

AN ECOLOGICAL STUDY OF BALD CYPRESS,

Taxodium distichum (L.) RICH.,

IN EASTERN NORTH CAROLINA

A thesis

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by

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ABSTRACT

Cynthia Elizabeth Blanck. AN ECOLOGICAL STUDY OF BALD CYPRESS, Taxodium distichum (L.) Rich., IN EASTERN NORTH CAROLINA. (Under the direction of Dr. Vincent J. Bellis) Department of Biology, East Carolina University, June 1980.

Bald cypress (Taxodium distichum) was studied at three sites along Albemarle Sound in northeastern North Carolina. At each site, there was an offshore stand of bald cypress which we termed a "Cypress Fringe". Behind the cypress fringe was a sandy beach, a small sand berm and finally a swamp forest of mixed bald cypress - tupelo gum.

Observations of the swamps revealed no bald cypress or tupelo gum seedlings although some young tupelo gum trees were noted. However, bald cypress seedlings were observed growing on the storm tide driftline along the beach. In order to determine whether the light intensities in these swamps were too low to support the growth of seedlings, bald cypress and tupelo gum seedlings were grown under controlled environmental conditions.

Seed germination experiments using selected temperature regimes revealed that both bald cypress and tupelo gum seeds germinated best at 30/20°C and 35°C. Following germination of the seed, seedlings were grown to a mean height of 13 cm for use in growth

response experiments. The plant growth chambers supplied four different light regimes. Light intensity, which was measured as Photosynthetically Active Radiation (PAR), roughly simulated field conditions as follows: PAR-27 (swamp), PAR-308 (intermediate), PAR-641 (beach) and PAR-1000 (full sunlight). After 3 months exposure of the seedlings to long day conditions statistical analysis of the data revealed that the seedlings in treatment group PAR-641 (beach) produced significantly higher values for each parameter measured ($p < 0.01$), with the exception of chlorophyll concentration per unit leaf area, than did the seedlings in the other three treatment groups. PAR-641 seedlings were taller, sturdier, and exhibited large diameters and higher dry weights. Seedlings grown under "swamp" conditions (PAR-27) produced short, slender stems, and lower dry weights.

Species comparison yielded higher values for tupelo gum seedlings for the following parameters: incremental growth rates; leaf area; wet weight; total dry weight; each compartment of biomass partitioning: leaves, roots, and stems; and stem diameter. Bald cypress seedlings exhibited higher chlorophyll concentrations, higher root/shoot ratios and greater photosynthetic ratios than tupelo gum seedlings.

The bald cypress fringe functions in its own regeneration. It serves as a seed source, dropping its seeds in the water where they are washed up on the driftline. And, as the field studies have shown, the cypress fringe also functions to trap sand and sediment, thus retarding erosion. The offshore bald cypress trees also dampen wind and wave energy that would destroy otherwise unprotected cypress seedlings.

Estimation of maximum local erosion rates was shown to be possible in areas with an offshore stand of bald cypress trees.

It is proposed that tupelo gum will, in the distant future, replace bald cypress over most of its range. It appears that, with constant stress from rising sea level, erosion, and angiosperm competition within the swamp, the range of bald cypress may be reduced to cypress domes and protected river systems in Florida.

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by

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INTRODUCTION

North Carolina, with nearly 3000 miles of estuarine shoreline, has one of the three largest estuarine systems in the United States. Comparison of recent and 30 year old air photos of North Carolina estuarine shoreline indicates shoreline erosion rates up to 20 feet per year. Erosion is widespread in the Albemarle-Pamlico region with typical shoreline losses of 2 to 3 feet per year (Bellis et al. 1975). Shoreline erosion is least evident along cypress swamps or headlands, or where the eroding bank is protected by a bald cypress (Taxodium distichum) fringe. The cypress in these areas act as natural buffers which reduce onshore wind and dissipate wave energy, thus retarding shoreline erosion. Extensive logging of bald cypress between 1870 and 1918 may have destroyed much of the cypress fringe and subjected the exposed shoreline to greater erosion. Although stump-sprouting is common in bald cypress, regeneration is poor. Logged cypress swamps are usually replaced by tupelo gum (Nyssa aquatica).

Three sites on the Albemarle Sound near Edenton, North Carolina were selected for an ecological study of T. distichum. Although each site differed, all had a row or stand of offshore cypress with a tupelo gum-bald cypress swamp behind, separated by a sandy beach. Each

swamp had an opening to the sound. During the course of this study the following field observations were made on natural processes.

Wherever a cypress fringe was prevalent, its buttressed trunk bases and anastomosing root systems appeared to form an effective natural bulkhead. It was observed that the cypress fringe lowered wave amplitude or changed wave direction from parallel to perpendicular to the beach. Sediments usually accumulated along this line (behind the fringe) which resulted in a sand bridge between the tree and the shoreline. Fallen trees functioned as natural groins and trapped sediment carried into the cypress fringe. Although cypress produces abundant viable seeds, seedlings and young trees were seldom observed in the forest behind the cypress fringe. Seed germination was abundant along former driftlines wherever beach accretion was observed. However, young seedlings frequently failed to mature because they were washed away during storms. Seedling survival was highest along the protected sand berm which formed from accreted sands behind the cypress fringe. The cypress fringe thus created the seedbed required for regeneration of a future cypress fringe. To help understand the distribution of bald cypress in the field, and to determine whether it was feasible to grow cypress in commercial quantities for use as natural bulkheads, it was necessary to investigate the requirements of seeds and seedlings for germination and growth under controlled conditions.

From these field observations, specific objectives were established:

1) study seed germination-temperature response, 2) determine the effects of various light intensities on growth of bald cypress and tupelo gum seedlings, and 3) measure and compare the photosynthetic rates of cypress and tupelo seedlings under various light intensities.

All laboratory studies were carried out in controlled environment chambers located at the Southeastern Plant Environmental Laboratories (S.E.P.E.L.) in Raleigh, North Carolina. Bald cypress and tupelo gum were used in these experiments because they frequently occur as codominants in swamp forests.

Field objectives included: 1) comparison of wave amplitude in front of an open beach and within the cypress fringe, 2) comparison of wind velocity in front of an open beach to that within the cypress fringe, 3) development of a method to estimate local rates of erosion based on the age of the cypress trees and their distance from the present shoreline.

LITERATURE REVIEW

Taxodium distichum (L.) Richard (bald cypress), one of the oldest components of the North American tree flora (Elliot and Mobley 1938), is one of only two extant deciduous conifers and derives its common name "bald cypress" from this characteristic. A unique feature of bald cypress is its ability to produce emergent outgrowths from its roots when the tree is growing under conditions of prolonged hydroperiod. These conical growths, called "cypress knees", have captured the interest of botanists and naturalists for over a century. Various theories have been proposed to explain the formation and function of cypress knees. Mattoon (1915) regarded cypress knees as stabilizing structures produced in response to soft substrate and the absence of a tap root in mature trees. Others, calling the structures "pneumatophores", suggested that they develop in response to fluctuating water level and function in gas exchange. Following the refutation of the pneumatophore theory by Kramer et al (1952), it was suggested that a cypress knee is a genetic characteristic expressed only when bald cypress roots are exposed to air (Whitford 1956). Although bald cypress has received much attention related to its unique morphology and habitat, longevity, resistance to decay and inherent beauty, relatively little experimental work has been carried out to elucidate its growth requirements.

An extensive paper by Mattoon (1915) described properties of the wood, geographical distribution, characteristics of the tree, and forest management procedures. Later research focused on describing forest communities in various regions of the Southeast (Wells 1924, 1928, North Carolina; Hall and Penfound 1939, Louisiana; Beaven and Oosting 1939, Maryland). Wells (1924) classified a pure bald cypress forest as an edaphic subclimax formation. He noted that, "pure cypress forest absolutely controls the area, but not permanently, for no reproduction of itself takes place while the old trees stand." Absence of regeneration as well as knee development in mature stands of bald cypress was also reported by Cain (1935).

While earlier work was oriented toward applied forestry, later research centered on the requirements and tolerances of individual tree species. Interest in cypress seeds and seedlings is illustrated by the seed soaking experiments of Toumey and Durland (1923), seed germination studies of Barton (1930) and submerging experiments by Welch (1931) and Demaree (1932). These studies demonstrated respectively that: Taxodium distichum seeds could remain viable after soaking for a period as long as 20-30 days in warm, stagnant water; cypress seeds demand a very high degree of soil moisture for successful germination; and that although cypress seedlings can successfully withstand submersion for short periods of time, prolonged submersion of the leaves results in death of the seedling. The late

1930's marked the end of major logging and commercial importance of bald cypress (Sternitzke, 1972). This resulted in waning research interest among botanists.

Difficulty in logging scattered trees and reports of slow growth and slow regeneration appear also to have dampened foresters' interest in bald cypress for almost three decades. It was not until the 1960's that experimentation with bald cypress was reinitiated. Once again interest centered around swamp forests as communities. Investigators began to explore relationships among community members as well as between specific organisms and the forest as a whole. Monk (1966, 1968) and Monk and Brown (1965) described environmental relationships of forest vegetation in the cypress forests of Florida. Wetland development possibilities seem to have heightened interest in swamp forest studies during the past decade.

Reproduction by Stump Sprouts and Seeds

Vegetative reproduction (also known as stump sprouting) occurs commonly in bald cypress and is particularly evident in logged areas (Mattoon 1915, Betts 1945). Poor reforestation by cypress, however, remains a puzzle to foresters. Langdon (1958) reported that cypress produce seeds every year with optimum seed production occurring every third year. Seeds are generally disseminated by flowing water since they are too heavy to blow far in the wind. However, seeds

are relatively large and buoyant and can remain afloat for at least several weeks until they are eventually deposited on moist soil. Thus proximity to flowing water may account in large measure for the geographic range of bald cypress along coastal plain streams and swamps of the southeastern United States.

When grown in culture, bald cypress apparently has rather exacting seedbed requirements (Mattoon 1915, Stubbs 1975). The USDA Woody-plant Seed Manual (USDA 1948) reports that cypress seed germination averages 40-60%, although it may range from 9% under poor conditions to 87% under optimum conditions. There are no data on seed germination under natural conditions.

Reproduction and the Influence of Water Level (Hydroperiod)

Adequate moisture is generally considered to be a major requirement for germination of bald cypress seeds (Mattoon 1915, Demaree 1932, USDA 1974). There must be enough water to allow swelling and softening of the hard seed coat. Soaking experiments on bald cypress seeds, as well as on seeds of its ecological associate, tupelo gum (Nyssa aquatica) (Langdon 1958), have indicated that water quantity and quality are both important factors affecting seed germination.

Today it is widely accepted that cut-over bald cypress swamp forests in the southeastern United States are not regenerating

naturally (Walker 1967). For bald cypress to become established in swamps, its seed must sprout on moist unflooded ground after flood waters recede, and the seedlings must grow tall enough the first year to avoid prolonged submersion during subsequent floods (Demaree 1932, Odum 1959). Montz and Cherubini (1973) considered floating alligator weed mats to be a contributing factor promoting germination of bald cypress seed because the floating mats prevented total submersion of the seed. Under these conditions bald cypress was able to extend into the Louisiana marsh. Under optimum conditions in nature, seedlings often reach heights of 8-10 inches during the first growing season and 16-20 inches by the second (Mattoon 1915, Demaree 1932, USDA 1972a).

Tupelo gum (N. aquatica) is a frequent associate of bald cypress in southern river swamp forests. Tupelo gum typically has a straight trunk with a flared or swollen base and alternate simple leaves which are thick and dark-green on the surface. The fruit (a drupe) is slightly cone-shaped with a pulpy endocarp and a seed coat with an outer fleshy layer and an extremely hard inner layer. Although tupelo gum cannot withstand inundation as long as bald cypress can, it can survive periodic immersion in several inches of standing water during seasonal fluctuations (USDA 1972b). A co-dominant with bald cypress in the swamp forest, tupelo gum is much more capable of reforestation following logging than bald cypress.

Although parent trees of bald cypress and tupelo gum can tolerate frequent inundation, germination of their seeds has been shown to be inhibited by total or prolonged submersion. According to DeBell and Naylor (1972), seed inhibition may result from oxygen deprivation in stagnant swamp waters.

Frequent periodic flooding rather than complete inundation by either flowing or stagnant water may promote increased growth in bald cypress (Silker 1948). Experimental studies by Hosner and Boyce (1962), Monk (1968), Dickson et al. (1965 as cited in Dickson and Broyer 1972), and Silker (1948) have shown that swamp forest dominants often grow better in saturated than unsaturated soil.

Seedling development in bald cypress and tupelo gum depends upon maintenance of adequate internal water tension. Dickson and Broyer (1972) reported that bald cypress seedlings are more sensitive to low soil moisture than seedlings of tupelo gum. Their studies indicated that seedling growth was inhibited by exposure to less than optimal soil moisture. They also reported that seedling growth was inhibited, even when soil moisture was adequate, if the dissolved oxygen content of the surrounding water was low. Apparently low oxygen tension inhibits moisture uptake by the seedling and thus creates symptoms of moisture stress.

Individual cypress trees show a limited capacity to adjust to inundation. If flooding is sudden and dramatic as in the case of

Reelfoot Lake, Tennessee, which formed during the New Madrid earthquake of 1812, then the trees do not survive. However, under conditions of gradual submergence bald cypress are able to adjust and survive. An example of this type is exemplified by Dead Lake, Florida, where slow sea level rise has left its record in a series of bald cypress trees stranded well out from the present shoreline (Vernon 1949).

Seed Germination

Information concerning the germination of bald cypress seeds is very limited. Toumey and Stevens (1928 as cited by Barton 1930) found that the average germination for seed samples after 50 days was 0.7% while the highest was 3%. Barton (1930) herself obtained less than 10% germination with unstratified seeds as compared with 39% following stratification for one month at 5°C. This led to the theory that T. distichum seeds exhibit a delay in germination resulting from a period of embryo dormancy. As Murphy and Stanley (1975) point out, the USDA Woody-plant Seed Manual (1948), the USDA Yearbook of Agriculture (1961), and the USDA Seeds of Woody Plants in the United States (1974) all recommend a 60-90 day cold stratification period for good germination. Therefore, most previous attempts to promote seed germination have concentrated on treatments designed to break physiological dormancy.

Biwas et al. (1972) attempted to induce seed germination by various chemical and physical treatments. Treatments intended to

overcome dormancy included stratification and soaking in various solutions (gibberellic acid, potassium nitrate and thiourea) or a combination of the two. They concluded that while cold stratification for 60 days or chemical treatment alone promoted greater and faster germination in bald cypress seeds, combined stratification and chemical applications did not enhance germination.

In contrast to experiments designed to break dormancy, Murphy and Stanley (1975) reported that bald cypress seeds do not require a period of physiological dormancy. They found that the main obstacle to bald cypress seed germination was the hard and impermeable seed coat. Therefore they investigated the effects on germination of T. distichum seeds of seed-coat removal, warm-water soaking, cold stratification, dry-cold storage and acid treatment. These experiments convinced them that bald cypress embryo development was inhibited by the physical barrier presented by the seed coat. Treatments which removed portions of the seed coat increased germination, while complete removal of the seed coat resulted in germination after only 24 hours.

Shade Tolerance

The relative shade tolerance of bald cypress has not been definitely established. As cited in various editions of Forest Service Bulletin 206, T. distichum has been listed in every shade tolerance category: very intolerant (Zon and Graves 1911), intermediate (Mattoon 1915) and

tolerant (Putnam 1951). Although Wells (1928 as cited by USDA 1965) found that bald cypress seedlings could germinate in heavily shaded places, regeneration was most successful in openings rather than beneath crown canopies. Moreover, although bald cypress is capable of steady growth under partial shade, optimum growth was observed under conditions of high light intensity (USDA 1965).

Browder et al. (1974) indicated that maximum biomass was achieved in seedlings grown at 80% available sunlight as measured with a photographic light meter. There were no reports in which optimum photosynthetically active radiation (PAR) was measured or determined.

MATERIAL AND METHODS

Study Sites

Three study sites were established along Albemarle Sound near Edenton, North Carolina (Fig. 1): 1) Bluff Point, approximately 35 km east of Edenton on the north shore of Albemarle Sound; 2) Sandy Point, approximately 23 km east of Edenton on the north shore of Albemarle Sound; and 3) Black Walnut Point, located on the western shore of Albemarle Sound, 18 km southeast of the U.S. Highway 17 bridge across the Chowan River.

Each site consisted of an offshore stand of bald cypress with a swamp forest behind. The forest canopy was dominated by tupelo gum (N. aquatica) with some bald cypress (T. distichum) also present. According to area residents, at least two of the sites (Bluff Point and Sandy Point) were logged during the early 1900's.

At Bluff Point (Fig. 2) the swamp is adjacent to the shore where a bank 7 m high gives way to the east to a low bank (height $\leq 2\text{m}$) and grades into a sandy beach. The swamp is separated from the beach by a sand berm. There is an open channel between the sound and the swamp which functions to maintain standing water in the swamp (from a few centimeters in the summer to several decimeters in the winter). Wind tides and lunar tides affect the water level in the sound and this in turn affects the direction of water flow through the channel. When

Fig. 1. Map of northeastern North Carolina showing the three study sites. Insert shows relation of map to the rest of the state.

