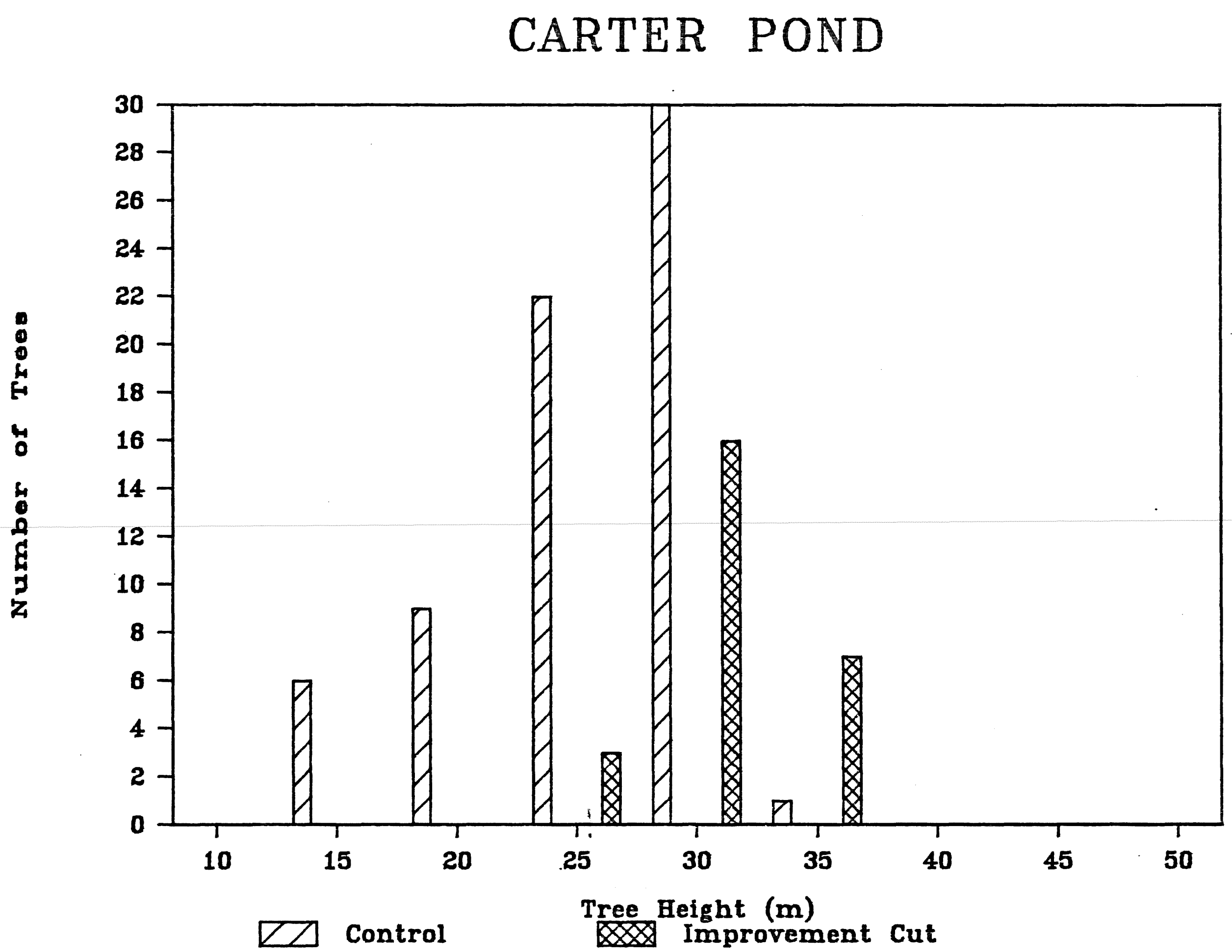

Figure 7. Distribution of tree heights in control and harvested plots in the swamp at North Carter Pond Road.

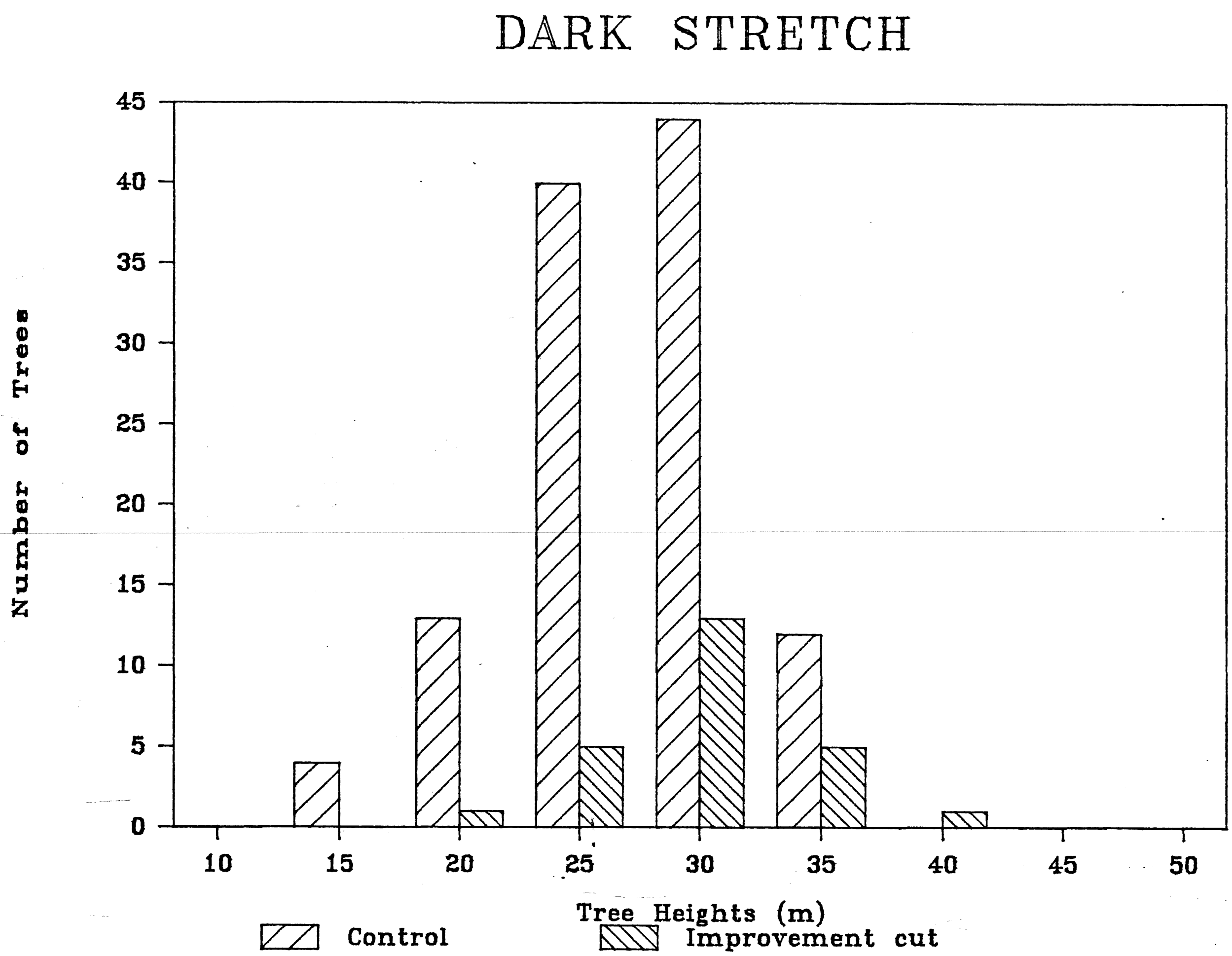

Figure 8. Distribution of tree heights in control and harvested plots in the swamp at Dark Stretch Road.

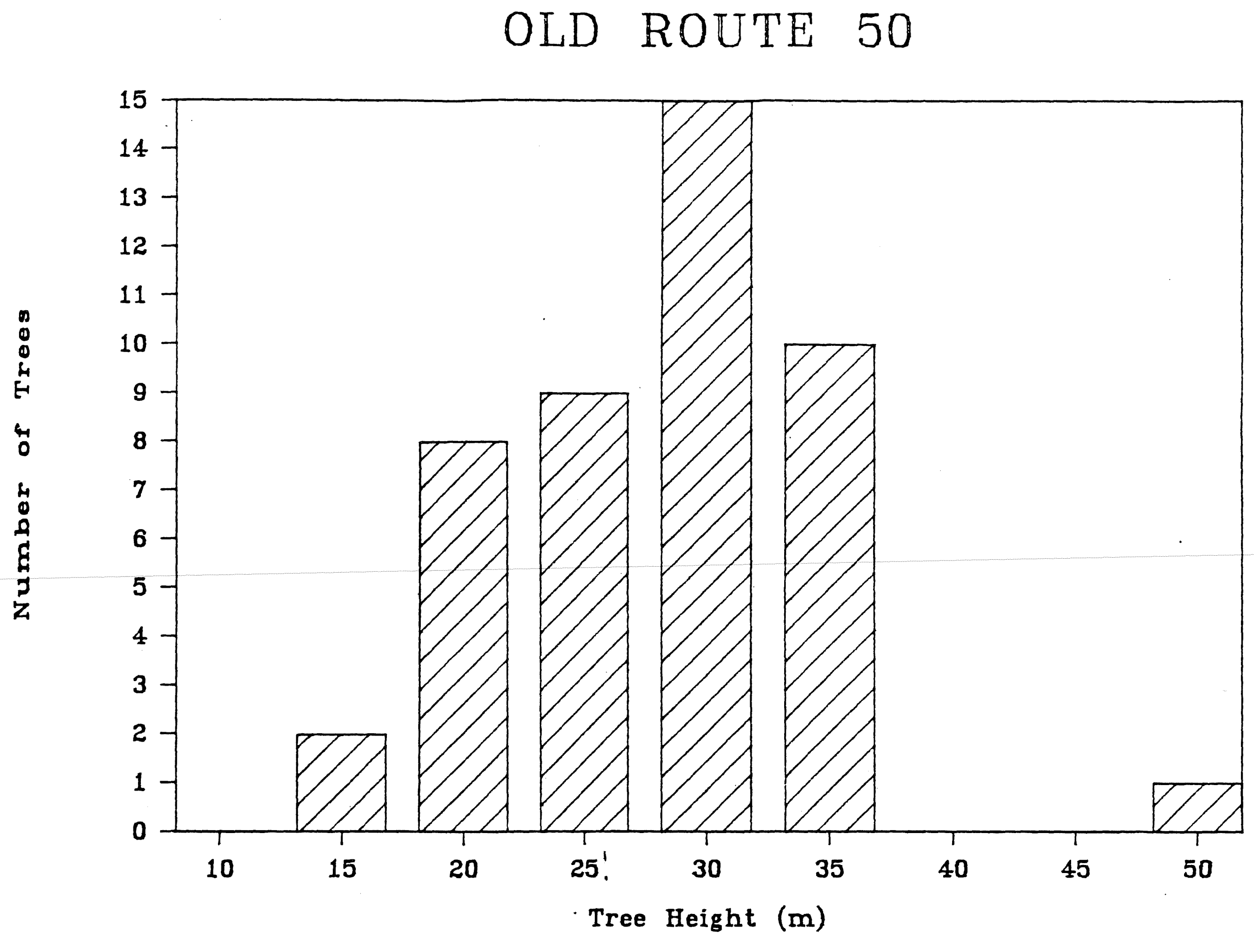

Figure 9. Distribution of tree heights in the swamp at Old Route 50.

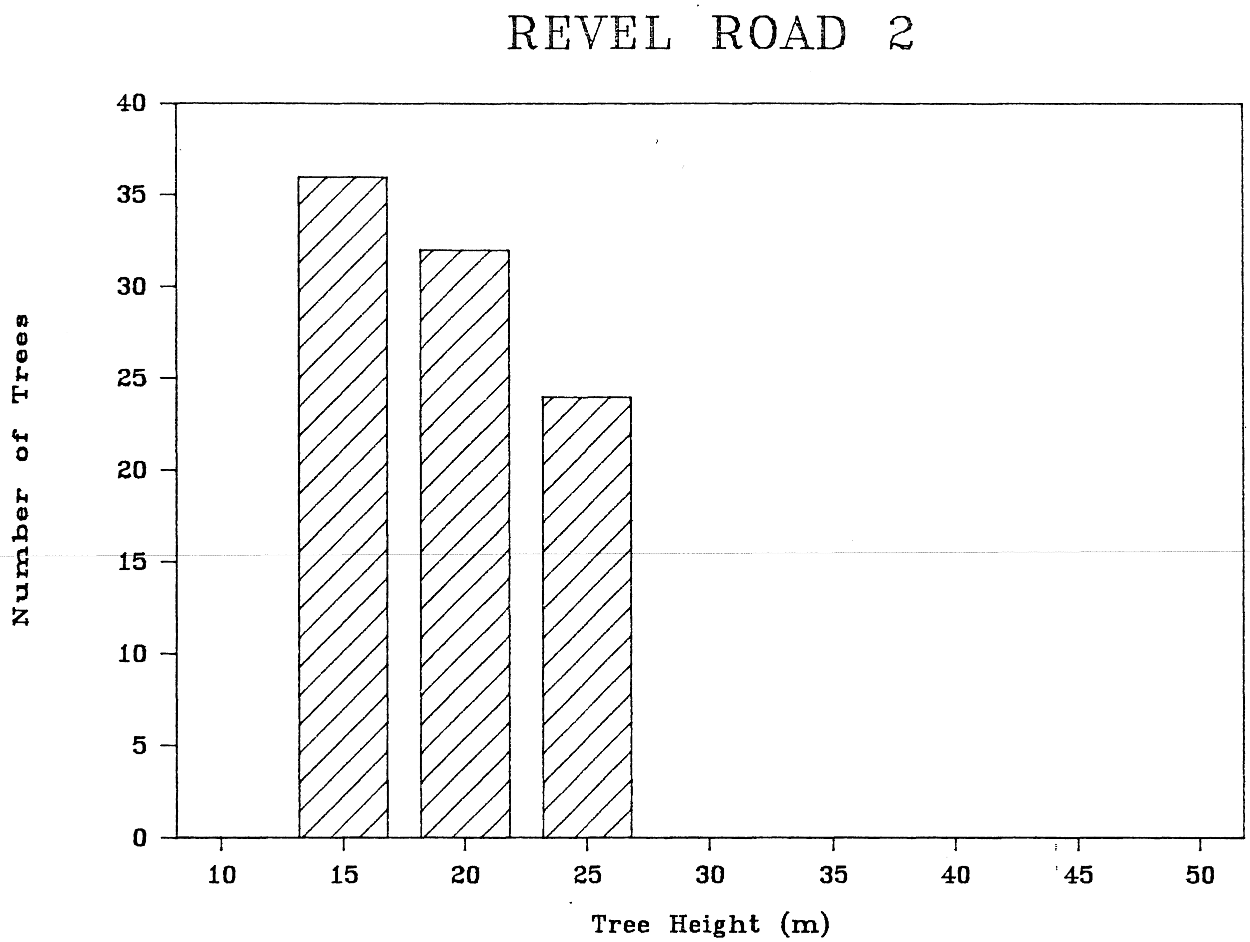

Figure 10. Distribution of tree heights in the swamp at Revel Road.

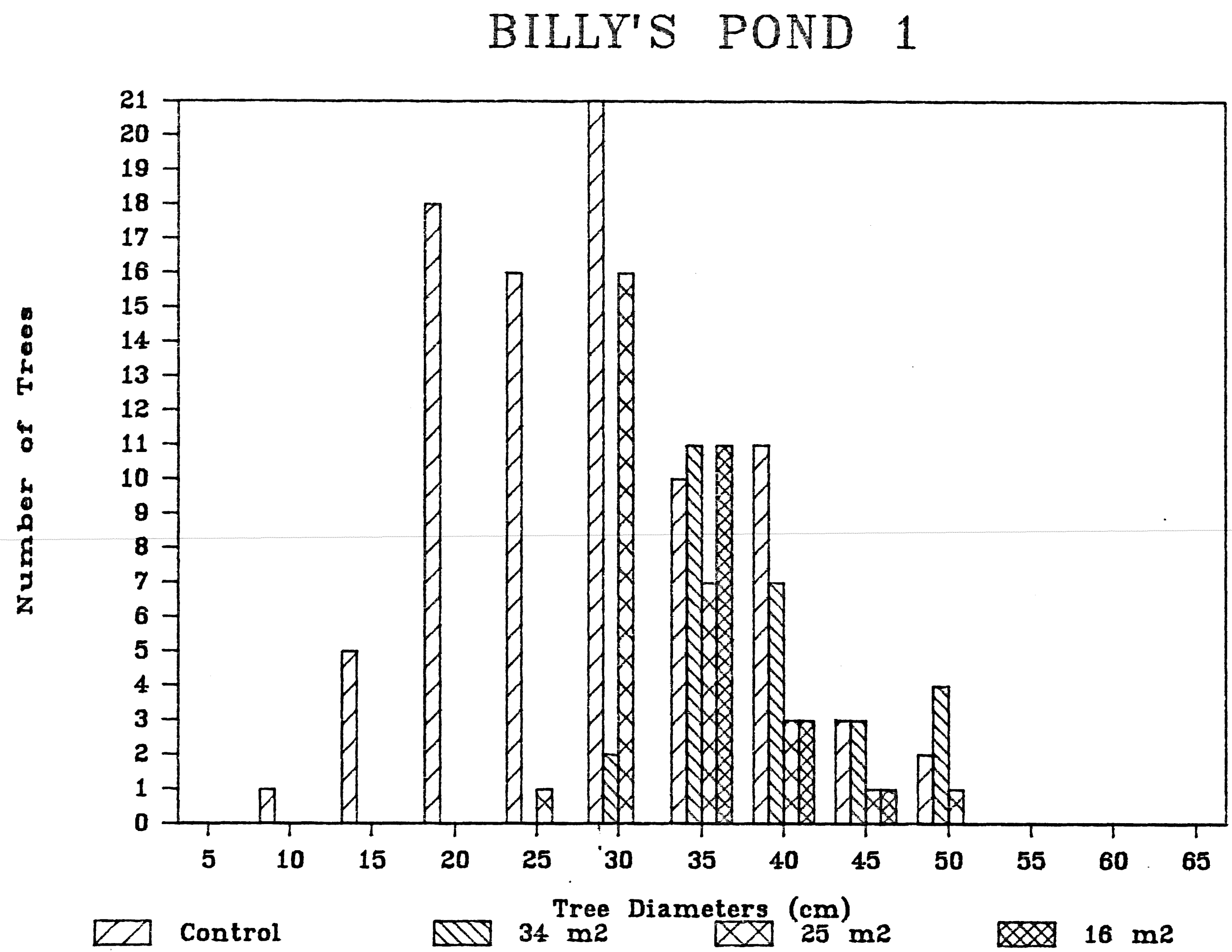

Figure 11. Distribution of tree diameters in control and harvested plots at Billy's Pond 1.