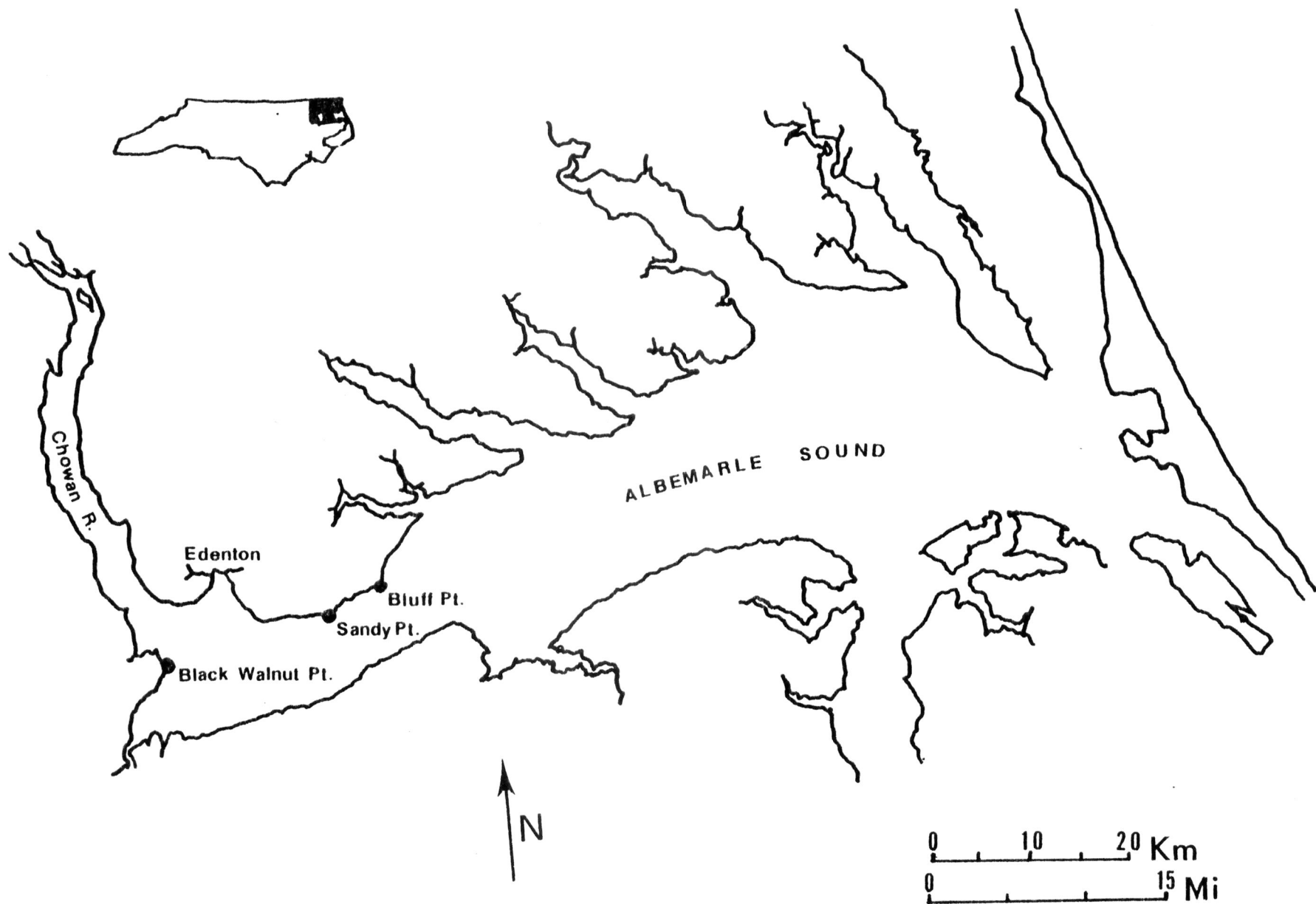


Fig. 2. Study site at Bluff Point on Albemarle Sound
in North Carolina.



water in the swamp is unusually high, water rushes through the channel into the sound. When the swamp level is low, the reverse is true, with oligohaline sound water entering the swamp.

Sandy Point is morphologically similar to Bluff Point. However the swamp is located farther back from the shore except at the open channel which is a sandy-mucky expanse 5-8 m wide grading down to the beach (Fig. 3). Thus the swamp and the sound are connected only during periods of high water.

Black Walnut Point is characterized by a flat sandy beach bordered by a clay-sand bank 5 m high (Fig. 4). To the south the bank grades horizontally into a low swamp of bald cypress and tupelo gum. The swamp itself grades directly into the sound with no sand berm to separate the offshore fringe from the leading edge of the swamp forest. Thus the front part of the swamp is continually inundated. Within the cypress fringe, trees are relatively sparse; however, density increases with proximity to the swamp.

These sites were chosen due to similar morphology, the fact that they offer easy access, and the variety of size classes and offshore distances of bald cypress trees.

Seeds

Fresh seeds of bald cypress were collected from three sites along Albemarle Sound in northeastern North Carolina during October and

Fig. 3. Study site at Sandy Point on Albemarle Sound
in North Carolina.



Fig. 4. Study site at Black Walnut Point on Albemarle
Sound in North Carolina.



November of 1975 (Fig. 1). Tupelo gum fruits were collected in December 1975 from a river swamp forest at Grimesland, Pitt County, North Carolina. Bald cypress seeds were picked from the cones and kept in dry storage until use. Tupelo gum fruits were kept in cold storage (5°C) in plastic bags.

Seed Germination

Bald cypress seeds were digested for 4 h in concentrated sulfuric acid, thoroughly washed and then rinsed in deionized water. Seed germination was carried out in dark germination chambers at the Southeastern Plant Environmental Laboratories (S.E.P.E.L.) at North Carolina State University in Raleigh, North Carolina. Eight germination temperatures were employed: 10°C, 15°C, 20°C, 25°C, 30°C, 35°C, 25/15°C, and 30/20°C. (In the case of divided temperatures, the two temperatures correspond to a day/night 12/12 h alternating temperature regime). Fifty seeds of each species were planted in Peatlite potting medium in 2 inch deep seed germination flats, and the seed flats exposed at each experimental temperature. Emergence of the hypocotyl was used as the criterion for germination success. Germination counts were made every other day. After 2 months all undeveloped seeds were split open to determine the number of "empty" seeds. Three 100 seed subsamples from the same seed batch were opened to determine the average number

of seeds with turgid embryos, i.e. "viable" seeds. Germination success was defined as the percentage of viable seeds which actually germinated.

A second group of seeds of both species was germinated under optimal environmental conditions for each species as determined by the first germination experiment. This was done to provide healthy uniform populations of seedlings for growth rate and photosynthetic response experiments.

A separate experiment was carried out at East Carolina University to determine the effect of varying exposure times to concentrated sulfuric acid on the germination of bald cypress seeds. Seeds from the original collection were digested in concentrated sulfuric acid for differing lengths of time: 1, 2, 2.5, 3, 3.5, and 4 hours. One hundred seeds from each treatment group were placed in Vermiculite and placed in a Percival Plant Growth Chamber, equipped with 1 Gro-Lux tube and 3 Westinghouse White-lite tubes. Chamber temperature was maintained at 25/15°C. Germination counts and percentages were calculated as described previously.

Growth Rate Experiments

Growth rate experiments were carried out in controlled environment chambers at S.E.P.E.L. Chamber temperatures were maintained at 26/20°C, 70% relative humidity and 400 ppm CO₂. Plants were grown under long day conditions: General Electric Cool White Fluorescent

and Westinghouse Incandescent tubes were lighted 9 h daily (8:00 A.M. - 5:00 P.M.) and incandescent lamps only were lighted for 3 h daily (11:00 P.M. - 2:00 A.M.). In addition to plants grown in environment chambers, another set of plants was exposed to a similar environmental regime in a greenhouse. This was done in order to permit comparison of plants grown under artificial light with plants exposed to sunlight.

All plants were watered with water containing nutrients twice daily 6 days a week and with deionized water once a week (Wednesday). Spectral quality of incident light was determined at the plant growing surface by a Quantum/Radiometer/Photometer, Lambda Instruments LI-185, which has a relative error of less than 5% for growth chamber lighting. Output could be recorded in foot-candles (ft-c), lux, total irradiance as watts per square meter ($\text{w}\cdot\text{m}^{-2}$), or intensity of photosynthetically active radiation (PAR) in the spectral range (400-700 nm) as microeinsteins per square meter per second ($\mu\text{E}\cdot\text{m}^{-2}\text{s}^{-1}$). PAR is a measure of the flux of light energy in the photosynthetically active region of the spectrum. PAR thus is a measure of the quanta of light available for photosynthesis. For example, on a clear sunny day, PAR approximates $1000 \mu\text{E}\cdot\text{m}^{-2}\text{s}^{-1}$. Light intensity values for the four chambers used in these experiments are indicated in Table 1. To facilitate identification of the experimental groups, each treatment will hereafter be referred to according to the appropriate light intensities: PAR-27, PAR-308, PAR-641, and PAR-1000 (greenhouse).

Table 1. S.E.P.E.L. Growth Chamber Experimental Lighting Conditions

Chamber	foot-candles (ft-c)	lux	total irradiance (w·m ⁻²)	PAR [*] (μE·m ⁻² s ⁻¹)
1	200	2152.8	180	27
2	1975	21258.9	1050	308
3	4000	43056.0	2875	641
4**	7430	80000.0	5500	1000

* Photosynthetically Active Radiation (400-700 nm)

** Averages on a clear sunny day

Measurements of light intensity were taken at the three field sites investigated along a transect through the swamp at each site. Readings represent mean PAR intensities at noon, in July, on a clear day. These PAR intensities, 25, 27, and 28, were duplicated by the S.E.P.E.L. chamber PAR-27. The high light intensity chamber, PAR-641, and the S.E.P.E.L. greenhouse were meant to simulate environmental beach conditions as closely as possible. Although it was not possible to construct a light saturation curve for bald cypress, it was felt that light saturation had occurred since most plants saturate at less than PAR-641 (Robert J. Downs, personal communication). Moreover, Larcher (1975) reports that winter-deciduous foliage trees and shrubs saturate within the lighting ranges of chambers PAR-641 and PAR-1000 (greenhouse). It should be noted that the chambers were lined with aluminum and thus were highly reflective. Moreover, the plants in the walk-in chamber and greenhouse were situated on stainless steel carts.

The seeds germinated over a 2 week period 6-16 February 1976. Once germinated, all cypress and tupelo gum seedlings were placed in the greenhouse (PAR-1000) to establish a healthy uniform population of seedlings. One month later, the seedlings were randomly divided into four groups. Twenty-four tupelo gum and eleven cypress seedlings were placed in each of the three treatment chambers (PAR-27, PAR-308, and PAR-641). Twenty-four tupelo gum and five cypress in

the comparison group were left in the greenhouse under natural light conditions (PAR-1000). The seedlings were allowed to grow under experimental conditions for 14 weeks.

Growth rate of the seedlings was measured as change in:

1) total height in cm above soil level, 2) gram dry weight of seedlings harvested periodically throughout the experiment, 3) stem diameter at 5 cm above soil level, and 4) total leaf area in cm^2 . Gram dry weight was measured by separating the plants into leaves, roots, and stems, and drying them at 89°C for 2 weeks prior to weighing. Stem diameter was measured with a vernier caliper. An Automatic Leaf Area meter, Hayashi Denko Company, Ltd, AAM-5 with a resolution of 0.01 cm^2 was used to determine leaf area.

Photosynthesis Rate Experiments

The photosynthetic chamber was constructed of Rohm and Haas Plexiglas *G Acrylic Safety Glazing (Fig. 5). The inner box measured $30.5'' \times 9'' \times 9''$ and was used as the gas chamber. A water jacket $9'' \times 18'' \times 18''$ was filled with water to maintain a steady temperature within the gas chamber. Two intake valves, one water and one gas, were located at the outer edge of the water chamber. The water intake opened directly into the water chamber, while the other intake introduced air into a plexiglass tube placed in the water tank paralleling the gas chamber and then into the gas chamber. The purpose of this

Fig. 5. Seedling Photosynthesis Chamber.



was to bring gas entering the chamber to chamber temperature. A plexiglass fan, placed directly opposite the air inlet in the gas chamber, circulated air upward across the plant to a larger fan situated in the middle of the opposite wall of the chamber, which mixed the air. A larger outlet was located at the top in the opposite corner from the inlet port. Tubing led directly from the air outlet to the gas analyzer. A large water outlet port positioned in the opposite top corner from the water inlet port led to a closed water coolant system which kept the gas chamber at 27-29°C. Shade screen was used to reduce light intensity as required for the experiments.

Photosynthesis was measured by placing individually potted seedlings in the sealed plexiglass chamber and monitoring CO₂ exchange with an infrared gas analyzer calibrated with scientific grade gas mixtures of 383 ppm or 430 ppm CO₂ in N₂ (this gave an experimental range of 47 ppm CO₂). Readings were recorded with a DigiTec Ht series 6120 digital recorder. Net photosynthetic rate was reported as mg CO₂·cm⁻²h⁻¹ of leaf area. During an experiment, the photosynthetic rate for each plant was determined at the particular light intensity at which the plant had been grown.

Photosynthetic Response to Light Intensity

Following each photosynthetic rate experimental run, the plant was harvested and the chlorophyll extracted from five leaves of tupelo

gum or five short shoots in the case of cypress. Two different methods were employed: 1) extraction of entire short shoots of cypress or entire 6 mm leaf discs of tupelo gum in 100% methanol using the technique of Mackinney (1941): and 2) extraction of chlorophyll by grinding in 80% acetone as described by Arnon (1949). Extract absorbances were determined on a Bausch and Lomb Spectronic 20. Conversion equations used to calculate mg chlorophyll per cm^2 were those reported in Sesták et al. (1971).

Age Estimates of Cypress Trees

Cores were extracted from offshore cypress trees at three sites with a 16 inch increment borer having a core diameter of 0.200 inch. The cores were transported to the lab in plastic soda straws. Cores were then glued (Resorcinol Waterproof Glue #226) into 0.2 inch grooves cut into 1 x 6 x 12 inch cypress boards and sanded until the cell structure of the core was visible. Core rings were counted by examination under a binocular dissecting microscope. Annual rings were characterized by an abrupt change in size of cells from small to large cells whereas "false" rings were distinguished from annual rings by a gradation from very large (spring wood) cells to small cells and back to large cells. The minimum age of a given tree was determined by the number of annual rings.

Wind Velocity and Wave Energy

Measurement of wind velocity in miles per hour (mph) using a Sims BT Electronic Anemometer was made in front of, in the middle of, and behind the offshore stand of cypress. A steady breeze was blowing during each set of measurements.

Mean wave amplitude was measured by taking the minimum and maximum wave heights hitting a meter stick embedded in the substrate over a 5 min interval and then determining the mean value. Wave pattern was also noted (whether uniform or disrupted). Wave amplitude measurements were taken within the group of trees and in an open area near shore.

Correlation with Shoreline Erosion

The perpendicular distance from each offshore cypress tree to the present shoreline was measured. Correlations between distance from the shoreline and age of each tree were determined. An indication of how fast the shoreline at a given site had eroded or flooded was determined by dividing the distance from the shoreline to the tree farthest out in the water by the age of the tree. This rate was then compared with erosion rates (based on aerial photos taken over a 30 yr period) published by the USDA Soil Conservation Service (1975).

Ecological Functions of the Cypress Fringe

General descriptions of the observed ecological functions of the offshore stand of cypress trees were made. Aerial and ground photographs using Kodak Panatomic X and Kodachrome 25 film were taken with an Asahi Pentax camera. Illustrations were made to supplement the descriptions.

RESULTS

Laboratory Studies for Bald Cypress

Germination of Seeds

Bald cypress seeds exhibited the highest germination percentage (63.8%) under the alternating temperature conditions of 30/20°C (Table 2). Below 25°C germination percentage dropped drastically. The highest temperature employed (35°C) produced a germination percentage 50% lower than the maximum. The mean viability percentage of these seeds was 72%.

Once the optimum temperature for seed germination was determined, another subsample of bald cypress seed was germinated under the alternating temperature regime of 30/20°C (Table 3). Overall viability of these seeds had dropped from 72% to 43.2% after 2 months additional dry storage. However, the difference in germination percentage after correction for seed viability was not significant ($p > 0.05$) (Table 3). Light germination averaged 64.5% as compared to 57.6% dark germination.

Exposure of seeds to concentrated sulfuric acid for 1 hour produced the highest overall germination percentage (Table 4). Germination was delayed as compared to the faster though slightly lower germination percentage produced by 3-4 hour treatments.

Table 2. Germination Percentages for Bald Cypress Seeds at Selected Temperatures^{1,2} (Seed Lot Viability = 72%)

Temp. (°C)	No. Planted (n)	Estimated Viable Seed (72% of n)	No. Germinated	% Germination Corrected for 72% Viability
10	25	18	0	0
15	50	36	0	0
20	50	36	2	6.0
20 ³	25	18	0	0
25	50	36	12	33.3
30	50	36	17	47.2
25/15 ⁴	50	36	19	52.7
35	50	36	14	38.8
30/20	50	36	23	63.8

¹Germination criterion was emergence of the hypocotyl

²Unless otherwise specified, all seeds received 10 min of light daily

³Seeds germinated under conditions of total darkness

⁴12/12 h day/night alternating temperature regime

Table 3. Germination Percentages for Bald Cypress Seeds at 30/20°C¹ (Seed Lot Viability = 43.2%)

	No. Planted (n)	No. Viable	No. Germinated	% Germination Corrected for 43.2% Viability
<u>Dark</u>	25	14	8	57.0
	25	12	7	58.0
<u>Light</u> ²	25	7	4	57.0
	25	2	1	50.0
	25	14	11	79.0
	25	13	7	54.9
	25	9	7	78.0
	25	14	7	50.0
	25	13	9	69.0
	25	10	7	70.0
<u>Germination Summary</u>				
Dark	50	26	15	57.6
Light	200	82	53	64.5
Total	250	108	68	62.2

¹12/12 h day/night alternating temperature regime. Germination criterion was emergence of the hypocotyl

²Seeds received 10 min of light daily

Table 4. Bald Cypress Seed Percent Germination Results Following Treatment in Concentrated Sulfuric Acid (H_2SO_4)

No. wks after treatment	Hrs of treatment*					
	1	2	2.5	3	3.5	4
1	1	9	4	13	12	21
2	0	2	2	4	6	4
3	7	3	2	3	6	1
4	15	4	2	3	3	2
5**	-	-	-	-	-	-
6	5	1	0	2	1	0
7	1	0	0	0	0	0
8	3	1	3	0	0	0
9	0	2	0	0	0	0
10**	-	-	-	-	-	-
11	3	0	0	0	0	0
12**	-	-	-	-	-	-
13	0	0	2	0	0	0
Total	35	22	15	25	28	28

*100 seeds per treatment

**No data collected at this time

There appears to be a trend correlating duration to treatment and germination rate, but these results are based on a single experiment and need to be investigated further.

Growth as Measured by Change in Height

Analysis of Variance and Duncan's New Multiple Range statistical tests were applied to the heights of all cypress seedlings at the time they were introduced into the chambers. There were no significant differences in the heights at the beginning of the experiment of these 4 week old seedlings ($p > 0.05$) (Table 5).

Growth rates for the cypress seedlings are based on 2 week measurement intervals (Fig. 6). These indicate that at PAR-27 the growth rate decreased from a mean of 3.8 cm during the week 0 to week 2 interval to a mean of 0.3 cm between week 8 to week 10. At the same time, the cypress seedlings in PAR-308 and PAR-641 both showed a substantial increase in growth following introduction into their respective S.E.P.E.L. chambers. However, growth rates appeared to decline during the last three growth measurement intervals. Plants in PAR-1000 exhibited a lower growth rate during the first 4 weeks of treatment than during the last 6 weeks. The initial slow increase observed at PAR-1000 may have resulted from generally cloudy conditions which occurred during this period. The increase in growth rate coincides with longer daylength and increasing light intensity during late April and early May.

Table 5. Analysis of Variance of Bald Cypress Seedling Incremental Growth Rates by PAR Treatment Means

Variable	Source	Degrees of freedom	Sum of squares	Mean squares	F Ratio	F Prob.
Wk 0 ¹	Between	3	5.99	1.99	0.07	0.97
	Within	30	823.69	27.45		
	Total	33	829.68			
Wk 2	Between	3	46.58	15.53	8.64	0.001
	Within	30	53.94	1.79		
	Total	33	100.52			
Wk 4	Between	3	2970.58	990.19	27.11	0.001
	Within	30	1095.81	36.53		
	Total	33	4066.39			
Wk 6	Between	3	416.51	138.84	13.65	0.001
	Within	30	305.11	10.17		
	Total	33	721.62			
Wk 8	Between	3	766.82	255.61	23.13	0.001
	Within	30	331.47	11.05		
	Total	33	1098.29			
Wk 10	Between	3	558.58	186.19	8.06	0.001
	Within	30	623.17	23.08		
	Total	33	1181.75			

Table 5. continued.....

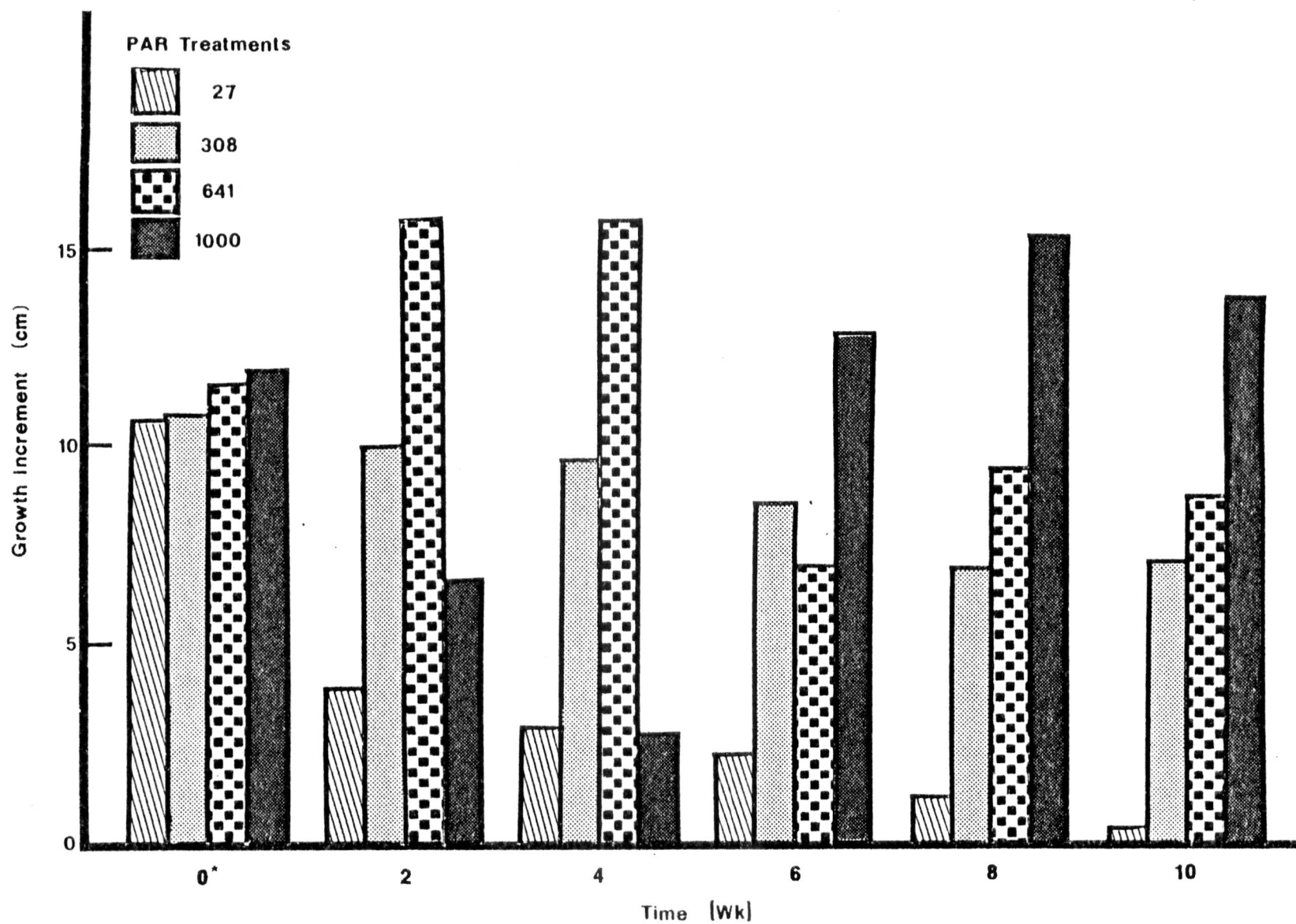
Variable	Source	Degrees of freedom	Sum of squares	Mean squares	F Ratio	F Prob.
Final ht ²	Between	3	16530.00	5510.00	88.76	0.001
	Within	30	1862.31	62.08		
	Total	33	18392.31			
Total diff ³	Between	3	15813.84	5271.17	152.94	0.001
	Within	30	1034.00	34.47		
	Total	33	16847.84			

¹Time of placement in S.E.P.E.L. chambers; age of seedling = 4 wks

²"Final ht" refers to the height of the cypress seedling at harvest

³"Total diff" refers to total incremental growth during treatment in S.E.P.E.L. chamber

Fig. 6. Growth increments of cypress seedlings under long day conditions. 0^* = height of cypress seedlings when introduced into S.E.P.E.L. chambers.



Following introduction of the cypress seedlings to experimental conditions, there was always a significant difference between the mean growth increment of seedlings among treatments as shown by Analysis of Variance (ANOVA) (Table 5). Duncan's New Multiple Range Test indicates where the significant differences lie (Table 6). Correlation coefficients from linear regression indicate a significant correlation ($p < 0.001$) between PAR intensity and total growth of cypress seedlings during treatment (Table 7).

Although data from PAR-1000 were not utilized in the linear regression analysis, Figure 7 shows the growth relationships among all four treatment groups throughout the experiment. Cypress seedlings grown under natural light intensity were intermediate in growth between seedlings in PAR-641 and PAR-308 at termination of the experiment (Figure 7). Cypress seedlings exposed to PAR-27 grew least in height ($\bar{x} = 76.8$ cm) (Table 6).

Another observation revealed that cypress seedlings at PAR-641 lost their cotyledons between week 2 and week 4, PAR-308 lost theirs between week 6 and week 8, while the plants at PAR-1000 still exhibited shrivelled cotyledons at the termination of the experiment. In contrast, cypress seedlings at PAR-27 retained green cotyledons throughout the experiment.

Table 6. Comparison of Incremental Growth (cm) of Bald Cypress Seedlings under Selected Light Intensities

Variable	Light Intensity (PAR)			
	27	308	641	1000
Wk 0 ¹	10.67 ^{a2}	11.00 ^a	11.54 ^a	11.78 ^a
Wk 2	3.82 ^a	10.00 ^b	15.82 ^b	6.68 ^a
Wk 4	2.91 ^a	9.73 ^b	15.76 ^c	2.74 ^a
Wk 6	2.22 ^a	8.52 ^b	6.88 ^b	12.80 ^c
Wk 8	1.02 ^a	6.90 ^b	9.39 ^b	15.40 ^c
Wk 10	0.36 ^a	6.96 ^b	8.68 ^b	13.66 ^c
Final height ³	20.79 ^a	54.07 ^b	76.80 ^c	62.98 ^b
Total Growth ⁴	10.42 ^a	43.08 ^b	65.30 ^d	51.20 ^c

¹Time of placement in phytotron chambers; age of cypress seedling = 4 wks

²There is no statistical difference between treatment means with the same superscripts. Means with differing superscripts are significantly different at the 0.05 level

³"Final height" refers to the height of the cypress seedling at harvest

⁴"Total growth" refers to total incremental growth during treatment in S.E.P.E.L. chamber

Table 7. Correlation between Light Intensity¹ and Bald Cypress Seedling Growth at Bimonthly Intervals (n = 29)

Variable	Correlation coefficient r	r ²	Level of significance	Intercept A	Slope B
Wk 0 ²	0.07	0.004	0.72	10.61	0.001
Wk 2	0.66	0.44	0.001	0.98	0.004
Wk 4	0.83	0.68	0.001	5.24	0.04
Wk 6	0.46	0.21	0.01	3.43	0.007
Wk 8	0.75	0.56	0.001	1.35	0.01
Wk 10	0.53	0.28	0.005	1.26	0.01
Final height ³	0.94	0.90	0.001	20.92	0.09
Total growth ⁴	0.96	0.92	0.001	10.56	0.09

¹Only 3 chambers (PAR - 27, PAR - 308, PAR - 641) were entered into the Linear Regression equation since light intensity in the controlled greenhouse (PAR - 1000) was not constant

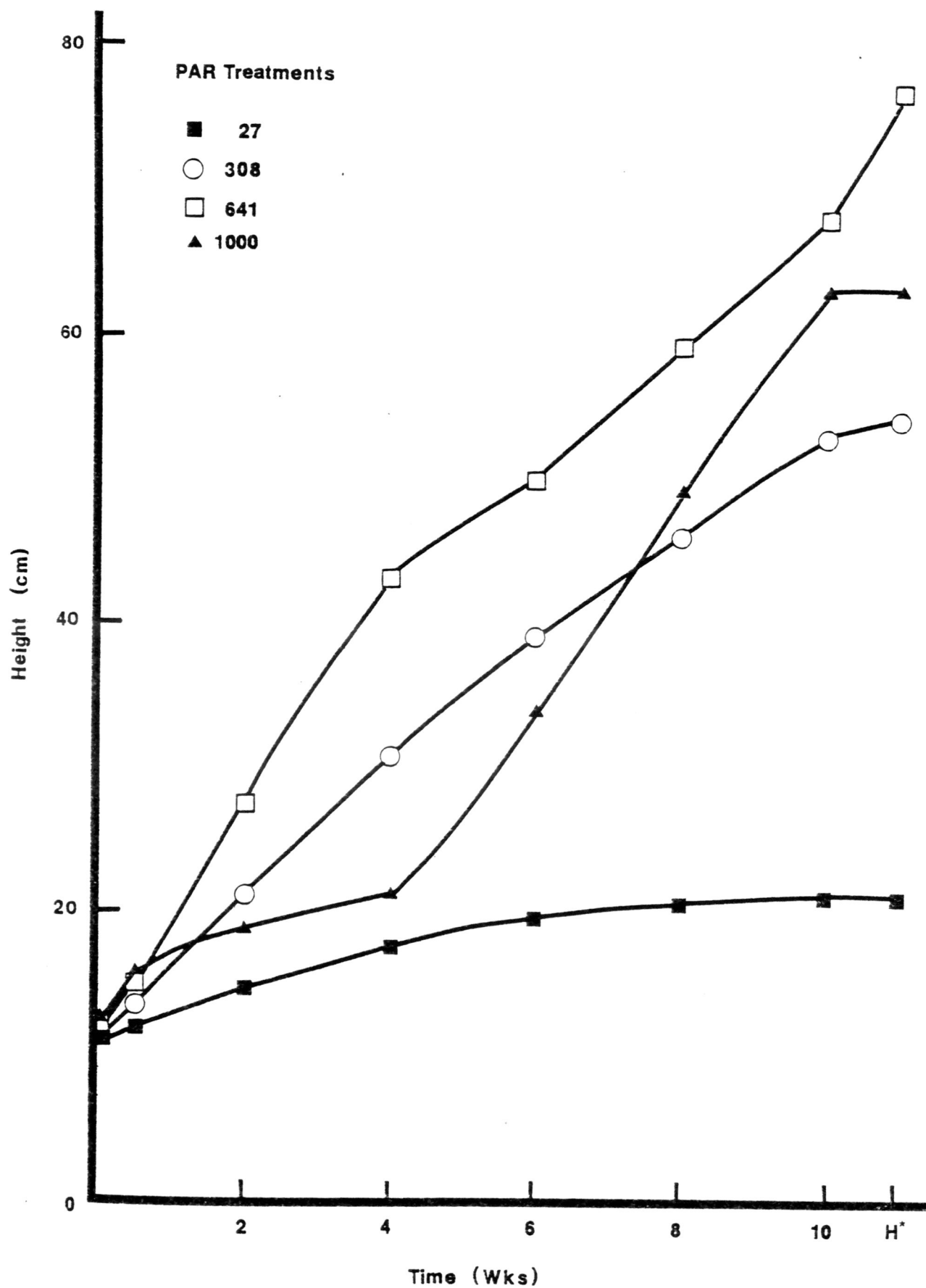
²Time of placement in S.E.P.E.L. chambers; age of cypress seedlings = 4 wks

³"Final height" refers to the height of the cypress seedling at harvest

⁴"Total growth" refers to total incremental growth during treatment in S.E.P.E.L. chamber

Fig. 7. Cypress seedling growth. H* refers to day of harvest.

One seedling from each PAR treatment was harvested each day for 9 days beginning at 11 weeks, of treatment.



Total Leaf Area

Total leaf area per seedling varied greatly among the four treatments (Table 8) with the lowest mean (41.13 cm^2) occurring at PAR-27 and the highest mean occurring at PAR-641 (415.16 cm^2). While mean total leaf area among treatments for bald cypress seedlings varied significantly ($p < 0.05$), there was no significant difference between the seedlings at PAR-308 and PAR-1000 or between those at PAR-1000 and PAR-641 (Table 8).

Linear regression analysis indicated a consistent tendency for bald cypress seedlings to produce more leaf area with increasing PAR intensity (Table 8). Pearson's Correlation Coefficient showed an 82% correlation ($r = 0.82$) between light intensity and total leaf area per bald cypress seedling.

Chlorophyll

Using the Student's t-test for Paired Data, it was determined that the acetone method for extractions gave a significantly better evaluation ($p < 0.001$) of chlorophyll content than did the methanol extraction method. From Table 9 it may be seen that the acetone method of extraction gave consistently higher chlorophyll content per unit leaf area than the methanol extraction method. Total chlorophyll ($\underline{a} + \underline{b}$) content ranged from a high of $222.6 \text{ mg} \cdot \text{cm}^{-2}$ (PAR-27) to a low of $153.7 \text{ mg} \cdot \text{cm}^{-2}$ (PAR-641) (Table 10). All bald cypress leaves contained larger quantities of chlorophyll $\underline{a}$ than chlorophyll $\underline{b}$ (Figure 8). Treatment

Table 8. Statistical Analyses of the Correlation between Light Intensity and Total Leaf Area of Bald Cypress Seedlings by PAR Treatment Means

PAR Treatment Group	Total Leaf Area (cm ²)					n
	$\bar{x}$	Min value	Max value	Standard deviation	Standard error	
27	41.13	9.80	76.64	23.56	7.46	10
308	294.50	123.30	465.40	118.74	39.58	9
641	415.16	181.31	649.66	145.64	48.55	9
1000	329.69	147.86	507.44	141.06	62.97	5

Analysis of Variance

Source	Degrees of freedom	Sum of squares	Mean squares	F ratio	F prob.
Between	3	730164.0	243388.0	19.2	0.001
Within	29	367064.0	12657.3		
Total	32	1097228.0			

Duncan's New Multiple Range Analysis

PAR Treatment	27 ^{a*}	308 ^b	641 ^c	1000 ^b _c
Mean (cm ²)	41.13	294.50	415.16	329.69

Table 8. continued.....