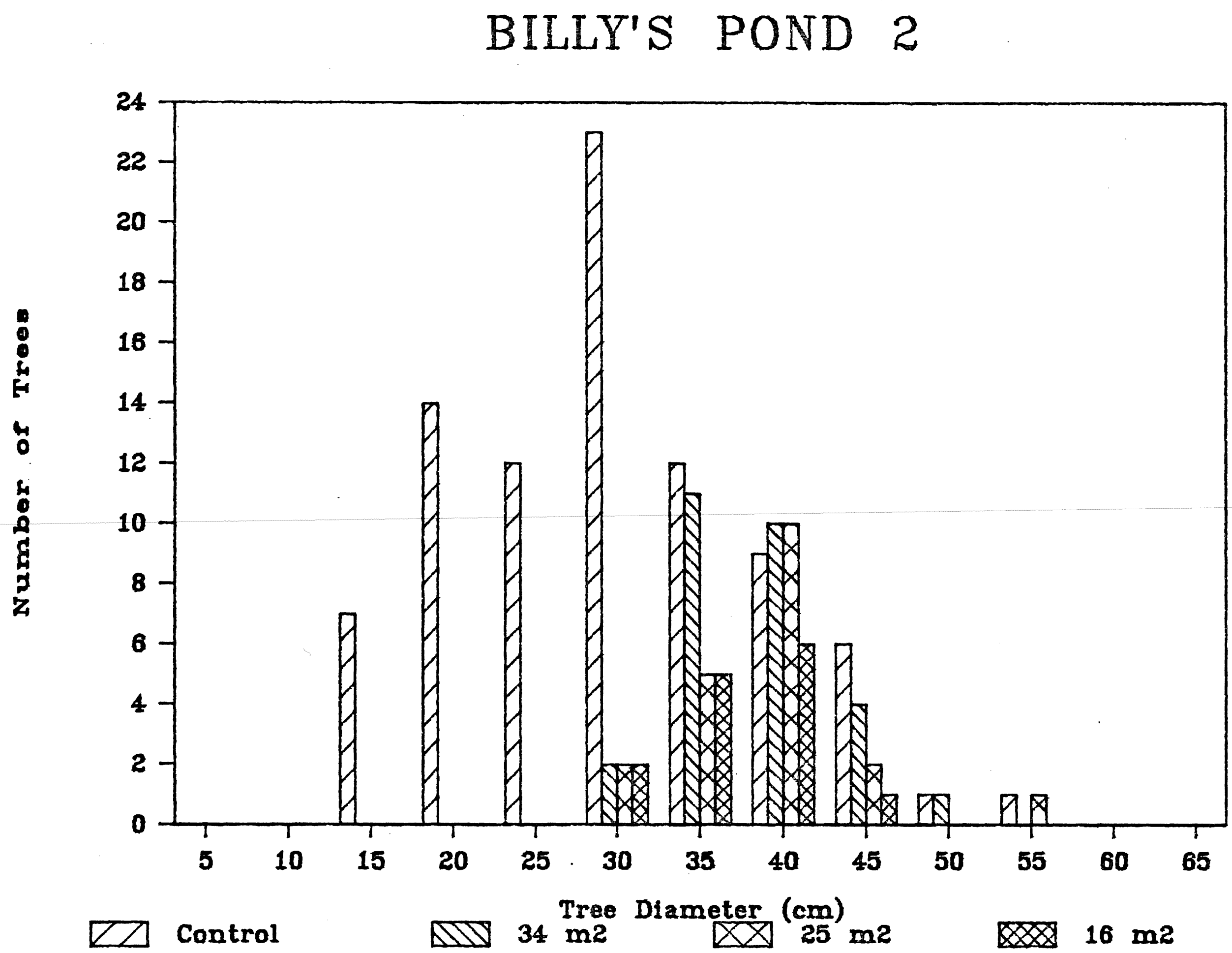

Figure 12. Distribution of tree diameters in control and harvested plots at Billy's Pond 2.

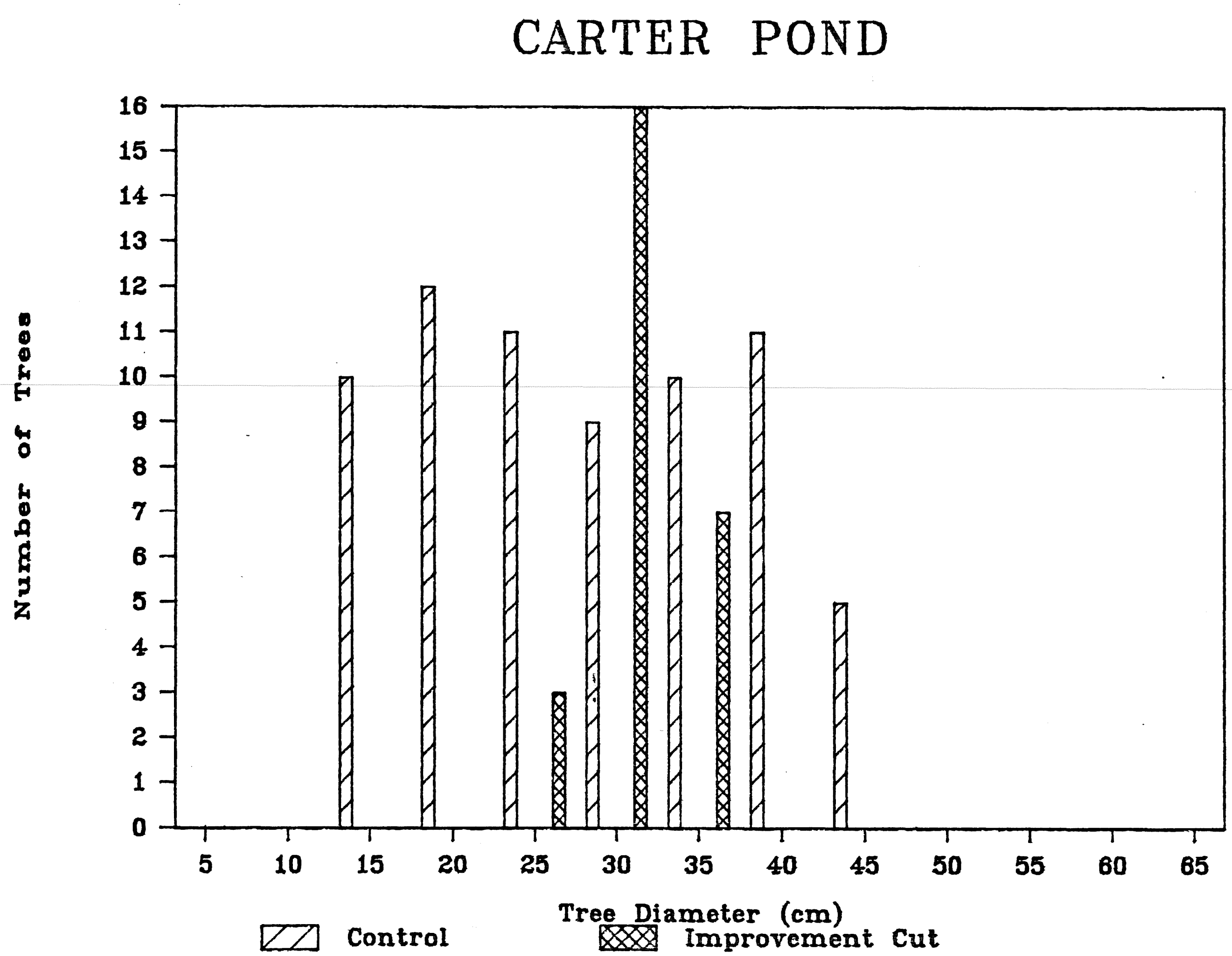

Figure 13. Distribution of tree diameters in control and harvested plots in the swamp at North Carter Pond Road.

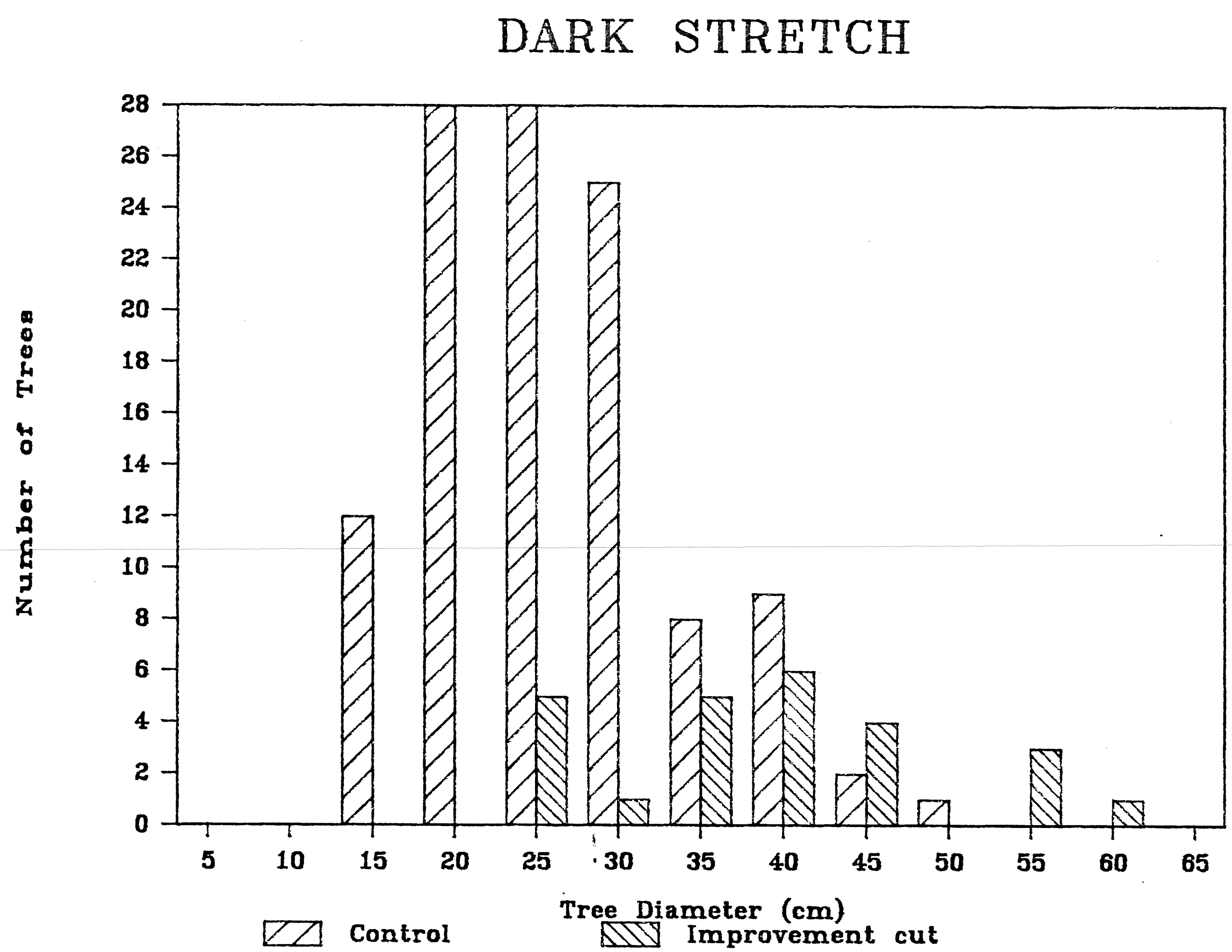

Figure 14. Distribution of tree diameters in control and harvested plots in the swamp at Dark Stretch Road.