Variable	Linear Regression**					n
	Correlation	r^2	Level of significance	Intercept	Slope	
	coefficient r			A	B	
Leaf area	0.81	0.67	0.001	51.9	0.61	28

* There is no statistical difference between treatment means with the same superscript. Means with differing superscripts are significantly different at the 0.05 level

**Only 3 chambers (PAR - 27, PAR - 308, PAR - 641) were entered into the Linear Regression equation since light intensity in the controlled greenhouse (PAR - 1000) was not constant

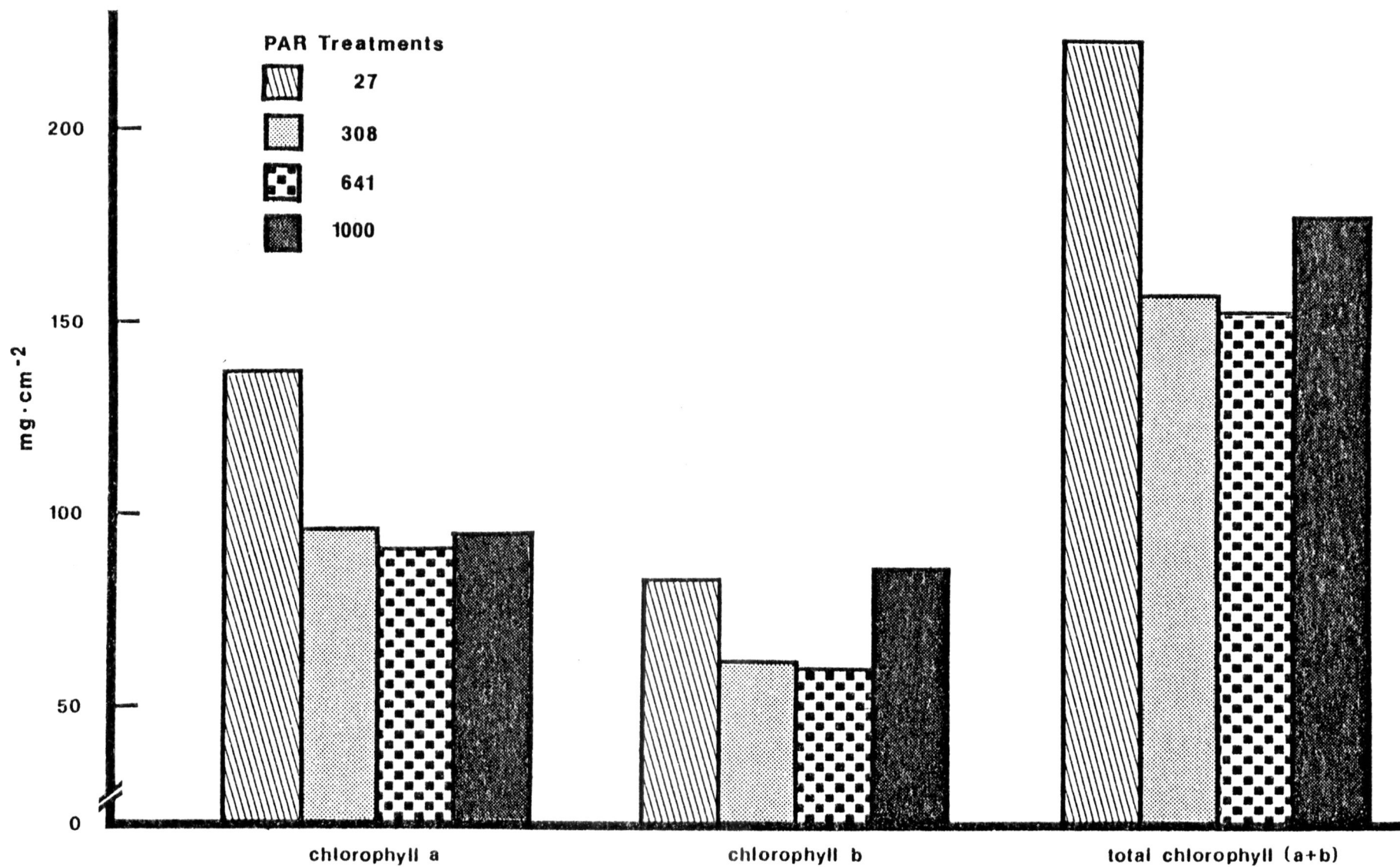
Table 9. Statistical Analysis of Two Methods of Chlorophyll Extraction of Bald Cypress Seedlings through Use of the Student's t-test with Paired Data

Extraction Method	Variable	Mean $\bar{x}$	Corr. coef. r	t Value	Degrees of freedom	2 Tail Prob.
Methanol	Chlorophyll <u>a</u>	86.25	0.78	-3.60	32	0.001
Acetone	Chlorophyll <u>a</u>	107.30				
Methanol	Chlorophyll <u>b</u>	34.33	0.53	-7.97	32	0.0001
Acetone	Chlorophyll <u>b</u>	70.98				
Methanol	Total Chlorophyll (<u>a&b</u>)	120.62	0.73	-5.71	32	0.0001
Acetone	Total Chlorophyll (<u>a&b</u>)	179.45				

Table 10. Statistical Analysis of Mean Chlorophyll Concentrations ($\text{mg}\cdot\text{cm}^{-2}$) of Bald Cypress Seedlings by PAR Treatment Group

PAR Treatment Group	Mean $\bar{x}$	Min value	Max value	Standard deviation	Standard error	n
Chlorophyll <u>a</u>						
27	136.95	70.59	343.03	82.96	26.25	10
308	96.51	70.39	126.91	16.43	5.48	9
641	92.18	60.64	118.66	19.04	6.35	9
1000	94.61	79.40	111.79	12.15	5.42	5
Chlorophyll <u>b</u>						
27	81.64	42.41	206.62	48.67	15.40	10
308	61.83	44.59	83.86	13.80	4.60	9
641	60.06	39.00	86.36	14.44	4.81	9
1000	85.80	66.73	124.87	22.60	10.09	5
Total Chlorophyll (<u>a</u> & <u>b</u>)						
27	222.66	119.65	557.36	134.12	42.44	10
308	158.34	114.91	208.60	29.16	9.72	9
641	153.68	99.46	35.77	217.88	72.63	9
1000	177.42	146.63	220.34	27.32	12.20	5
Chlorophyll Ratio (<u>a/b</u>)						
27	1.68	1.29	2.29	0.29	0.09	10
308	1.58	1.21	1.69	0.15	0.05	9
641	1.55	1.37	1.73	0.33	0.12	9
1000	1.12	0.89	1.22	0.11	0.05	5

Fig. 8. Concentration of chlorophyll in leaves of bald
cypress seedlings.



PAR-27 contained the highest concentration of chlorophyll a ($\bar{x} = 136.9$ $\text{mg} \cdot \text{cm}^{-2}$) and thus exhibited the lowest ratio of chlorophyll a/b (1.1). PAR-641 contained the least amount of both chlorophylls (Fig. 8).

An Analysis of Variance test on data obtained by the acetone extraction method revealed no significant difference among the mean chlorophyll content of the bald cypress seedlings within any of the four treatment groups.

It should be noted that seedlings at PAR-1000 had a reddish tinge to the leaves while plants at PAR-641 exhibited a dark green color. This in conjunction with the chlorophyll data, suggests that an accessory pigment may have been present but was not measured. Perhaps this masking pigment (anthocyanin?) was produced in response to the higher light intensity or spectral quality of natural sunlight as compared with the fluorescent tubes in the S.E.P.E.L. chambers.

Seedling Fresh and Dry Weight

Seedlings grown at PAR-641 produced the greatest biomass. The fresh weight (living weight) of bald cypress seedlings at treatment PAR-641 produced a mean of 46.15 g while similar seedlings at PAR-27 averaged only 2.87 g (Appendix Table A). Higher effective insolation generally resulted in increased standing biomass up to PAR-641 ($r = 0.84$) (Table 11). The mean fresh weight at PAR-1000 fell between the means of PAR-27 and PAR-308, and Duncan's Multiple Range Test showed no significant difference between PAR-1000 and PAR-308.

Table 11. Statistical Analyses of the Correlation between Light Intensity and Fresh Weight (g) of Bald Cypress Seedlings by PAR Treatment Means

ANOVA						
Source	Degrees of freedom	Sum of squares	Mean squares	F Ratio	F Prob.	
Between	3	9185.13	3061.71	23.51	0.001	
Within	29	3777.04	130.24			
Total	32	12962.17				
Duncan's New Multiple Range Analysis						
Group	27	308	641	1000		
Mean (g)	2.87 ^{a*}	30.00 ^b	46.15 ^c	28.76 ^b		
Linear Regression**						
Variable	Corr. coef. r	r ²	Level of significance	Intercept A	Slope B	n
Wet wt	0.84	0.70	0.001	3.4	0.07	28

*There is no statistical difference between treatment means with the same subscript. Means with differing superscripts are significantly different at the 0.05 level

**Only 3 chambers (PAR - 27, PAR - 308, PAR - 641) were entered into the Linear Regression equation since light intensity in the controlled greenhouse (PAR - 1000) was not constant

There was no significant difference between the total dry weight values for cypress seedlings in treatment groups PAR-1000 and PAR-308, although there was a significant difference between those two treatments and PAR-641 (Table 12). Linear regression analysis between light intensity and total dry weight produced by bald cypress seedlings resulted in an 86% correlation (Table 12). Minimum mean total dry weight occurred at PAR-27 ($\bar{x}$ = 0.52 g) with a maximum at PAR-641 ($\bar{x}$ = 12.04 g).

The partitioning of biomass (gram dry weight) was surprising: the PAR-1000 leaf biomass almost equalled the PAR-641 leaf biomass while the stem and root biomass at PAR-1000 was much smaller than at PAR-641 (Figure 9). As expected, dry weight for the PAR-27 seedling parts was quite low (< 0.2 g). Increased light intensity resulted in increased biomass in leaves ($r = 0.80$), roots ($r = 0.77$), and stems ($r = 0.78$) with significant differences ($p < 0.05$) between treatment groups PAR-27, PAR-308, and PAR-641 (Table 13). The mean values for PAR-1000 fell between different treatment groups in each category (Table 13).

Root/shoot ratios, however, revealed no significant differences among the three lowest PAR treatment groups, but there was a significant difference between PAR-1000 and each of the other treatment groups (Table 13).

Table 12. Statistical Analyses of the Correlation between Light Intensity and Total Dry Weight (g) of Bald Cypress Seedlings by PAR Treatment Means

ANOVA						
Source	Degrees of freedom	Sum of squares	Mean squares	F Ratio	F Prob.	
Between	3	629.11	209.71	25.99	0.001	
Within	29	233.93	8.07			
Total	32	863.05				
Duncan's New Multiple Range Analysis						
Group	27	308	641	1000		
Mean (g)	0.52 ^{a*}	6.21 ^b	12.03 ^c	6.30 ^b		
Linear Regression**						
Variable	Corr. coef. r	r ²	Level of significance	Intercept A	Slope B	n
Dry wt	0.86	0.73	0.001	0.15	0.02	28

*There is no statistical difference between treatment means with the same superscript. Means with differing superscripts are significantly different at the 0.05 level

**Only 3 chambers (PAR - 27, PAR - 308, PAR - 641) were entered into the Linear Regression equation since light intensity in the controlled greenhouse (PAR - 1000) was not constant

Fig. 9. Biomass partitioning (gram dry weight) in bald
cypress seedlings grown at selected light intensities.
(PAR = Photosynthetically Active Radiation)

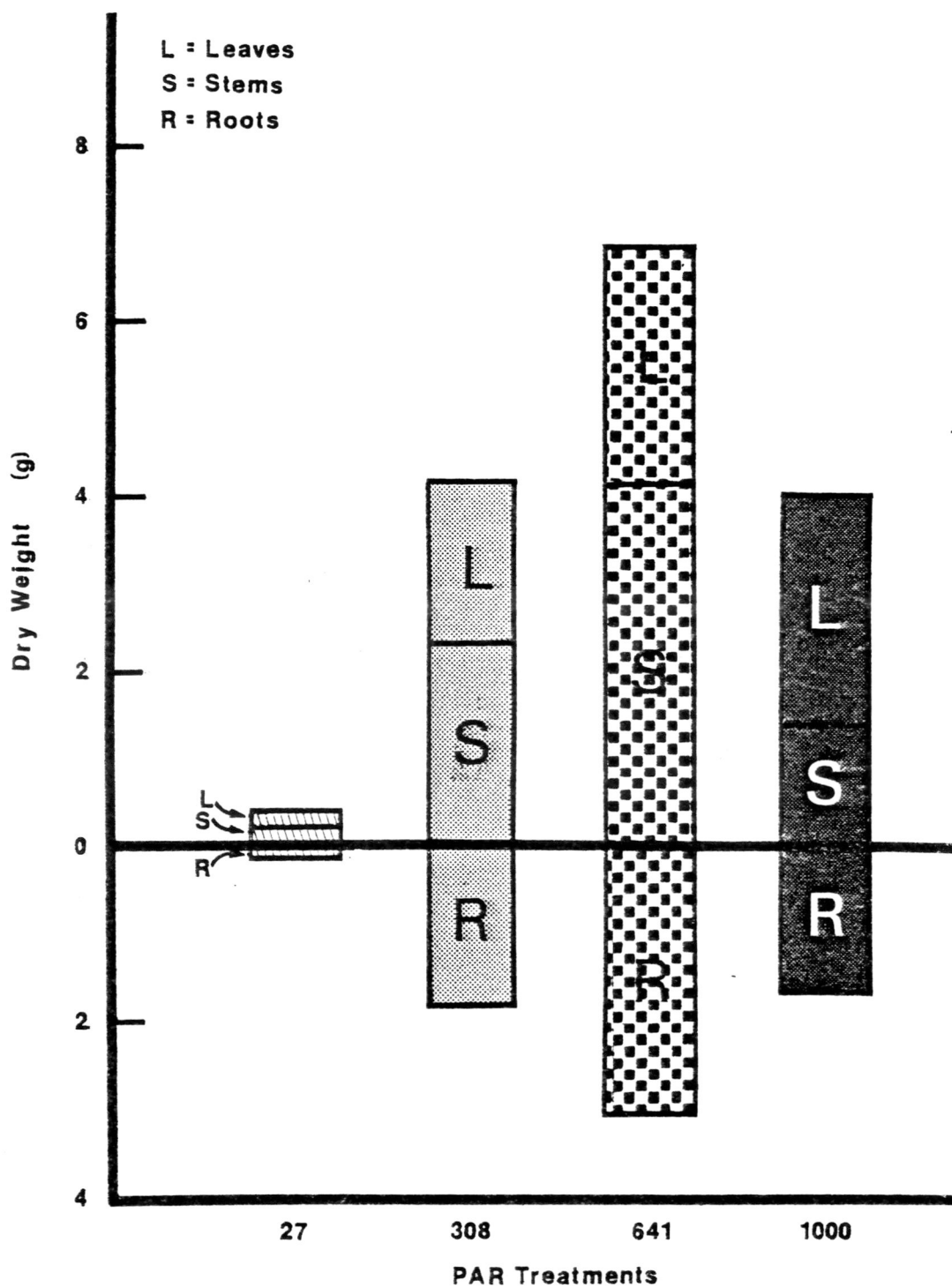


Table 13. Statistical Analyses of the Correlation between Light Intensity and Biomass Partitioning (gram dry weight) of Bald Cypress Seedlings by PAR Treatment Means

Duncan's New Multiple Range Analysis				
Group	27	308	641	1000
Structure				
Leaves	0.16 ^{a*}	1.73 ^b	2.64 ^c	2.59 ^c
Roots	0.13 ^a	1.77 ^b	3.02 ^c	1.67 ^b
Stems	0.18 ^a	2.39 ^b	4.21 ^c	1.47 ^a
Root/Shoot Ratio	0.88 ^a	0.72 ^a	0.71 ^a	1.28 ^b

Linear Regression**						
Variable	Corr. coef. r	r ²	Level of significance	Intercept A	Slope B	n
Leaves	+0.80	0.64	0.001	0.19	0.00	28
Roots	+0.77	0.59	0.001	0.11	0.00	28
Shoots	+0.78	0.62	0.001	0.12	0.01	28
Root/Shoot Ratio	-0.32	0.10	0.100	0.86	-0.00	28

*There is no statistical difference between treatment means with the same superscript. Means with differing superscripts are significantly different at the 0.05 level

**Only 3 chambers (PAR - 27, PAR - 308, PAR - 641) were entered into the Linear Regression equation since light intensity in the controlled greenhouse (PAR - 1000) was not constant

Diameter

The diameter of each bald cypress seedling was measured in millimeters at 8 weeks and again when harvested at approximately 15 weeks. Correlation between higher light intensity and increased seedling diameter was stronger at the end of the experiment (Table 14). Figure 10 shows the relationship among mean treatment diameters on each date.

Duncan's New Multiple Range Test revealed significant differences between mean diameters of each treatment at 8 weeks, with PAR-27 exhibiting the smallest diameter ($\bar{x} = 0.39$ mm) and PAR-1000 exhibiting the greatest diameter ($\bar{x} = 5.32$ mm) (Table 14). However at harvest, although PAR-27 still had the smallest diameter ($\bar{x} = 0.46$ mm), PAR-641 exhibited the greatest diameter ($\bar{x} = 7.63$ mm) (Table 15). This approximately reverses the pattern seen at 8 weeks (Figure 10). Bald cypress seedlings at PAR-1000 were not significantly different from either the cypress seedlings at PAR-641 or PAR-308.

Photosynthetic Rates of Bald Cypress Seedlings

The net photosynthetic rate of the treated seedlings ranged from a mean of $0.12 \text{ mg CO}_2 \cdot \text{cm}^{-2} \text{h}^{-1}$ (PAR-27) to a mean of $0.30 \text{ mg CO}_2 \cdot \text{cm}^{-2} \text{h}^{-1}$ (PAR-641) (Table 16). It was not possible to measure the photosynthetic rate of greenhouse seedlings (PAR-1000) because these plants utilized more than the 50 ppm to which the infrared gas analyzer scale had been calibrated. Successful measurement of greenhouse

Table 14. Statistical Analyses of Mean Diameters (mm) of Bald Cypress Seedlings by PAR Treatment Means

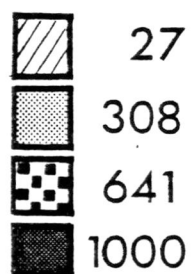
Duncan's New Multiple Range Analysis						
Group	27	308	641	1000		
Variable Mean						
Dia. at 4 Wks	0.39 ^{a*}	1.69 ^b	2.80 ^c	5.32 ^d		
Dia. at Harvest	0.46 ^a	6.11 ^b	7.63 ^c	6.83 ^b		
Linear Regression**						
Variable	Corr. coef. r	r ²	Level of significance	Intercept A	Slope B	n
Dia. at 4 Wks	0.67	0.45	0.001	0.36	0.00	28
Dia. at Harvest	0.89	0.79	0.001	0.93	0.01	28

* There is no statistical difference between treatment means with the same superscript. Means with differing superscripts are significantly different at the 0.05 level

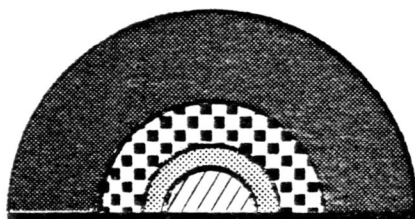
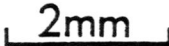
** Only 3 chambers (PAR - 27, PAR - 308, PAR - 641) were entered into the Linear Regression equation since light intensity in the controlled greenhouse (PAR - 1000) was not constant

Fig. 10. Bald cypress seedling diameter. Harvest diameter =
diameter at harvest (after 10 weeks of treatment).

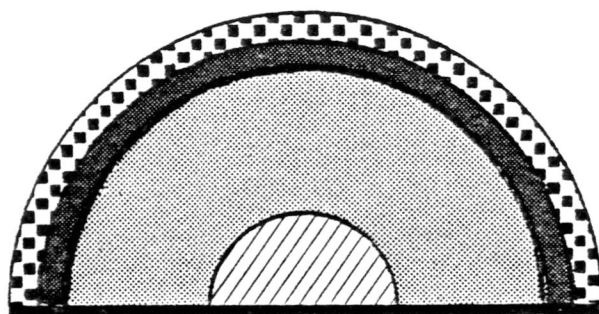
PAR Treatments



Scale



4 Wk Diameter



Harvest Diameter

Table 15. Mean Diameters (mm) of Bald Cypress Seedlings by PAR Treatment Group

Diameter after 4 Wks Treatment						
Group	n	Mean	Standard deviation	Standard error	Min value	Max value
27	10	0.39	0.25	0.08	0.05	0.75
308	9	1.69	1.39	0.46	0.30	4.05
641	9	2.80	1.44	0.48	0.80	4.30
1000	5	5.32	0.34	0.15	4.95	5.70

Diameter at Harvest (after 10 Wks Treatment)						
Group	n	Mean	Standard deviation	Standard error	Min value	Max value
27	10	0.46	0.24	0.08	0.10	0.80
308	9	6.11	1.20	0.40	4.95	7.75
641	9	7.63	1.51	0.50	4.70	8.90
1000	5	6.83	0.33	0.14	6.40	7.30

Table 16. Statistical Analysis of Photosynthetic Rates ($\text{mg CO}_2 \cdot \text{cm}^{-2} \text{h}^{-1}$) of Bald Cypress Seedlings by PAR Treatment Group

Photosynthetic Rates (mg CO ₂ ·cm ⁻² h ⁻¹)									
Group	N	Mean	Standard deviation	Standard error	Min value	Max value			
27	10	0.12	0.02	0.01	0.09	0.16			
308	9	0.23	0.02	0.01	0.21	0.27			
641	9	0.30	0.33	0.01	0.26	0.36			
Duncan's New Multiple Range Analysis									
Group		27		308		641		1000	
Mean		0.12 ^{a*}		0.23 ^b		0.30 ^c		----	
Linear Regression**									
Variable		Corr. coef. r	r ²	Level of significance		Intercept A		Slope B	n
Photosynthetic Rate		0.94	0.89	0.001		0.12		0.00	28

* There is no statistical difference between treatment means with the same superscript. Means with differing superscripts are significantly different at the 0.05 level.

** Only 3 chambers (PAR - 27, PAR - 308, PAR - 641) were entered into the Linear Regression equation since light intensity in the controlled greenhouse (PAR - 1000) was not constant

plants at PAR-1000 would have required a different mixture of scientific gases with a wider range of ppm CO₂ and a new calibration scale. However, when cypress seedlings from PAR-1000 were allowed to equilibrate for 2 hours at each of the other treatment conditions, subsequent measurement of net photosynthetic rate at each PAR was consistently lower than for plants grown under those conditions (See Appendix Table B).

An increase in photosynthetic rate corresponded to each successive increase in PAR intensity ($r = 0.94$) (Table 16). Using Duncan's New Multiple Range Test, a significant difference existed between all pairs among the three treatment groups measured (Table 16). Since photosynthetic rate for PAR-1000 exceeded the capacity of instrument calibration, it is obvious that the net photosynthetic rate of the PAR-1000 seedlings exceeded that of the PAR-641 seedlings.

Laboratory Studies for Tupelo Gum

Germination of Seeds

The mean viability percentage of tupelo gum seeds planted in the S.E.P.E.L. chambers was determined to be 79.2%. An initial experiment was performed in order to determine optimal seed germination temperature. These results indicated that tupelo gum seeds germinated best at the warmest temperature (65% germination at 35°C after correction for seed viability). There was no germination of tupelo gum seeds at 20°C or lower (Table 17).

A second planting of seeds was carried out under conditions near optimal temperature as determined by the first experiment. Seedlings thus produced were used in the experiments described below. Mean seed viability was 84.3%. Overall germination for the second experiment was 42.4%, corrected for viability (Table 18). Tupelo gum had the highest overall germination percentage (corrected for viability) in the alternating temperature 30/20°C (55.8%). It is interesting to note that at 35°C, germination in the dark was not significantly different from germination in the light (Table 18).

Growth as Measured by Change in Height

Analysis of Variance and Duncan's New Multiple Range statistical tests were run on the heights of all tupelo gum seedlings when they were first introduced to experimental conditions in the plant growth

Table 17. Germination Percentages for Tupelo Gum Seeds at Selected Temperatures^{1,2} (Seed Lot Viability = 79.2%)

Temp. (°C)	No. Planted (n)	Estimated Viable Seed (79.2% of n)	No. Germinated	% Germination Corrected for 79.2% Viability
10	30	24	0	0
15	50	40	0	0
20	50	40	0	0
20 ³	30	24	0	0
25	50	40	8	20.0
30	50	40	11	27.5
25/15 ⁴	50	40	8	20.0
35	50	40	22	65.0

¹Germination criterion was emergence of the hypocotyl

²Unless otherwise specified, all seeds received 10 min of light daily

³Seeds germinated under conditions of total darkness

⁴12/12 h day/night alternating temperature regime

Table 18. Germination Percentages for Tupelo Gum Seeds at High Temperatures^{1,2} (Seed Lot Viability = 84.3%)

Temp. (°C)	No. Planted (n)	No. Viable	No. Germinated	% Germination Corrected for 84.3% Viability
30	30	27	13	48.1
	30	25	10	40.0
	30	25	6	24.0
	15	13	4	30.8
35	30	25	17	68.0
	30	27	16	59.2
	30	17	8	47.0
	15	14	2	14.2
35 ³	30	26	12	46.1
	20	15	6	40.0
30/20 ⁴	30	26	8	30.8
<u>Germination Summary</u>				
30	105	90	33	36.6
35	155	124	61	49.1
35 ³	50	41	18	43.9
35	105	83	43	51.8
30/20	90	81	27	33.3
Total	350	295	121	41.0

Table 18. continued.....

¹Germination criterion was emergence of the hypocotyl

²Unless otherwise specified, all seeds received 10 min of light daily

³Seeds germinated under conditions of total darkness

⁴12/12 h day/night alternating temperature regime

chambers. There were no significant differences in the heights of the seedlings at this time (seedlings were 4 weeks old) (Table 19).

Incremental growth of the tupelo gum seedlings was measured at 2 week intervals (Fig. 11). These measurements indicate that at PAR-27 incremental growth decreased from a mean of 18.6 cm during the first 2 weeks of the experiment (seedling age 4-6 weeks), to a mean of 5.97 cm at the conclusion of the study one month later. At the same time, similar tupelo gum seedlings exposed at PAR-308 and PAR-641 both showed increasing incremental growth during both the 0-2 week interval and the 2-4 week interval. Following introduction into the treatment chambers, PAR-641 exhibited a significantly greater mean incremental growth rate than the other treatments (Table 19). In fact, growth appeared to increase with higher light intensities except for the seedlings exposed to full sunlight (Table 20). Linear regression analysis of incremental growth data available at week 6 produced a correlation coefficient of 0.82 between incremental growth of tupelo gum seedlings and light intensity (Table 21). Tops of the tupelo gum seedlings were cut off after the 10th week of age (after 6 weeks of treatment) because they were becoming too tall for the photosynthesis chamber. All plants were cut at the 12th internode and measurements made of the cut segment and remaining stem (Fig. 12). It was necessary to remove a relatively longer section from tupelo gum seedlings grown at PAR-641 because they had grown so much taller than the other

Table 19. Comparison of Incremental Growth (cm) of Tupelo Gum Seedlings under Selected Light Intensities

Variable	Light Intensity (PAR)			
	27	308	641	1000
Wk 0*	16.04 ^{a**}	16.11 ^a	16.39 ^a	18.19 ^a
Wk 2	18.6 ^a	26.8 ^b	36.6 ^c	22.4 ^a
Wk 4	15.4 ^a	24.4 ^b	28.0 ^c	16.4 ^a
Wk 6	3.93 ^a	14.05 ^b	20.97 ^c	5.97 ^a

*Time of placement in phytotron chambers

**There is no statistical difference between treatment means with the same superscript. Means with differing superscripts are significantly different at the 0.05 level

Fig. 11. Growth increments of tupelo gum seedlings at two week intervals. 0^* = height of tupelo gum seedlings when introduced into S.E.P.E.L. chambers

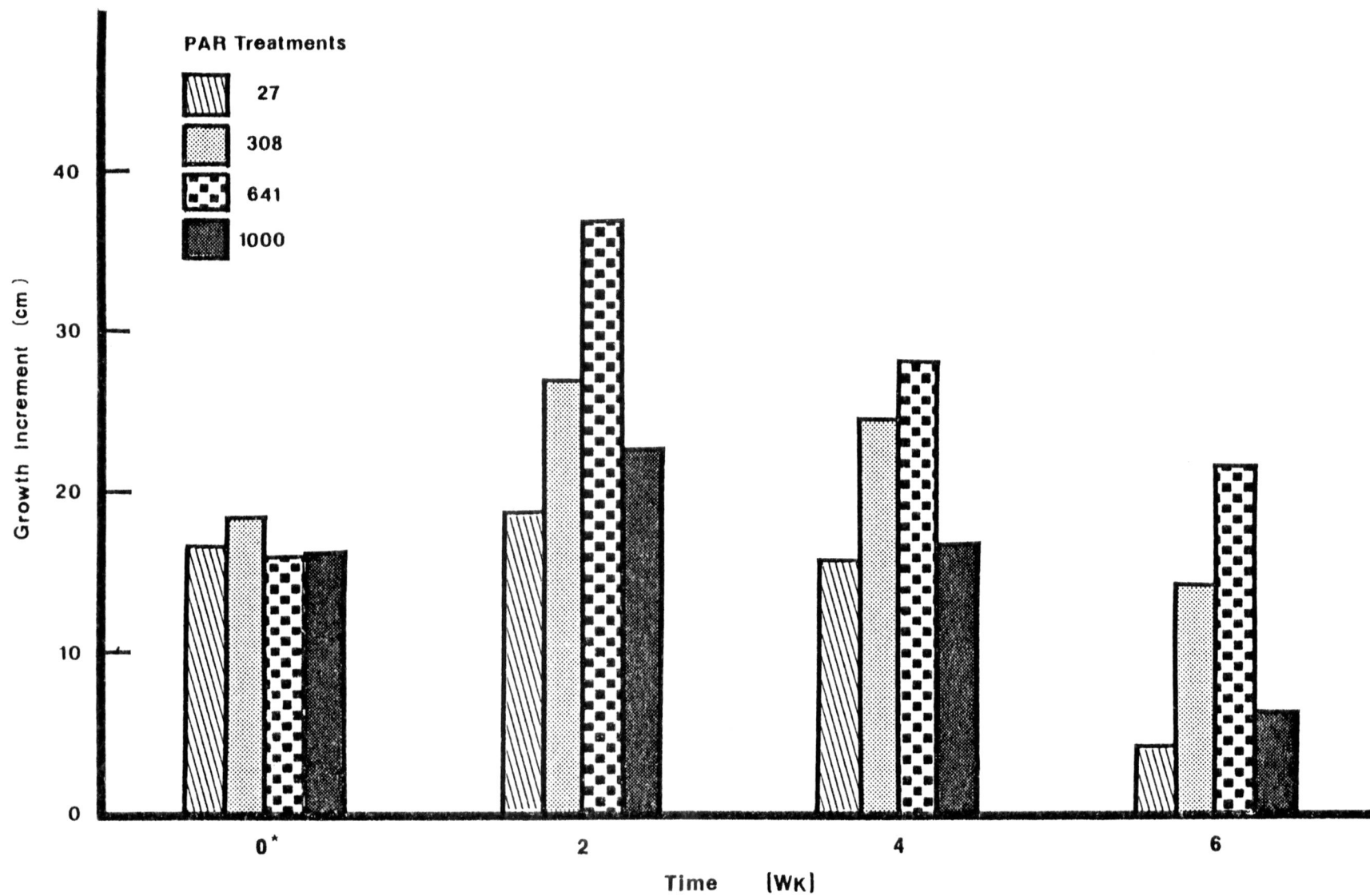


Table 20. Statistical Analysis of Tupelo Gum Seedling Incremental Growth Rates (cm) under Selected Light Intensities (n = 24)

PAR Treatment Group	Mean $\bar{x}$	Min value	Max value	Standard deviation	Standard error
Total Height at 0 Wks					
27	16.4	6.4	26.3	5.80	1.18
308	18.2	4.7	26.0	5.87	1.20
641	15.9	4.2	24.7	6.24	1.30
1000	16.0	6.2	24.3	5.67	1.16
Difference in Height 0-2 Wks					
27	18.6	7.5	31.4	6.52	1.33
308	26.8	16.3	47.2	6.60	1.81
641	36.6	18.5	61.6	11.14	2.32
1000	22.4	8.9	37.8	6.73	1.38
Difference in Height 2-4 Wks					
27	14.8	6.7	22.5	4.07	0.83
308	23.2	14.9	39.0	4.70	0.96
641	27.2	16.9	34.8	4.47	0.93
1000	16.7	8.5	24.5	3.65	0.75
Difference in Height 4-6 Wks*					
27	3.9	2.1	9.2	1.44	0.29
308	14.1	5.2	30.5	5.57	1.14
641	21.3	10.7	28.9	6.08	1.27
1000	5.9	3.8	11.4	1.64	0.33

* All seedlings were topped after 6 wks of treatment (age of tupelo seedling = 10 wks)

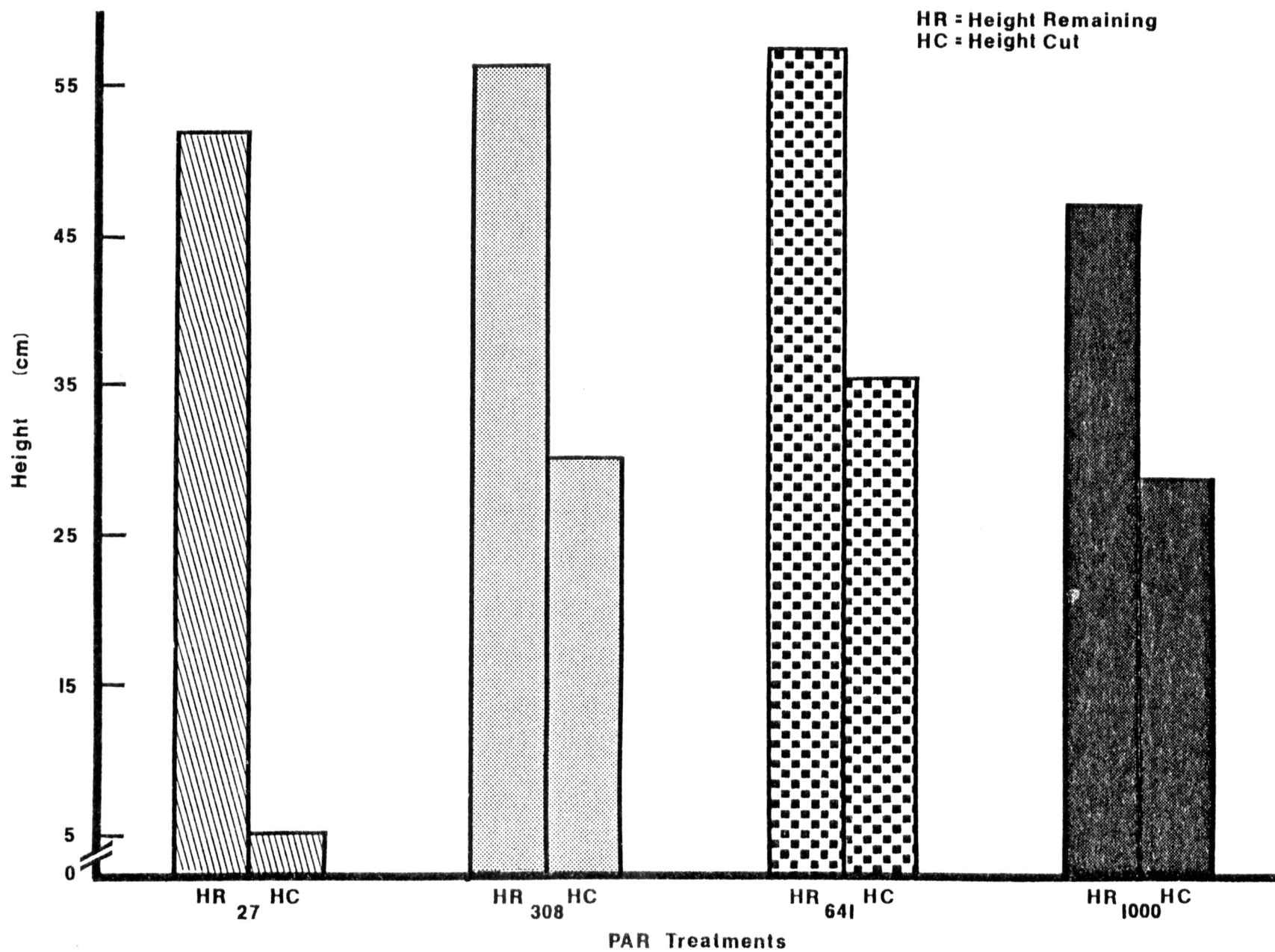
Table 21. Statistical Analysis of the Correlation between Light Intensity and Bimonthly Growth Rates of Tupelo Gum Seedlings by PAR Treatment Groups*

Week	Corr. coef. r.	r^2	Level of significance	Intercept A	Slope B	n
0**	-0.02	0.00	0.85	17.09	-0.00	70
2	0.47	0.22	0.0001	3.41	0.01	70
4	0.74	0.54	0.0001	30.46	0.04	70
6	0.82	0.67	0.0001	4.01	0.03	70

* Time of placement in the phytotron chamber

** Only 3 chambers (PAR - 27, PAR - 308, PAR - 641) were entered into the Linear Regression equation since light intensity in the controlled greenhouse (PAR - 1000) was not constant

Fig. 12. Tupelo gum seedling stem heights (cm) following topping at the 12th internode after 6 weeks of treatment. (HR = mean height of tupelo gum seedlings immediately after tops were cut off. HC = mean length of stem tip removed by topping.)



experimental plants. Although relatively more of the stem material of PAR-641 was removed during topping, these plants still had longer remaining stems than any other experimental group (Table 22).