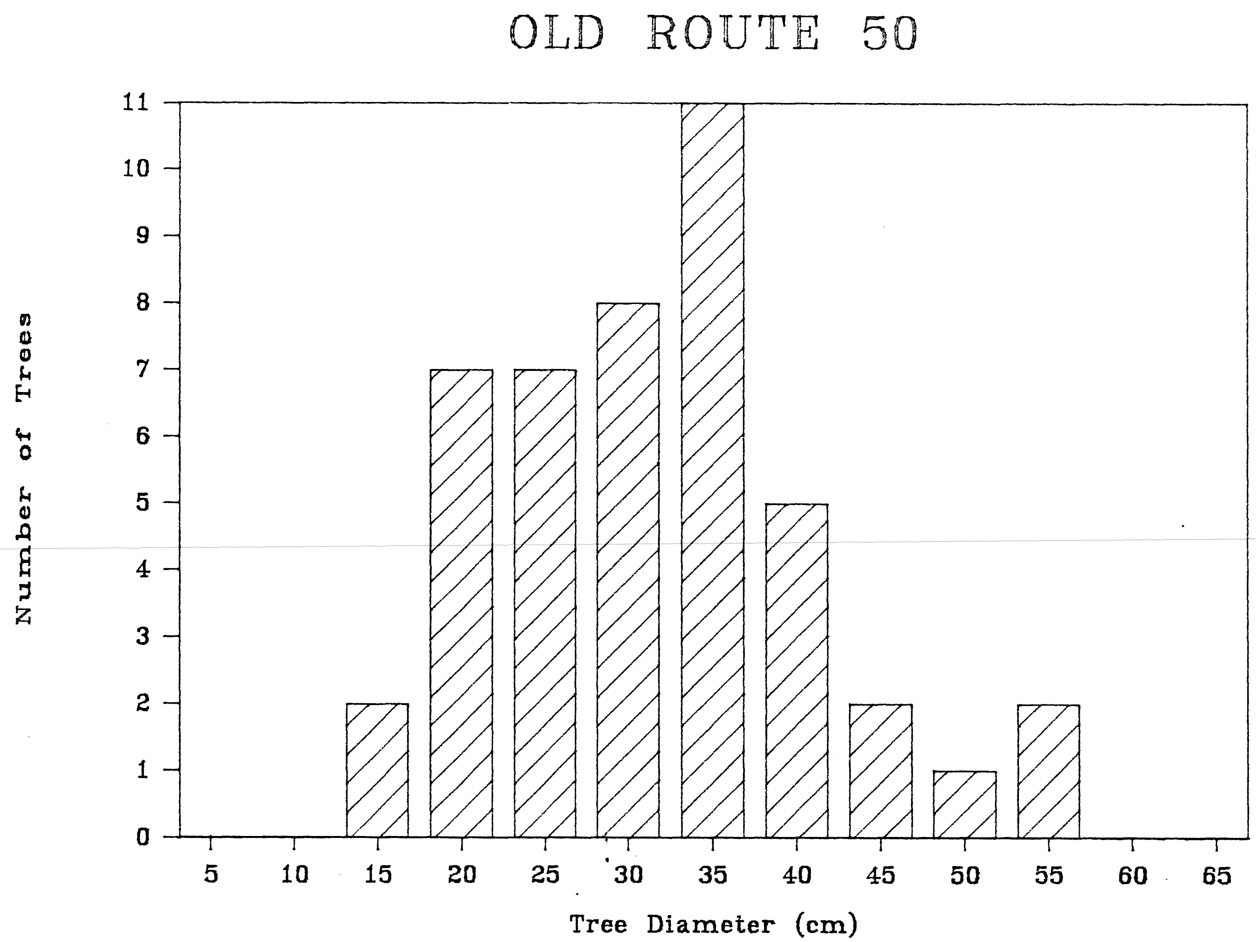

Figure 15. Distribution of tree diameters in the control swamp on Old Route 50.

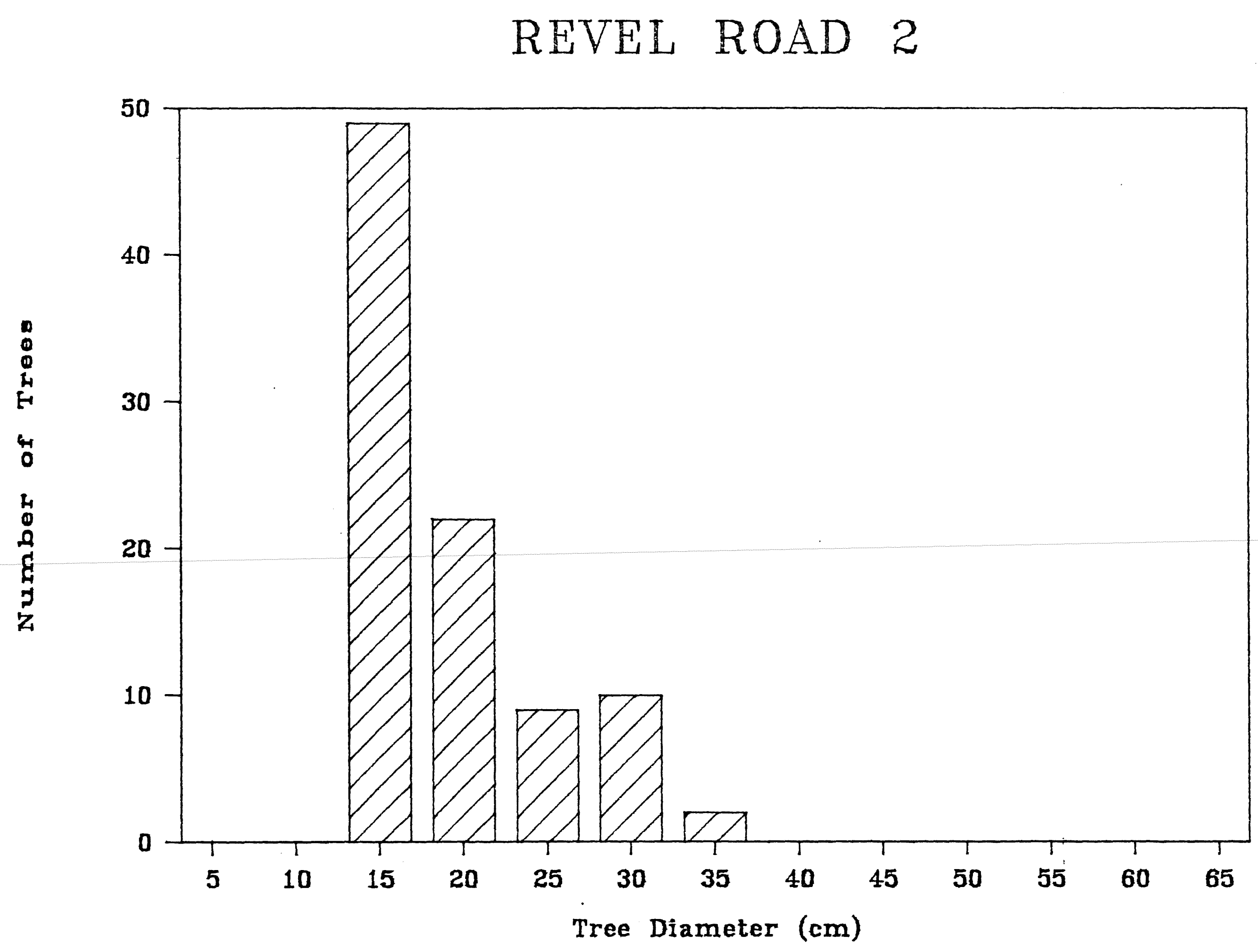

Figure 16. Distribution of tree diameters in the control swamp on Revel Road.