Increase in plant height coincided with increasing PAR (Fig. 13). Seedlings at PAR-641 showed the greatest total height increase ($\bar{x}$ = 101.8 cm) after 6 weeks exposure to experimental conditions while PAR-27 showed the least ($\bar{x}$ = 54.3 cm). Plants grown at PAR-1000 appeared more similar to plants grown at PAR-27 ($\bar{x}$ = 61.1 cm) than those grown at PAR-641. This would indicate that stem elongation of seedlings in PAR-1000 (natural sunlight conditions) was inhibited by the higher natural light intensities or some other factor associated with greenhouse conditions such as light spectral quality.

Leaf Area

Mean leaf area per plant of the four treatment groups tended to increase with increasing light intensity (Table 23). Tupelo gum seedlings grown at PAR-1000 had an almost two-fold increase in leaf area per plant over those grown at PAR-27. Leaf area per plant of seedlings grown at PAR-1000 proved to be significantly greater ($p < 0.05$) than any of the other three treatments, none of which were significantly different from each other (Table 23). These leaf area values should be interpreted with caution as they do not represent the total leaf area of 3.5 month old seedlings. Rather these values represent only those leaves present at

Table 22. Statistical Analyses of the Correlation between Light Intensity and Tupelo Gum Seedling Growth by PAR Treatment Groups as Measured by Length of Stem Topped (cm) and Height Remaining after Topping (cm)

Variable	Source	Degrees of freedom	Sum of squares	Mean squares	F Ratio	F Prob.
H. Cut ¹	Between	3	1457.44	485.81	13.74	0.001
	Within	86	3041.63	35.57		
	Total	89	4499.06			
H. Left ²	Between	3	10641.16	3547.05	79.80	0.01
	Within	82	3644.75	44.45		
	Total	85	14285.91			

Duncan's New Multiple Range Analysis

Group	27	308	641	1000
Variable Mean				
H. Cut	5.25 ^{a3}	30.31 ^b	34.92 ^c	29.06 ^b
H. Left	51.84 ^b	56.57 ^c	57.39 ^c	47.32 ^a

Linear Regression⁴

Variable	Corr. coef. r	r ²	Level of significance	Intercept A	Slope B	n
H. Cut	0.78	0.61	0.0001	8.54	0.05	62
H. Left	0.34	0.12	0.004	52.35	0.01	66

Table 22. continued.....

- ¹"H. Cut" refers to length of stem tip removed by topping (removing apical meristem) at the 12th internode
- ²"H. Left" refers to height of tupelo gum seedlings immediately after they were topped at the 12th internode
- ³There is no statistical difference between treatment means with the same superscript. Means with differing superscripts are significantly different at the 0.05 level
- ⁴Only 3 chambers (PAR - 27, PAR - 308, PAR - 641) were entered into the Linear Regression equation since light intensity in the controlled greenhouse (PAR - 1000) was not constant

Fig. 13. Tupelo gum seedling height.

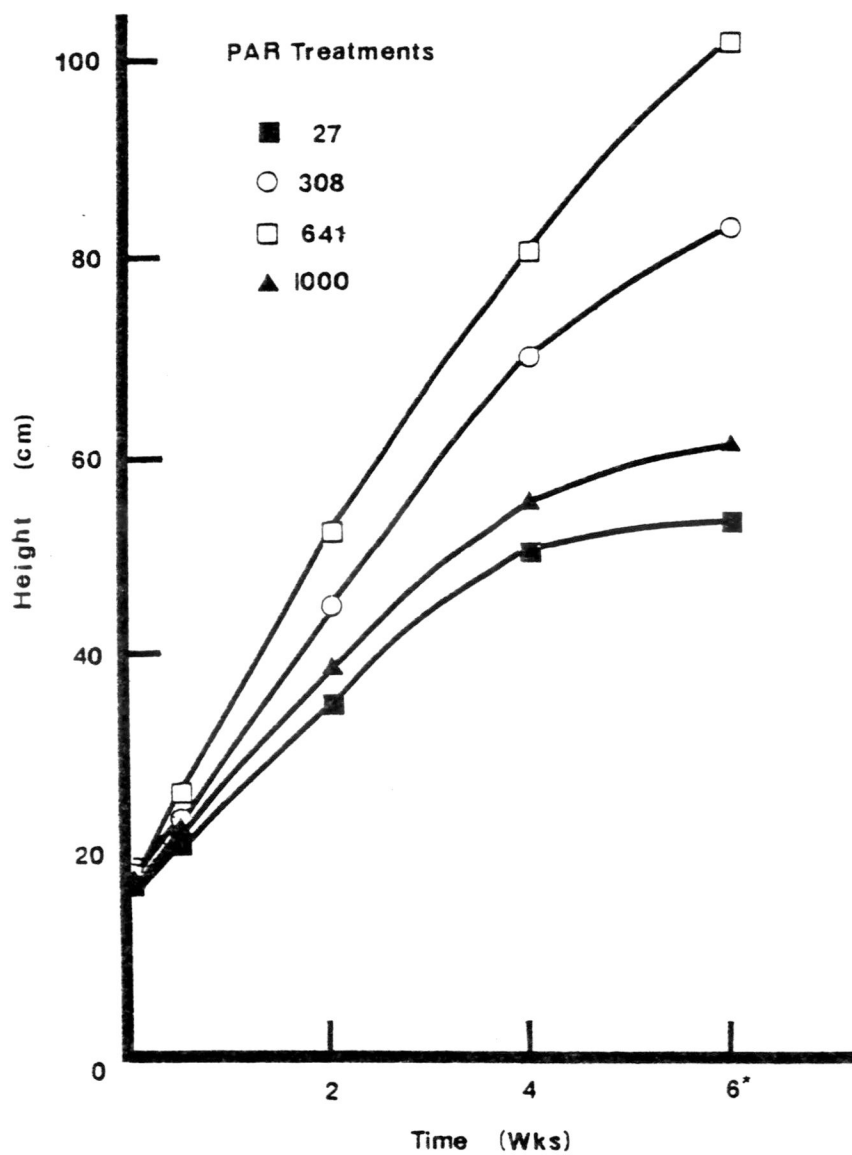


Table 23. Statistical Analyses of the Correlation between Light Intensity and Leaf Area (cm^2) of Tupelo Gum Seedlings by PAR Treatment Group

Source	Degrees of freedom	Sum of squares	Mean squares	F Ratio	F Prob.
Between	3	370380.00	123460.00	8.24	0.001
Within	34	509500.00	14985.29		
Total	37	879880.00			

Duncan's New Multiple Range Analysis

Group	27	308	641	1000
Mean (cm^2)	479.01 ^{a*}	578.53 ^a	491.16 ^a	717.73 ^b

Linear Regression**

Variable	Corr. coef. r	r^2	Level of significance	Intercept A	Slope B
Leaf Area	0.02	0.00	0.92	512.60	0.011

* There is no statistical difference between treatment means with the same superscript. Means with differing superscripts are significantly different at the 0.05 level

** Only 3 chambers (PAR - 27, PAR - 308, PAR - 641) were entered into the Linear Regression equation since light intensity in the controlled greenhouse (PAR - 1000) was not constant

harvesting and do not take into account leaves removed from the plants while removing stem tip growth when the plants became too tall for the chambers after 6 weeks exposure to experimental conditions.

Chlorophyll

The acetone method of chlorophyll extraction produced higher values of chlorophyll content than did the methanol method. Only acetone values are discussed since analysis of paired data revealed that the acetone method of chlorophyll extraction was significantly ($p < 0.001$) more efficient than the methanol extraction method (Table 24). (See Appendix Table C for methanol values)

Distribution of mean chlorophyll concentration per unit leaf area (Figure 14) showed no significant difference in chlorophyll a content among the four treatment groups ($p > 0.05$) (Table 25). However, PAR-308 contained a significantly greater quantity of chlorophyll b ($p < 0.05$) than PAR-1000, PAR-641 or PAR-27 (Table 26). Tupelo gum seedlings exposed at PAR-308 contained the highest mean concentration of chlorophyll b ($\bar{x} = 45.60 \text{ mg} \cdot \text{cm}^{-2}$) and thus the lowest ratio of chlorophyll a/b (1.11), while PAR-1000 contained the lowest mean concentration of chlorophyll b ($\bar{x} = 32.86 \text{ mg} \cdot \text{cm}^{-2}$). Seedlings exposed to the lowest light intensity (PAR-27) had the highest ratio of chlorophyll a/b (1.47) (Table 26). Maximum total chlorophyll content (a+b) per unit leaf area ($\bar{x} = 95.99 \text{ mg} \cdot \text{cm}^{-2}$) was found for tupelo gum

Table 24. Statistical Analysis of Two Methods of Chlorophyll Extraction of Tupelo Gum Seedlings Through Use of the Student's t-test with Paired Data

Extraction Method	Variable	Mean x	Corr. coef. r	t Value	Degrees of freedom	2-Tail Prob.
Methanol	Chlorophyll <u>a</u>	44.25	0.56	-4.52	39	0.0001
Acetone	Chlorophyll <u>a</u>	49.58				
Methanol	Chlorophyll <u>b</u>	18.45	0.45	-12.32	39	0.001
Acetone	Chlorophyll <u>b</u>	37.54				
Methanol	Total Chlorophyll (<u>a&b</u>)	62.76	0.62	-11.08	39	0.001
Acetone	Total Chlorophyll (<u>a&b</u>)	86.47				

Fig. 14. Concentrations of chlorophyll in leaves of tupelo gum seedlings.

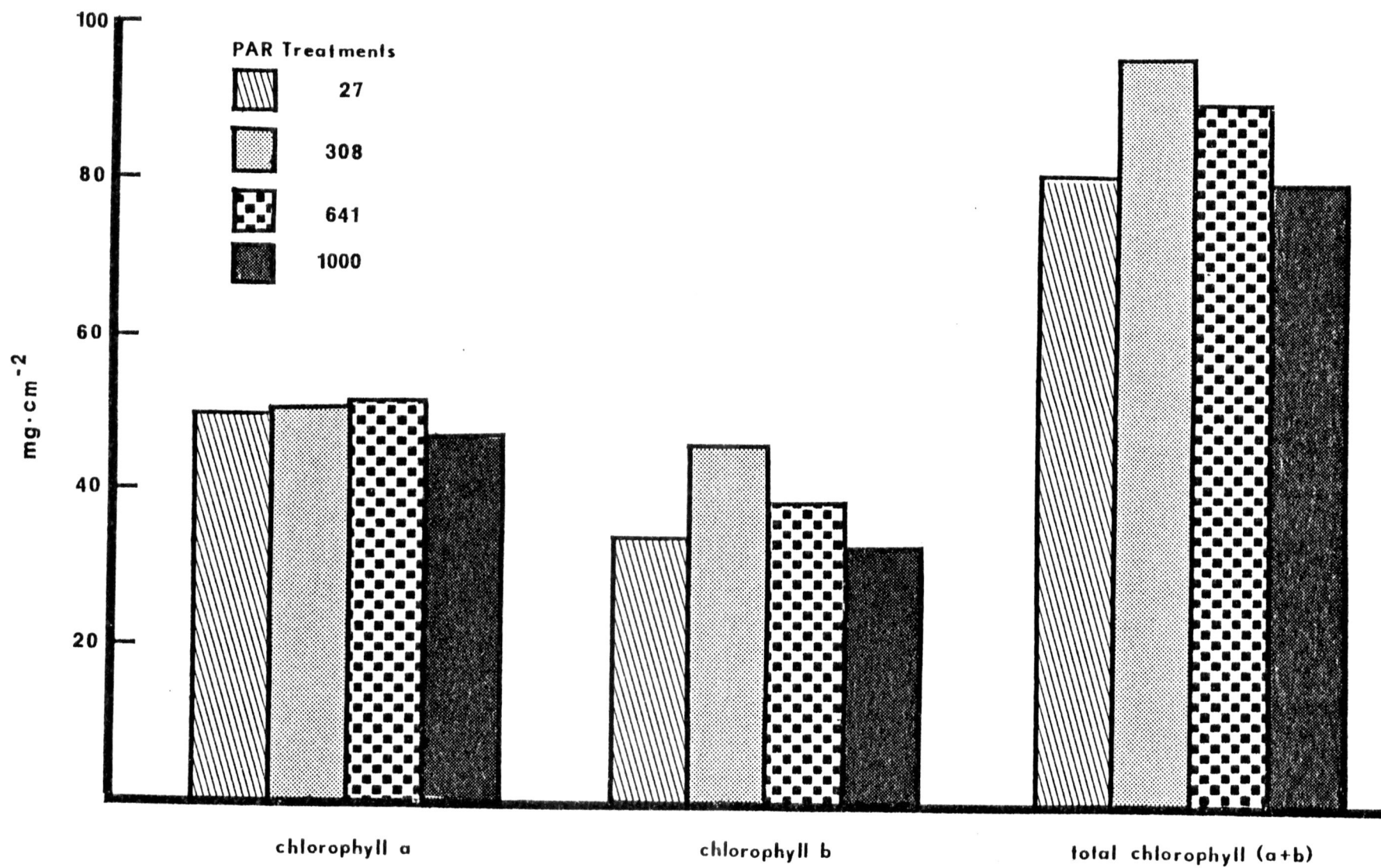


Table 25. Analysis of Variance of Tupelo Gum Seedling Chlorophyll Concentration Per Unit Leaf Area ($\text{mg}\cdot\text{cm}^{-2}$) by PAR Treatment Means

Variable (Chlorophyll)	Source	Degrees of freedom	Sum of squares	Mean squares	F Ratio	F Prob.
<u>a</u>	Between	3	175.31	58.44	0.94	0.44
	Within	34	2121.31	62.39		
	Total	37	2296.63			
<u>b</u>	Between	3	1001.65	333.88	3.2	0.03
	Within	34	3532.45	103.90		
	Total	37	4534.10			
Total (<u>a&b</u>)	Between	3	1943.00	647.67	2.4	0.08
	Within	34	9214.56	271.01		
	Total	37	11157.56			

Table 26. Statistical Analyses of Mean Chlorophyll Concentrations Per Unit Leaf Area ($\text{mg}\cdot\text{cm}^{-2}$) of Tupelo Gum Seedlings by PAR Treatment Group

Duncan's New Multiple Range Analysis				
Group	27	308	641	1000
Variable				
Chl. <u>a</u>	49.78 ^{a*}	50.58 ^a	52.67 ^a	46.85 ^a
Chl. <u>b</u>	33.88 ^a	45.60 ^b	40.10 ^a	32.86 ^a
Tot. Chl. (<u>a&b</u>)	80.83 ^a	95.99 ^a	92.76 ^a	79.77 ^a

Linear Regression**						
Variable	Corr. coef. r	r ²	Level of significance	Intercept A	Slope B	n
Chl. <u>a</u>	0.14	0.02	0.48	49.47	0.00	27
Chl. <u>b</u>	0.19	0.04	0.33	36.82	0.01	27
Total Chl. (<u>a&b</u>)	0.25	0.06	0.21	83.83	0.02	27

*There is no statistical difference between treatment means with the same superscript. Means with differing superscripts are significantly different at the 0.05 level

**Only 3 chambers (PAR - 27, PAR - 308, PAR - 641) were entered into the Linear Regression equation since light intensity in the controlled greenhouse (PAR - 1000) was not constant

seedlings grown at PAR-308 (Fig. 14). Linear regression analysis revealed no significant correlation between light intensity and chlorophyll concentrations of the leaves (Table 26).

Seedling Fresh and Dry Weight

Mean standing biomass (fresh weight) after 14 weeks growth increased as light intensity increased (Table 27). PAR-1000 seedlings had a mean fresh weight of 47.04 g while that for PAR-27 was 11.83 g. Linear regression analysis revealed a positive correlation ($r = 0.89$) between light intensity and seedling fresh weight (Table 28). Although Duncan's New Multiple Range analysis revealed no significant difference between seedlings grown at PAR-1000 and PAR-641, both of these groups differed significantly from PAR-27 and PAR-308 (Table 28).

Since fresh weight may vary with time of day, watering regime, etc., dry weight is usually a more useful measurement. Tupelo gum seedlings at PAR-641 produced the greatest mean dry weight ($\bar{x} = 16.29\text{g}$) while PAR-27 seedlings exhibited the lowest dry weight ($\bar{x} = 2.60\text{ g}$) during the 14 week period (Fig. 15). Statistical analysis revealed significant differences between all treatment groups. Linear regression analysis resulted in a correlation of 0.94 between light intensity and total dry weight of tupelo gum seedlings (Table 29).