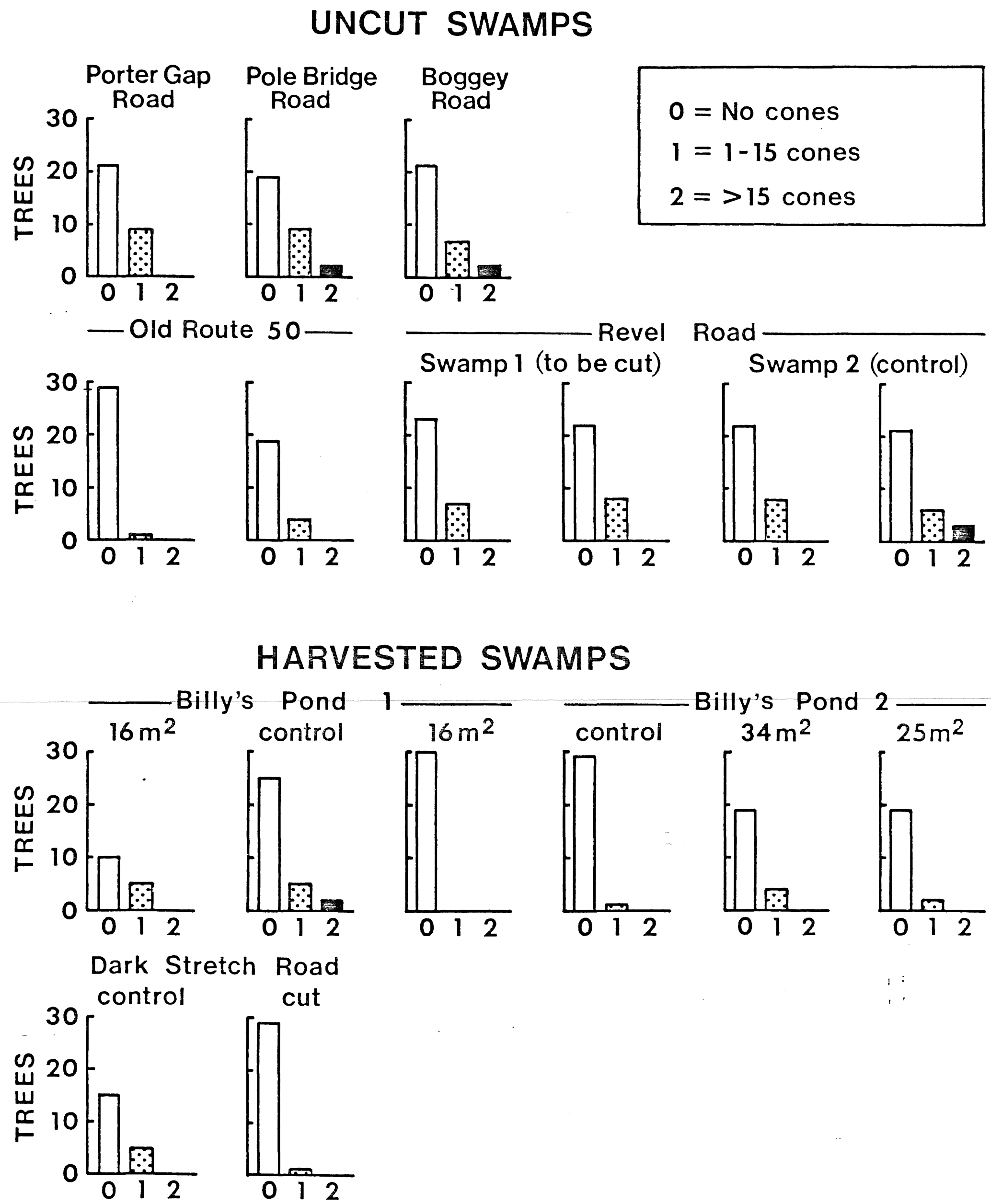

Figure 17. Cone production in 8 cypress swamps in the Withlacoochee State Forest.

Seedlings were found in four of the nine study swamps (Figure 18). There appeared to be no consistent relationship to harvesting or to cone production levels the previous fall.

Coppice Production

Among the eight harvested plots, nearly two-thirds of the stumps had some coppice, either live or dead (Figure 19). Only in the plot at North Carter Pond Road was coppice absent on more than half the stumps. Although the thinned plots with the most basal area had higher percentages of stumps with coppice than the more open plots, the sample size is too small to draw any definite conclusions. Both of the stand improvement plots produced coppice, but the incidence in the plot at Carter Pond Road was only half the level at Dark Stretch Road.

After the stand improvement plot at Dark Stretch Road was harvested, slabs were removed from several stumps for manufacturing clock faces. This is a common practice in Florida swamps, although it is often done illegally by trespassers, as in this case. Six of the seven stumps from which faces had been removed had coppice. This is a higher percentage than demonstrated by the other stumps in that swamp: 37 out of 47. However, it is not clear if the coppice had sprouted before the clock faces were cut.

The presence of significant amounts of coppice on the clock-faced stumps raises the question of whether stumps that have been cut lower produce more coppice. The differences in heights of stumps that produced coppice and those that did not were analyzed with an unpaired t-tests corrected for unequal variances (Steel and Torrie 1960). Of the 357 stumps examined in the eight plots (the stumps with clock faces removed were not included), the difference between the average height of those

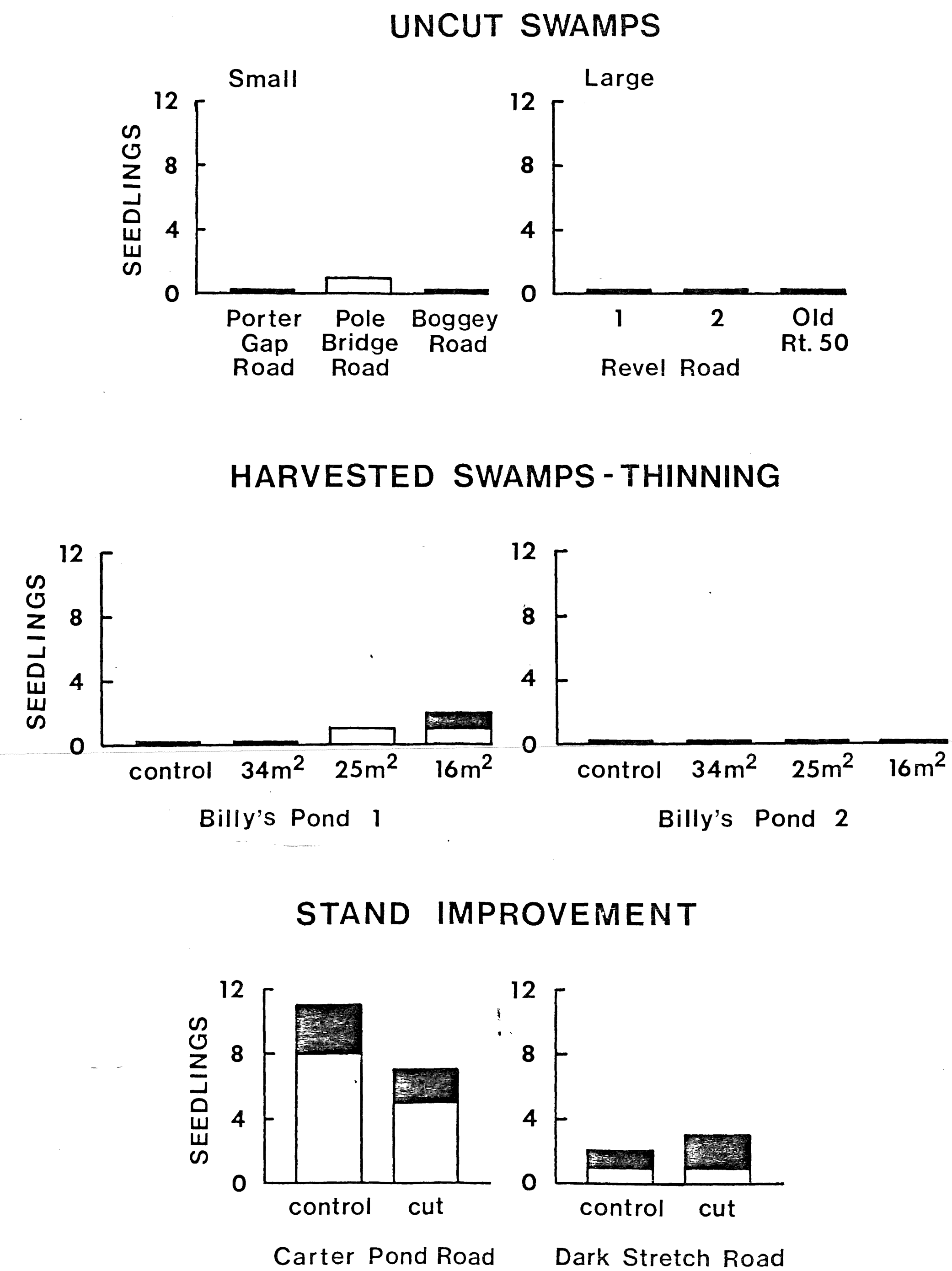

Figure 18. Seedlings in 9 cypress swamps in the Withlacoochee State Forest.

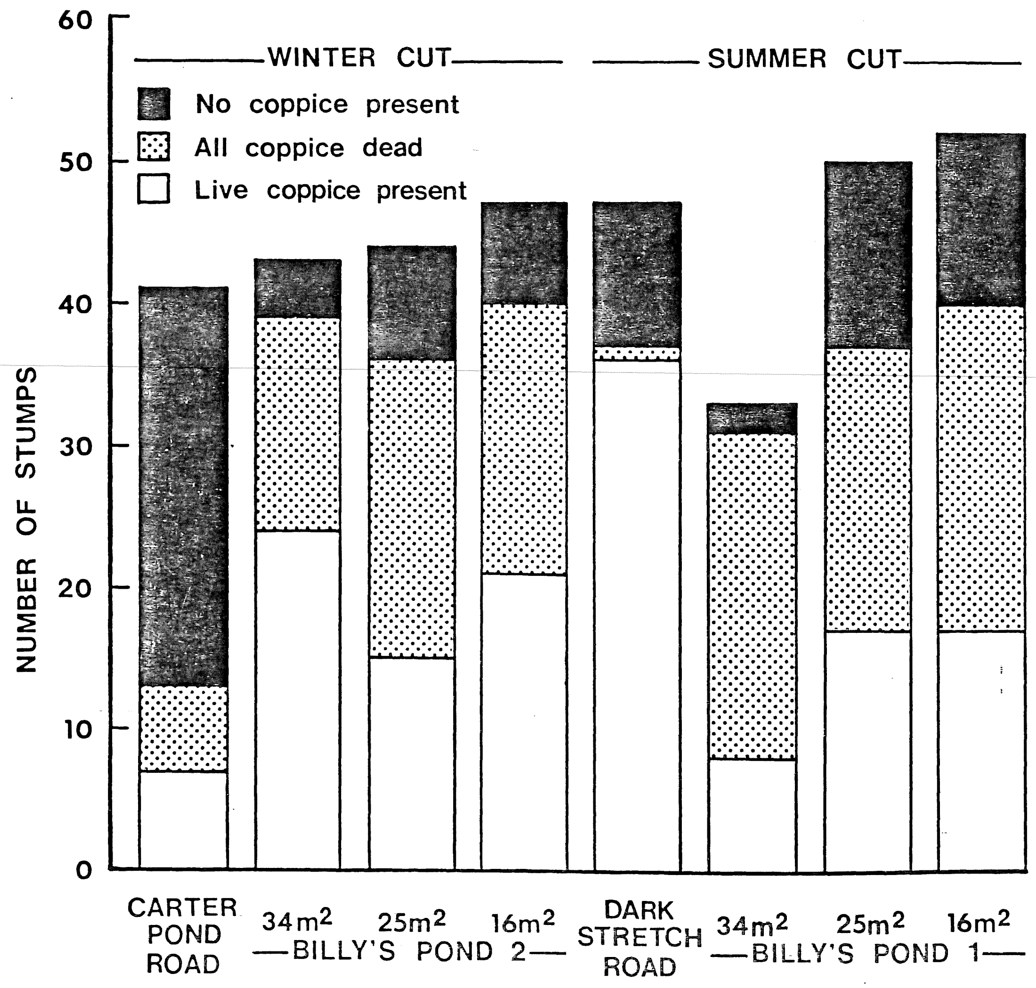

Figure 19. Coppice production at harvested plots in the Withlacoochee State Forest.