Partitioning of biomass (gram dry weight) revealed that while PAR-1000 leaf biomass was greater than the PAR-641 leaf biomass, the

Table 27. Statistical Analysis of Tupelo Gum Seedling Fresh Weights (g) by PAR Treatment Group

PAR Treatment Group	Mean x	Min value	Max value	Standard deviation	Standard error	n
27	11.83	8.39	14.95	2.03	0.68	9
308	36.56	27.63	50.83	7.47	2.49	9
641	46.87	35.50	59.22	7.78	2.59	9
1000	47.04	34.67	58.92	6.55	1.97	11

Table 28. Statistical Analyses of the Correlation between Light Intensity and Fresh Weight (g) of Tupelo Gum Seedlings by PAR Treatment Means

ANOVA						
Source	Degrees of freedom	Sum of squares	Mean squares	F Ratio	F Prob.	
Between	3	7666.63	2555.54	62.39	0.001	
Within	34	1392.72	40.96			
Total	37	9059.36				

Duncan's New Multiple Range Analysis					
Group	27	308	641	1000	
PAR Treatment Group	11.83 ^{a*}	36.56 ^b	47.04 ^c	46.88 ^c	

Linear Regression**						
Variable	Corr. Coef. r	r ²	Level of significance	Intercept A	Slope B	n
Wet wt.	0.89	0.79	0.001	13.44	0.05	27

* There is no statistical difference between treatment means with the same superscript. Means with differing superscripts are significantly different at the 0.05 level

** Only 3 chambers (PAR - 27, PAR - 308, PAR - 641) were entered into the Linear Regression equation since light intensity in the controlled greenhouse (PAR - 1000) was not constant

Fig. 15. Total biomass (dry weight) of tupelo gum seedlings
grown at selected light intensities. (PAR =
Photosynthetically Active Radiation)

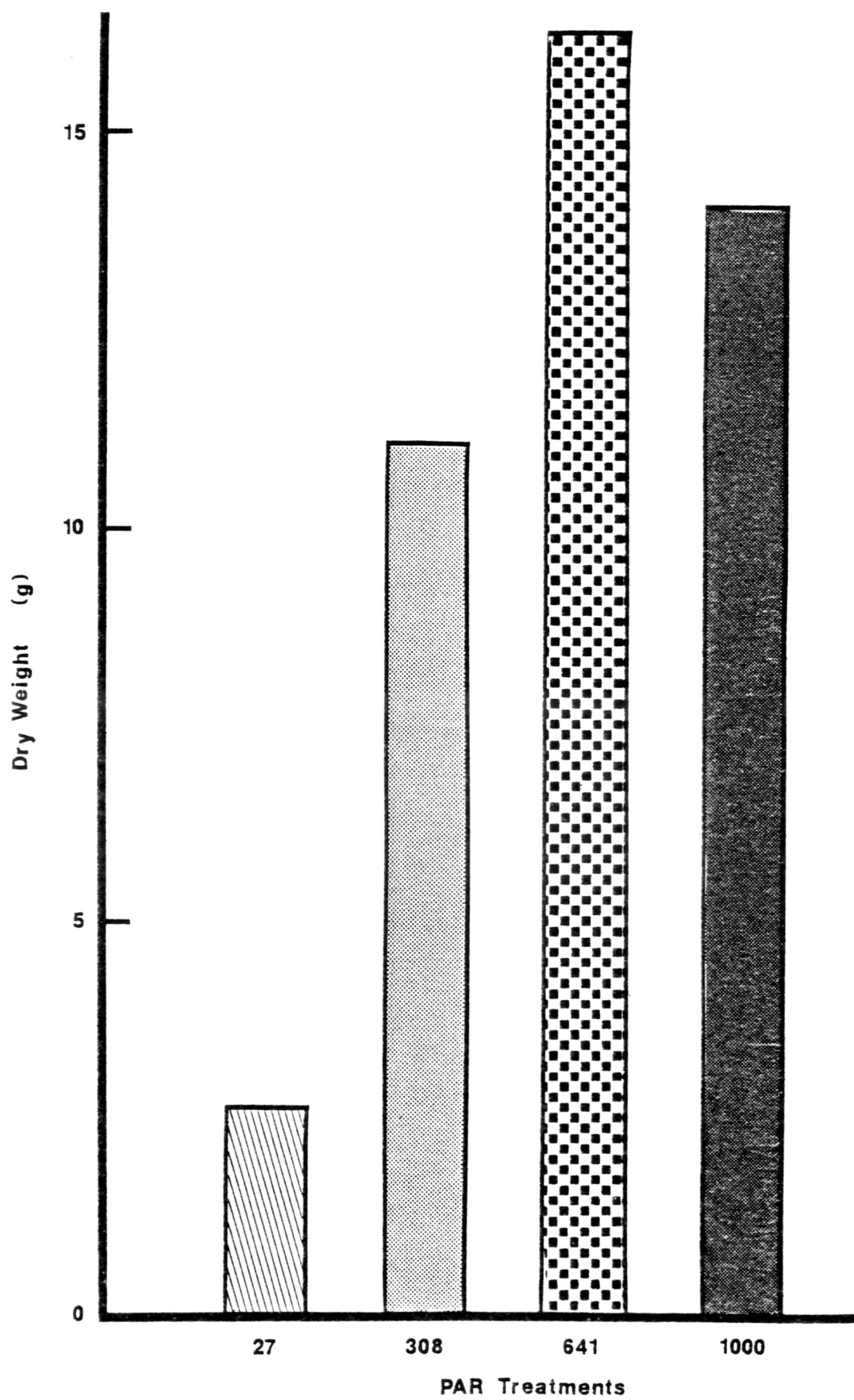


Table 29. Statistical Analyses of the Correlation between Light Intensity and Biomass (gram dry weight) of Tupelo Gum Seedlings by PAR Treatment Means

ANOVA						
Source	Degrees of freedom	Sum of squares	Mean squares	F Ratio	F Prob.	
Between	3	991.91	330.64	92.66	0.0001	
Within	34	121.32	3.57			
Total	37	1113.24				
Duncan's New Multiple Range Analysis						
Group	27	308	641	1000		
Mean	2.60 ^{a*}	11.07 ^b	16.29 ^d	14.09 ^c		
Linear Regression**						
Variable	Corr. coef. r	r^2	Level of significance	Intercept A	Slope B	n
Dry wt. (g)	0.94	0.87	0.001	2.79	0.02	27

*There is no statistical difference between treatment means with the same superscript. Means with differing superscripts are significantly different at the 0.05 level

**Only 3 chambers (PAR - 27, PAR - 308, PAR - 641) were entered into the Linear Regression equation since light intensity in the controlled greenhouse (PAR - 1000) was not constant

stem biomass and root biomass of the PAR-1000 seedlings was much less in comparison to the PAR-641 seedlings (Figure 16). The dry weight partitioning left PAR-27 tupelo gum seedlings with less than 1.5 g in each category. Increased light intensity resulted in increased biomass in leaves ($r = 0.64$), roots ($r = 0.90$) and stems ($r = 0.92$). Duncan's New Multiple Range Analysis revealed significant differences ($p < 0.05$) between treatment groups PAR-27, PAR-308, and PAR-641 in mean root and mean stem biomass (Table 30). Mean values for PAR-1000 seedlings were lower than those for PAR-641 seedlings in both root biomass and stem biomass.

Root/shoot ratios revealed no significant difference between tupelo gum seedlings exposed at PAR-308 with either PAR-641 or PAR-1000. However PAR-27 seedlings produced a significantly smaller root/shoot ratio ($\bar{x} = 0.42$) than the other treatment groups (Table 30).

Diameter

After 4 weeks exposure to experimental conditions (8 weeks of age) mean diameter at PAR-1000 was approximately 1.0 mm greater than the diameter at PAR-308, and 0.5 mm less than at PAR-641 (Figure 17, Table 31). Interestingly, PAR-641 seedlings consistently produced the greatest mean stem diameter and PAR-27 seedlings consistently produced the least mean stem diameter (Table 31). All four treatment groups were significantly different both times measurements were made.

Fig. 16. Biomass partitioning (gram dry weight) in tupelo gum seedlings grown at selected light intensities.
(PAR = Photosynthetically Active Radiation)

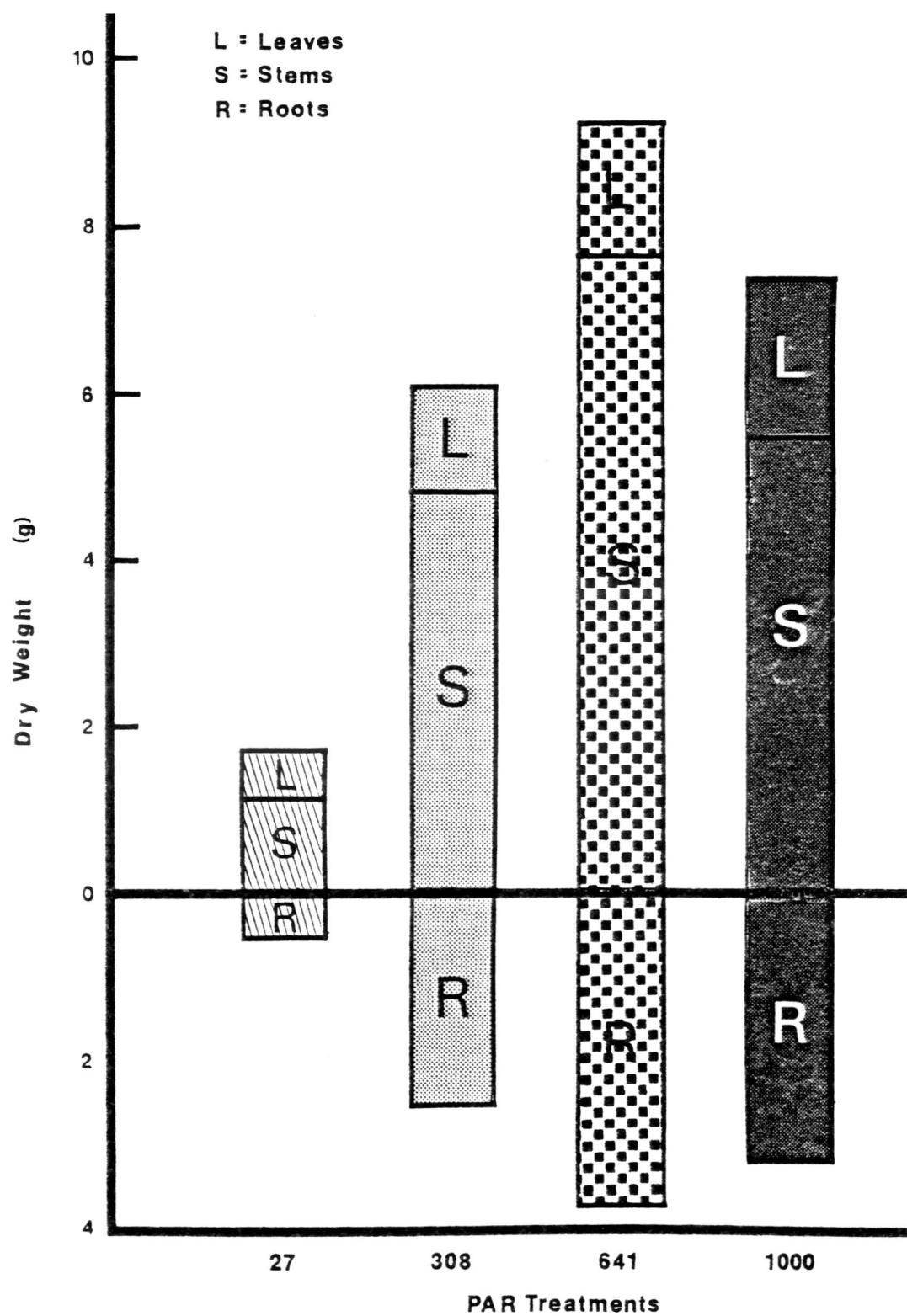


Table 30. Statistical Analyses of the Correlation between Light Intensity and Biomass Partitioning (gram dry weight) of Tupelo Gum Seedlings by PAR Treatment Means

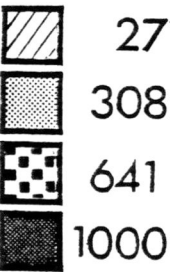
Duncan's New Multiple Range Analysis						
Group		27	308	641	1000	
Variable Mean						
Leaves		0.55 ^{a*}	1.24 ^b	1.37 ^b	1.87 ^c	
Roots		0.48 ^a	2.64 ^b	3.57 ^c	3.18 ^c	
Stems		1.17 ^a	4.79 ^b	7.34 ^c	5.47 ^b	
Root/Shoot Ratio		0.42 ^a	0.55 ^b	0.51 ^b	0.58 ^c	
Linear Regression**						
Variable	Corr. coef. r	r ²	Level of significance	Intercept A	Slope B	n
Leaves	0.64	0.41	0.001	0.63	0.00	27
Roots	0.90	0.82	0.001	0.61	0.00	27
Stems	0.92	0.84	0.001	1.19	0.00	27
Root/Shoot Ratio	0.40	0.15	0.04	0.45	0.00	27

*There is no statistical difference between treatment means with the same superscript. Means with differing superscripts are significantly different at the 0.05 level

**Only 3 chambers (PAR - 27, PAR - 308, PAR - 641) were entered into the Linear Regression equation since light intensity in the controlled greenhouse (PAR - 1000) was not constant

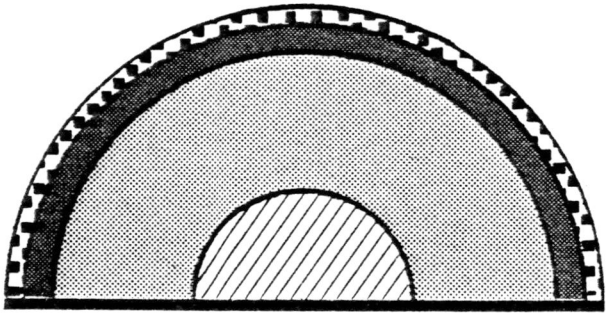
Fig. 17. Tupelo gum seedling diameter when grown at selected light intensities (PAR). Harvest diameter = diameter at harvest (after 10 weeks treatment).

PAR Treatments

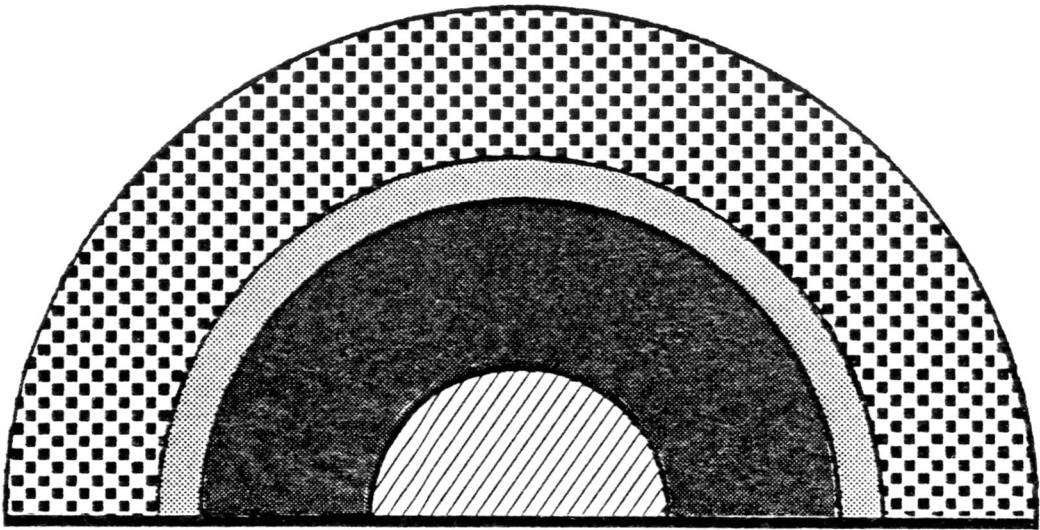


Scale

2mm



4 Wk Diameter



Harvest Diameter

Table 31. Mean Diameters (mm) of Tupelo Gum Seedlings by PAR Treatment Group

Diameter after 4 Wks Treatment						
Group	n	Mean	Standard deviation	Standard error	Min value	Max value
27	24	2.65	0.79	0.16	1.10	3.85
308	24	6.38	0.76	0.15	4.90	7.90
641	24	7.67	0.65	0.14	6.20	8.60
1000	24	7.17	0.70	0.14	6.05	8.60
Diameter at Harvest (approximately 10 Wks Treatment)						
Group	n	Mean	Standard deviation	Standard error	Min value	Max value
27	24	3.86	0.44	0.09	3.05	4.55
308	24	9.24	0.53	0.11	8.10	9.95
641	24	13.03	0.41	0.09	12.30	13.75
1000	24	8.21	0.52	0.11	7.10	9.30

Linear regression analysis revealed correlations of 0.90 and 0.98 between light intensity and mean diameter produced by tupelo gum seedlings after 4 weeks and 11 weeks exposure to experimental conditions, respectively (Table 32). At termination of the experiment, the mean stem diameter for PAR-1000 had only increased 1.0 mm, that for PAR-308 had increased almost 3.0 mm, and that for PAR-641 had increased almost 5.5 mm. This seems to indicate that the initial spurt of growth for PAR-1000 was in diameter, not height.

If height and diameter are considered together (Fig. 18), it can be seen that neither parameter alone provides an independent estimate of the effect of light intensity on tupelo gum seedlings. Although the plants at PAR-27 demonstrated considerable growth as measured by height, the seedlings became so etiolated that it was necessary to stake them to keep them from falling. By comparison, seedlings grown under natural light conditions (PAR-1000) were sturdy although not extremely tall. The greatest height and diameter values were obtained from the tupelo gum seedlings at PAR-641. These seedlings appeared extremely healthy, were tall and sturdy, had dark green leaves, and had developed a woody stem after only 3.5 months of growth. It should also be noted that while tupelo gum seedlings grown at the lowest light intensity (PAR-27) retained their cotyledons and exhibited spindly green shoots, all other treatments produced seedlings which dropped their cotyledons and produced woody tissue.