that produced no coppice (72.3 cm; n=83) and those that produced coppice (64.7 cm; n=274) was significant at the 1% level. Examination of individual plots showed that in six of the eight plots stumps producing no coppice were higher than stumps with coppice (Figure 20). However, in only one of these plots -- the stand improvement cut at Dark Stretch Road, where the stumps were cut higher -- did a t-test show a significant difference ($P<0.05$).

A linear regression between the height of a stump and the natural logarithm of the number of sprouts produced at the Dark Stretch Road site showed a significant inverse relationship ($P<0.0001$, $r^2 = 0.34$). However, the relationship between height and coppice production is clearly not absolute: of the 23 stumps 100 cm or taller throughout the entire study area, more than half (including the tallest) bore coppice. Fifteen of the 23 tallest stumps were in the Dark Stretch Road stand improvement cut, and ten of these bore coppice.

More than half the stumps bearing coppice produced more than one sprout. In the two plots in which numbers of sprouts were enumerated, at least one-third the stumps produced more than ten sprouts (Table 3). On nearly half the stumps, coppice was produced at high, medium, and low positions on the stump (Figure 21). If coppice was produced at only one or two of these levels, the middle third of the stump was the most likely location, and sprouts were more likely to be in adjacent thirds than at the two ends of a stump.

Table 3. Number of sprouts on cut stumps in two harvested plots.

Swamp	None	1 - 10	>10	Maximum
Dark Stretch Road	10	18	25	350
Billy's Pond 1	13	20	19	99

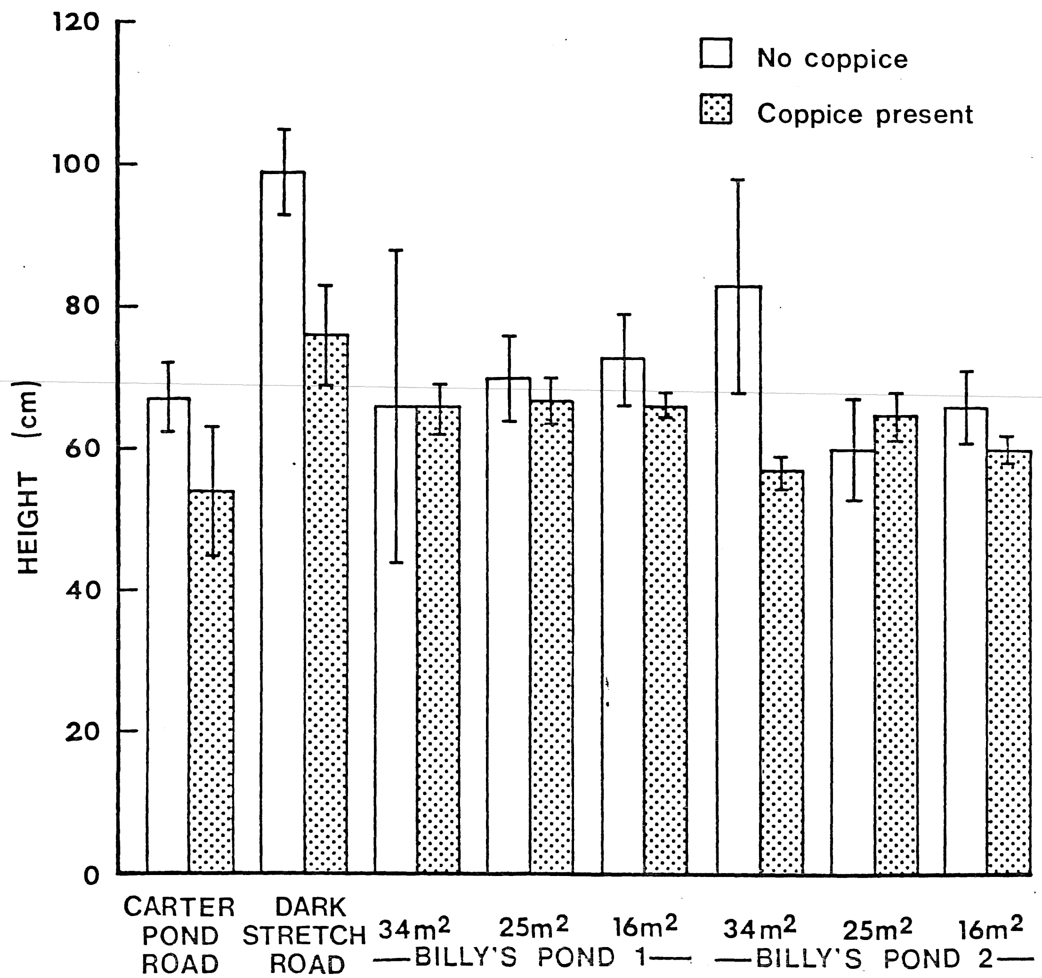

Figure 20. Coppice production and average heights of stumps at eight plots in the Withlacoochee State Forest.

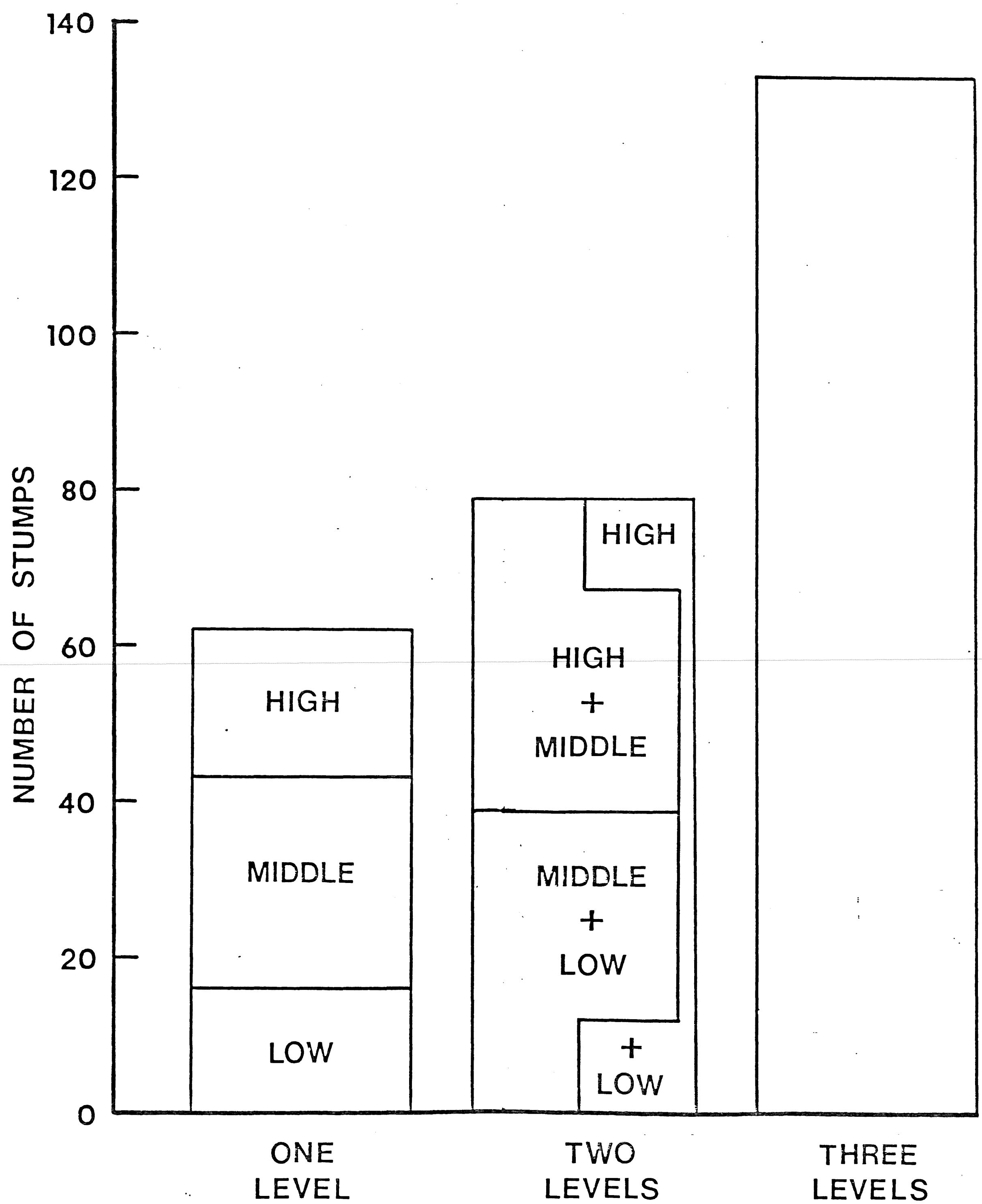

Figure 21. Distribution of sprouts on stumps at the harvested plots in the Withlacoochee State Forest.

Although total coppice production was substantial, only in the stand improvement cut in the Dark Stretch Road swamp did more than half of the stumps bear live coppice. None of the plots that were cut in Winter 1984 (North Carter Pond Road and Billy's Pond 2) showed substantially greater coppice mortality than the swamps that were cut in Summer 1984.

Evapotranspiration

ET rates estimated for the swamp at Pole Bridge Road were higher than those at the other two swamps (Table 4). The highest rates estimated (0.58 and 0.59 cm day^{-2}) were during August and September 1982, respectively; the lowest rate, 0.02 cm day^{-1}, was measured in January 1984. Average annual ET was estimated to be 79 cm in the Withlacoochee State Forest during the 3 yrs for which data were available, and average daily rates calculated for each month varied from 0.04 - 0.35 cm (Figure 22). Average annual rainfall for the 3-yr period was 151 cm.

Because solar radiation is one of the major climatic functions controlling ET rates, linear regression equations relating ET and solar radiation were calculated. Because no solar radiation data were available for the Withlacoochee State Forest, monthly averages of solar radiation from Gainesville, 116 km to the north, were used for this analysis. I assumed that although daily values might not be comparable, particularly during the summer when thunderstorms are scattered throughout the region, monthly averages were probably closely related. Although differences exist among the individual swamps, Table 5 demonstrates that all three behaved similarly.

Table 4. Monthly ET rates in three cypress domes in the Withlacoochee State Forest.

MONTH	BOGGEY ROAD	POLE BRIDGE ROAD	PORTER GAP ROAD
	----------	CM DAY^{-1}	----------
4/82	--	--	0.36
5/82	0.24	--	0.27
6/82	0.33	--	0.47
7/82	--	--	--
8/82	0.27	0.58	--
9/82	0.28	0.59	--
10/82	0.10	0.34	--
11/82	0.11	0.11	0.08
1/83	0.05	0.06	--
2/83	0.09	0.13	--
3/83	0.10	0.18	--
4/83	0.26	0.39	--
5/83	0.29	0.48	0.37
6/83	0.27	0.40	0.34
7/83	0.27	0.42	0.28
8/83	0.31	0.31	0.26
9/83	0.26	0.45	0.28
10/83	0.20	0.39	0.20
11/83	0.07	--	0.06
12/83	0.08	--	0.04
1/84	0.02	--	--
2/84	--	0.14	--
3/84	0.13	0.15	--
4/84	0.23	0.36	0.32
5/84	0.26	0.42	0.22
6/84	0.29	0.41	0.28
7/84	0.20	0.32	0.21
8/84	0.25	0.28	0.24
9/84	0.16	0.25	0.11

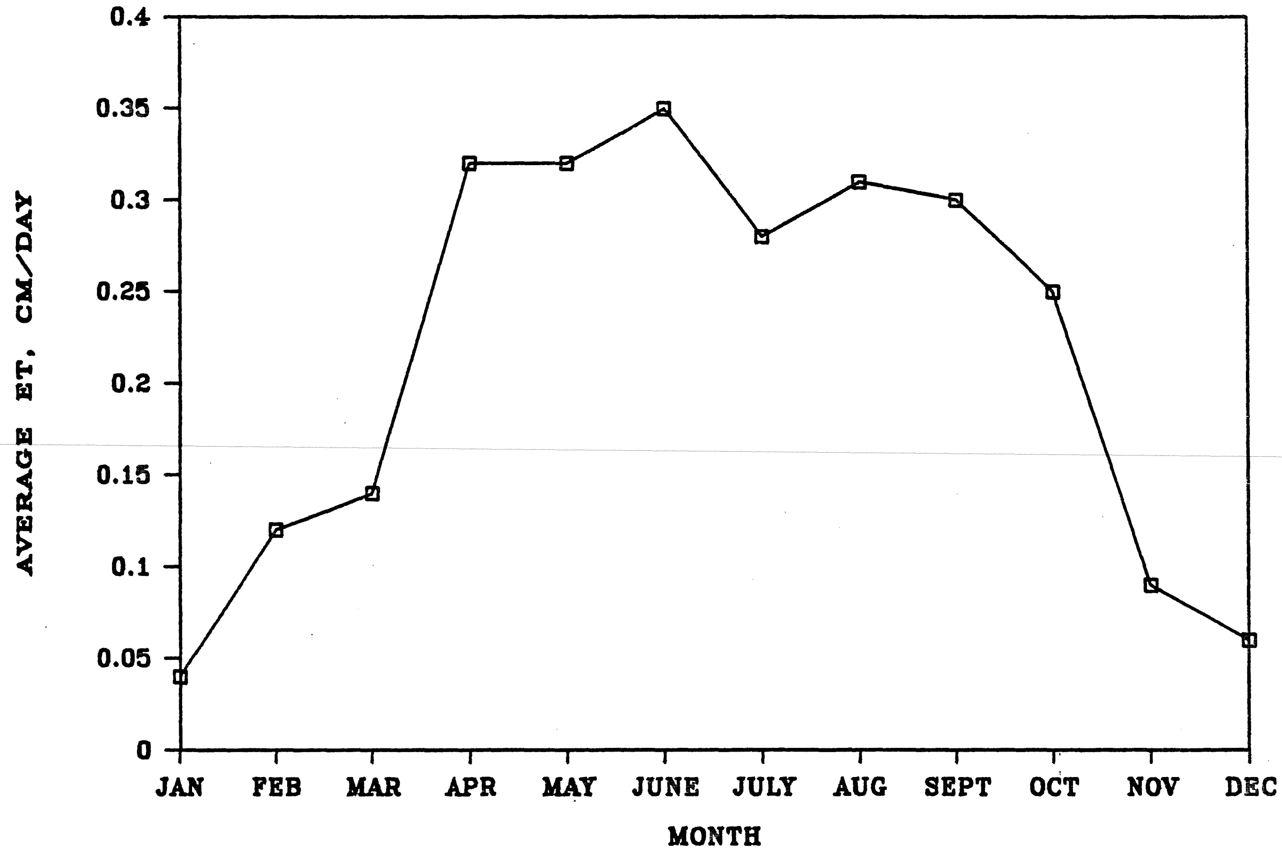

Figure 22. Average annual pattern of evapotranspiration measured in 3 swamps over 3 years in the Withlacoochee State Forest.

Table 5. Regression equations relating evapotranspiration (Y, cm day^{-1}) and solar radiation (X, langleys mo^{-1}) in three cypress swamps in the Withlacoochee State Forest.

	F	P	r^2
BOGGEY ROAD			
$Y = -0.0493 + 2.108\times10^{-5}X$	42.98	0.0001	0.70
POLE BRIDGE ROAD			
$Y = 0.0534 + 2.325\times10^{-5}X$	6.05	0.027	0.29
PORTER GAP ROAD			
$Y = -0.0487 + 2.152\times10^{-5}X$	20.81	0.0008	0.65
COMBINED			
$Y = -0.0092 + 2.153\times10^{-5}X$	24.35	0.0001	0.34

The relationships between infiltration rate and stage were highly signficant in all three swamps (SAS 1982) (Table 6). Including Julian day in the stepwise regression equation, however, increased the coefficient of determination considerably in the Porter Gap Road swamp, increased it slightly in the Pole Bridge Road swamp, and did not affect the overall equation.

Water Quality

Changes in water quality throughout the 4-month study showed no consistent trends (Figure 23; data are listed in Appendix). Total Kjeldahl nitrogen and organic nitrogen increased substantially in one swamp after thinning, but three months later both swamps had lower concentrations than the two control swamps (Figure 23a-b). One of the

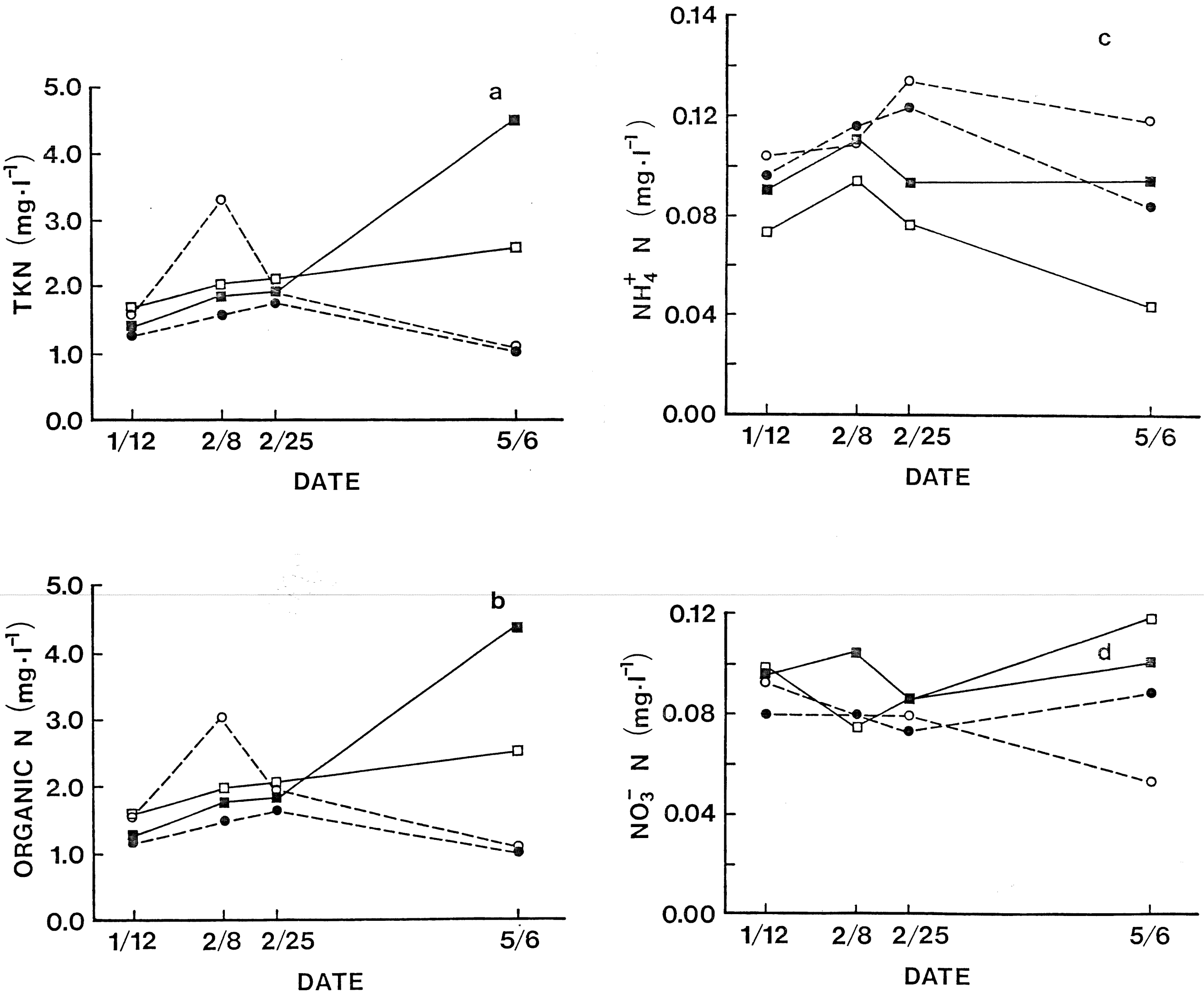

Figure 23. Concentrations of nitrogen in 4 swamps in the Withlacoochee State Forest. Circles denote concentrations in two swamps that were harvested in early February 1983: North Carter Pond Road (dark circle) and Billy's Pond 2 (light circle). Squares denote two control swamps: Billy's Pond 1 (dark square) and Dark Stretch Road (light square). a: Total Kjeldahl nitrogen; b: organic nitrogen; c: ammonium; d: nitrate

Table 6. Effects of stage and time (Julian day) on infiltration rates in stepwise regression equations applied to three swamps in the Withlacoochee State Forest. Significance probability of all F values is 0.0001.

Swamp	Number of Observations	Independent Variables	r^2	F
Boggey Road	527	Stage	0.06	31
Pole Bridge Road	468	Stage	0.17	97
		Stage+Time	0.18	50
Porter Gap Road	344	Stage	0.26	119
		Stage+Time	0.35	90
Combined	1339	Stage	0.09	130

control swamps is smaller than the others, and this swamp showed an increase in total Kjeldahl nitrogen relative to the other swamps. Dierberg and Brezonik (1984) demonstrate a positive relationship between organic nitrogen and water level. Because the swamps were drying during the study period and this was the smallest swamp, the increase in total Kjeldahl nitrogen may be explained by the change in water level. No trends at all were apparent in the NO_3^--N data or the NH_4^+-N data (Figure 23c-d).

DISCUSSION

With one exception, the cypress swamps being studied in the Withlacoochee State Forest are similar to one another in growth rates, basal area, and tree density. They clearly fall within the range described by other relatively undisturbed swamps that have been studied in Florida and south Georgia (Table 7). Revel Road 2 swamp has less biomass than the others, but it is characteristic of swamps with less organic matter in the substrate.

Table 7. Basal area in nine swamps.

Swamp	Basal Area m^2 ha^{-1}	Source
Corkscrew Swamp - 1	38	Duever et al. 1984
Sewage Dome 2	41	Deghi et al. 1980
Corkscrew Swamp - 2	43	Duever et al. 1984
Withlacoochee State Forest	44	Parendes 1983
Waldo Swamp	50	Nessel et al. 1982
Withlacoochee State Forest	56	Parendes 1983
Withlacoochee State Forest	59	Ibid.
Owen's Illinois	59	Brown 1978
Okefenokee Swamp	80	Schlesinger 1978

Regeneration After Harvesting

Thinning and stand improvement cuts are usually conducted to increase growth rates in remaining trees. Consequently, regeneration is not desired. However, if cypress trees do not respond sufficiently to thinning, it may be desirable to clearcut in part of a stand in order to begin regeneration in one portion of a stand while another is still accumulating biomass. This strategy (shelterwood) is a common silvicultural technique.

Differences in stem density caused by thinning and stand improvement cuts did not stimulate cone production or increase seed germination or survival rates during the first year following harvesting. I observed prolific cone production at two other sites, however: on the remaining live trees in a small burned pond cypress swamp less than 10 km from the Withlacoochee State Forest; and on bald cypress trees along the Santa Fe River in Alachua County, approximately 150 km to the north. Consequently, it is possible that cone production in cypress trees is affected by trauma, such as fire damage, by environmental cues that vary among ecosystems as well as among years, and/or by genetic differences between pond and bald cypress trees.

Regeneration by coppice production occurred in all the harvested stands. The pattern in the two plots where sprouts were counted resembled a Poisson distribution, with 19% to 25% of the stumps in the two plots showing no coppice, and 37% - 47% with more than ten sprouts (Table 3). Although this is an encouraging response for a shelterwood cut or a clearcut, competition from the regrowing trees may reduce the growth rates of the remaining trees in a thinned plots.

High water levels after harvesting and the use of equipment such as feller-bunchers may affect coppice production. Survivorship rates are also unknown, although the coppice regrowth was not destroyed by unusually cold weather in January 1985, if it was affected at all.

Evapotranspiration from Cypress Swamps

Determining ET from changes in volume related to stage assumes that there is no nighttime ET, and that nighttime decreases in stage are attributable only to infiltration. Although this appears to be a reasonable assumption, given the lack of solar radiation to drive evaporation, the lack of a significant temperature differential between the water and air, the lack of wind at the water surface, and the high relative humidity within the swamp (Heimburg 1976), the infiltration data suggest that a slight seasonal effect may be present. However, because no ET rates are calculated for rainy days, when ET can be expected to be minimal, it can also be argued that ET rates are underestimated. I assumed these two effects cancelled one another, and that my calculations approximate ET. The strong relationship between ET and solar radiation supports this conclusion.

ET rates measured in the swamp on Pole Bridge Road are clearly different from the rates in the other two swamps. Ecologically, however, the three swamps appear to be very similar. Mean water depth measured in the centers of the swamps did not differ significantly during Parendes' study; alhough organic matter was deeper than in the other two, the differences were not significant. Growth rate was the slowest of the three, although, again, the difference was not significant.

In spite of differences in absolute ET rates among the three swamps, the combined regression equation in Table 5 demonstrates that the swamps behaved similarly in terms of both seasonal patterns and overall relationship to solar radiation.

Riekerk (in press) estimated ET in slash pine flatwoods in north Florida over the same 3-yr span as this study to be 103 cm yr^{-1}, or 74% of rainfall. Average annual ET at our site was 79 cm, or 52% of rainfall. These results corroborate earlier reports of low ET rates in cypress swamps (Brown 1981, Heimburg 1984) and provide a more direct comparison between ET rates in a wetland and in an upland than has been available previously.

Impact of Harvesting on Water Quality

This study suggests that, although harvesting may initially increase the content of organic nitrogen in the water column, this is not likely to be long-lasting, and that natural changes in nitrogen concentration caused by water level fluctuation may have as dramatic an effect. If harvesting in cypress swamps were confined to times of low water, any resulting changes in water quality could be restricted to the harvested swamp, preventing changes from occurring downstream. A major question that remains is whether long-term changes in water quality are effected in the swamp by harvesting and the subsequent exposure of the water and sediments to increased solar radiation.

MANAGEMENT IMPLICATIONS

Cypress regeneration depends in part on cone production, which was uniformly low in the study area during the 1984 period of reproductive activity. However, considerable coppice production was recorded in swamps that were cut both in the summer and the winter. This response may prove to be detrimental if it leads to a decrease in growth rates in the remaining trees; it may be a dependable method of regeneration if partial or complete clearcutting proves to be the best regeneration techniques.

A preliminary analysis suggested that water quality changes resulting from harvest operations may be short-lived and perhaps indistinguishable from changes that occur naturally during the rise and fall of water in the swamp. However, ET from cypress swamps was less than from pine flatwoods. This suggests that large-scale harvesting of cypress swamps may lead to increased water loss in a region. Consequently, it is essential to determine the impacts of different harvest methods on water loss and to analyze the speed with which these impacts are diminished through succession.

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APPENDIX

Swamp

Thinned - 1	January 12 $\bar{x}$	SE	February 8 $\bar{x}$	SE	February 25 $\bar{x}$	SE	May 6 $\bar{x}$	SE
NH_4	0.104	0.027	0.109	0.026	0.134	0.027	0.119	0.017
NO_3	0.093	0.027	0.080	0.022	0.080	0.012	0.054	0.025
TKN	1.625	0.299	3.417	0.645	2.083	0.389	1.229	0.243
Organic N	1.532	--	3.308	--	1.949	--	1.110	--
Thinned - 2								
NH_4	0.096	0.023	0.116	0.024	0.124	0.024	0.084	0.024
NO_3	0.080	0.017	0.080	0.018	0.074	0.022	0.089	0.024
TKN	1.271	0.206	1.583	0.244	1.792	0.210	1.146	0.815
Organic N	1.175	--	1.467	--	1.668	--	1.062	--
Control - 1								
NH_4	0.074	0.017	0.094	0.017	0.076	0.018	0.044	0.019
NO_3	0.098	0.028	0.075	0.015	0.086	0.026	0.119	0.034
TKN	1.667	0.145	2.083	0.187	2.125	0.118	2.583	0.569
Organic N	1.593	--	1.989	--	2.049	--	2.539	--
Control - 2								
NH_4	0.091	0.267	0.115	0.017	0.094	0.021	0.095	0.022
NO_3	0.096	0.022	0.105	0.019	0.086	0.022	0.101	0.022
TKN	1.375	0.219	1.875	0.280	1.917	0.345	4.500	1.025
Organic N	1.284	--	1.760	--	1.823	--	4.405	--