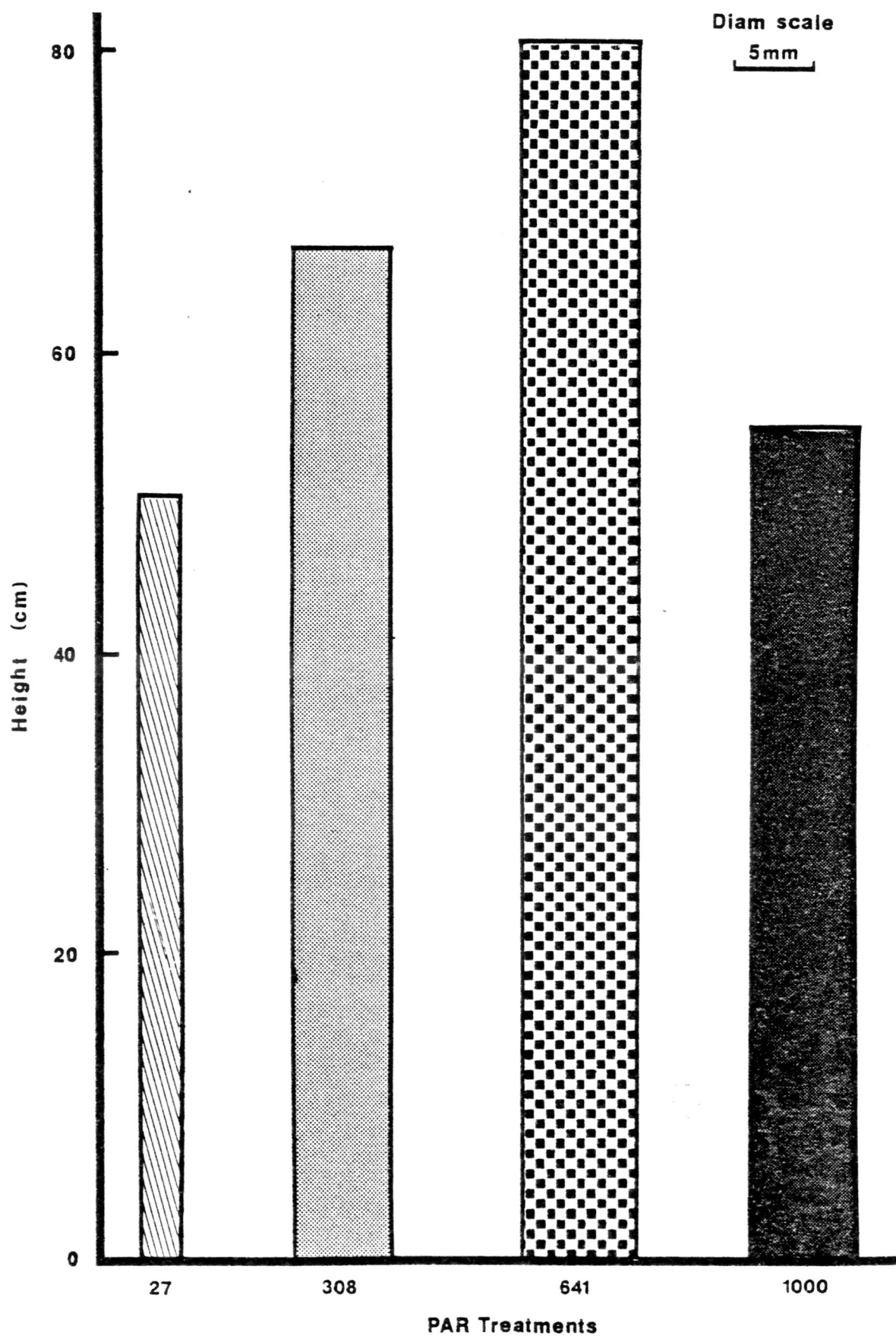
Table 32. Statistical Analysis of Mean Diameters (mm) of Tupelo Gum Seedlings by PAR Treatment Means

Duncan's New Multiple Range Analysis						
Group	27	308	641	1000		
Variable Mean						
Dia. at 4 Wks	2.65 ^{a*}	6.38 ^b	7.67 ^d	7.17 ^c		
Dia. at Harvest	3.86 ^a	9.23 ^c	13.03 ^d	8.21 ^b		
Linear Regression**						
Variable	Corr. coef. r	r ²	Level of significance	Intercept A	Slope B	n
Dia. at 4 wks	0.90	0.81	0.0001	2.94	0.01	70
Dia. at Harvest	0.98	0.96	0.001	3.88	0.15	70

*There is no statistical difference between treatment means with the same superscript. Means with differing superscripts are significantly different at the 0.05 level

**Only 3 chambers (PAR - 27, PAR - 308, PAR - 641) were entered into the Linear Regression equation since light intensity in the controlled greenhouse (PAR - 1000) was not constant

Fig. 18. Relationship between diameter and height in tupelo gum seedlings for PAR treatment means.



Photosynthetic Rate of Tupelo Gum Seedlings

Photosynthetic rate of the tupelo gum seedlings tended to parallel increasing light intensity (Table 33). Mean values ranged from 0.15 mg CO₂·cm⁻²h⁻¹ (PAR-641) to 0.05 mg CO₂·cm⁻²h⁻¹ (PAR-27).

Photosynthetic rate of the greenhouse seedlings (PAR-1000) can be assumed to be higher than those of PAR-641 since greenhouse plants utilized more than the 50 ppm to which the gas analyzer had been calibrated.

Linear regression analysis showed a significant ($p < 0.001$) positive correlation ($r = 0.87$) between increasing light intensity and photosynthetic rate for tupelo gum seedlings. Further statistical analysis with Duncan's New Multiple Range Test revealed significant differences ($p < 0.05$) in this response among the three treatment groups (Table 33).

Table 33. Statistical Analyses of Photosynthetic Rates ($\text{mg CO}_2 \cdot \text{cm}^{-2} \cdot \text{h}^{-1}$) of Tupelo Gum Seedlings by PAR Treatment Means

Group	n	Mean	Standard deviation	Standard error	Min value	Max value
27	9	0.05	0.01	0.00	0.04	0.06
308	9	0.12	0.03	0.01	0.09	0.17
641	8	0.15	0.02	0.01	0.11	0.17

Duncan's New Multiple Range Analysis

Group	27	308	641	1000
Variable	0.05 ^{a*}	0.12 ^b	0.15 ^c	—

* There is no statistical difference between treatment means with the same superscript. Means with differing superscripts are significantly different at the 0.05 level

Field Studies

Observations on Erosion

Erosion is widespread in the Albemarle-Pamlico region with typical shoreline losses of 2 to 3 feet per year. Shoreline erosion is least evident along bald cypress swamps or headlands, or where the eroding bank is protected by an offshore stand (fringe) of bald cypress (Bellis et al. 1975). The fringes of bald cypress in these areas appear to act as natural buffers which dissipate storm wind and wave energy and thus retard shoreline erosion. By sheer physical obstruction, offshore bald cypress seem to dampen both wind and wave energy directed at the shoreline. Furthermore, as waves make contact with the trees, suspended loads of sediment and debris settle from the water. This could result in some shoreline accretion through sediment deposition over time.

A bald cypress fringe also appears to protect plants and animals found in the fringe from high energy forces. At the same time, the offshore trees provide shade for animals, nesting sites for birds, and a substrate for growth of other vegetation such as swamp rose and poison ivy anastomosing root system. Stress indicators such as lighter leaf color, lower crown, and broken crown are evident in trees of the bald cypress fringe.

Distance from the Shoreline

Approximately 20 tree-to-shoreline distances were measured at each of three cypress fringe sites. Trees at Bluff Point had a greater mean distance from the shoreline ($\bar{x} = 37.7$ m) than the other two sites. The maximum distance at Bluff Point was 57.7 m in contrast to a minimum distance of 20.0 m. Black Walnut Point trees had the least mean distance from the shoreline ($\bar{x} = 25.8$ m) (Table 34). Although there was a significant difference ($p < 0.05$) between mean distances measured at Bluff Point and the other two sites (Table 35), this is not surprising since the field sites and trees at these sites were arbitrarily selected to produce a range of distances, frequencies, and tree sizes. Thus data from all three sites were pooled for analysis.

Trunk Diameter and Age

The mean trunk diameters were 0.50 m, 0.46 m, and 0.43 m for Black Walnut Point, Bluff Point and Sandy Point, respectively. Each group of trees had a variance of less than 0.2 m (Table 34). ANOVA and Duncan's New Multiple Range Test indicated no significant difference between means of the tree sites (Table 35).

Since accurate ages could not be obtained for most of the trees due to rotten and/or hollow centers, the evident annual ring counts underestimate age. Although the mean number of rings was 116, Black Walnut Point varied most from the mean with a site mean of 131. The number of annual rings per tree ranged from 11 to 239

Table 34. Field Data for Bald Cypress Trees at the Three Study Sites on Albemarle Sound, N.C.

# Annual Rings Counted	Diameter* (m)	Distance from Shoreline (m)	Tree No.
<u>Black Walnut Point</u>			
73	0.26	48.65	7
80	0.43	51.10	8
89	0.61	6.15	15
93	0.41	37.80	5
107	0.45	6.68	1
114	0.33	16.91	18
114	0.54	19.30	14
119	0.60	20.62	17
132	0.49	15.54	6
148	0.45	15.87	13
149	0.52	32.10	2
149	0.69	49.30	9
156	0.65	28.65	11
159	0.35	7.30	16
159	0.47	23.00	12
160	0.50	9.93	10
180	0.56	42.64	4
186	0.66	34.70	3
<u>Bluff Point</u>			
60	0.24	37.01	22
69	0.31	26.44	33
73	0.23	30.12	23
76	0.50	57.73	20
81	0.52	24.46	31
82	0.29	20.04	35
88	0.60	37.62	32
92	0.49	41.20	27
100	0.41	37.11	34
109	0.50	57.73	19
110	0.40	51.05	26
110	0.49	34.77	21
112	0.60	32.79	29
135	0.42	26.44	36
137	0.47	53.35	25
141	0.68	21.03	30
143	0.47	55.78	24
148	0.66	35.06	28

Table 34. continued.....

# Annual Rings Counted	Diameter* (m)	Distance from Shoreline (m)	Tree No.
<u>Sandy Point</u>			
11	0.42	20.95	52
53	0.24	31.40	40
55	0.24	30.30	45
68	0.28	33.75	38
78	0.50	7.21	55
90	0.32	32.40	42
101	0.32	23.40	50
104	0.83	21.92	54
115	0.30	17.32	47
115	0.37	34.20	39
115	0.44	31.80	43
117	0.39	30.95	44
118	0.40	14.65	48
119	0.31	22.75	51
125	0.46	13.50	49
129	0.76	32.60	37
130	0.25	32.20	46
133	0.68	60.66	56
165	0.61	59.85	57
200	0.43	30.60	41
239	0.50	16.60	53

* Diameters were measured immediately above the flared buttress characteristic of bald cypress tree bases

Table 35. Statistical Analyses of the Correlation between Study Site and Distance from the Shoreline and Diameter of Bald Cypress Trees Found in Albemarle Sound, N.C.

ANOVA						
Variable	Source	Degrees of freedom	Sum of squares	Mean squares	F Ratio	F Prob.
Distance	Between	2	1420.66	710.33	3.79	0.03
	Within	54	10128.75	187.57		
	Total	56	11549.41			
Diameter	Between	2	4.41	2.20	1.08	0.35
	Within	54	110.00	2.03		
	Total	56	114.41			

Duncan's New Multiple Range Analysis

Group	Black Walnut Point	Bluff Point	Sandy Point
Variable Mean			
Distance	25.85 ^{a*}	37.76 ^b	28.52 ^a
Diameter	4.98 ^a	4.60 ^a	4.31 ^a

*There is no statistical difference between treatment means with the same superscript. Means with differing superscripts are significantly different at the 0.05 level

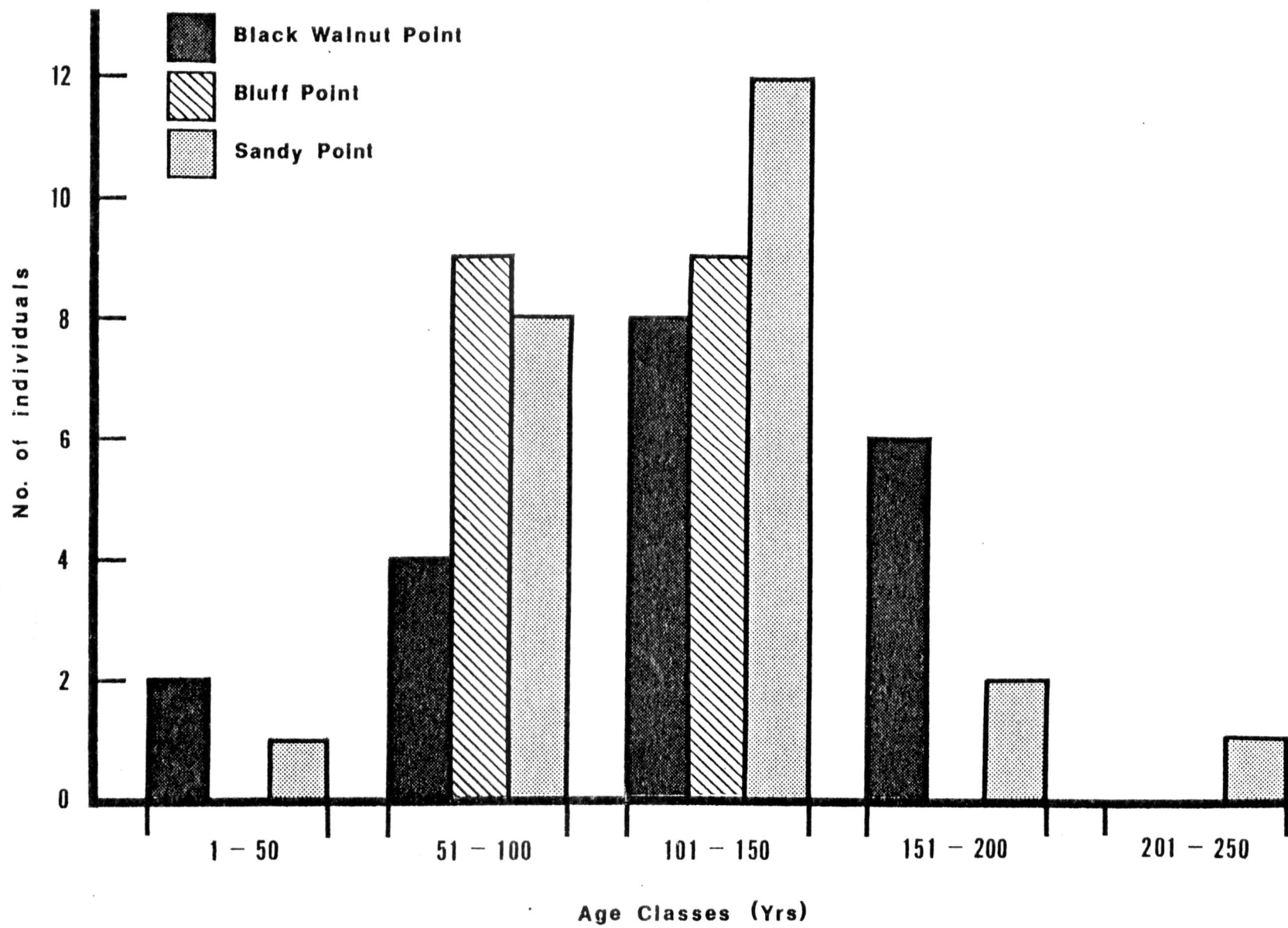
with a mean of 116 (Figure 19). Black Walnut Point had trees with annual ring counts in each age class up to 201, Sandy Point had trees represented in each class, while Bluff Point trees only fell into the two middle classes.

Data for all trees that were ≥ 5 m from the present driftline are given in Table 34. At Black Walnut Point a tree only 2.76 m from the present driftline and having a diameter of 0.08 m was not included in the table because it was so anomolous. Trees within 5 m of the present driftline were also excluded to rule out trees such as those young bald cypress which were planted along the shore at Black Walnut Point approximately 8 years ago. Although the 0.08 m diameter tree had only 8 annual rings, there was already evidence that the bole of the tree was beginning to rot; this was indicated by soft, mushy, discolored wood in the center of the extracted core.

Distance from the Shoreline vs Age

Bald cypress seedlings were not observed in the swamp during 1975, but were found along the driftlines on the beach. Since cypress seeds do not germinate under water, it was assumed that the offshore trees once germinated on a similar beach driftline which had since either flooded or eroded away. This assumption formed the basis for the hypothesis that the distance to the present driftline divided by the age of the offshore cypress trees would give an average local erosion rate.

Fig. 19. Frequency distribution in age classes between
sites as based on the number of annual rings counted.



Problems arose, however, when it was discovered that it was not possible to accurately determine the age of the individual trees offshore. Ninety-five percent of these trees, with their roots submerged throughout the year, were either rotten or hollow in the center. The correlation between distance and age was slightly negative indicating that the trees farthest out in the water had fewer annual rings still present and therefore were more rotten. Due to the rotten centers, only minimal ages could be determined by counting the annual rings present in the healthy wood (Table 36). This technique yields a conservative estimate of tree age. Still, distance to the driftline divided by minimal ages would give a local maximum rate of erosion. These rates may be compared with local erosion rates which are based on the comparison of recent and 30 year old aerial photographs (Table 36). The greatest local erosion rate calculated from minimal ages of offshore trees for Black Walnut Point was 2.23 ft/yr as compared with the lowest rate of 0.20 ft/yr. Thus an average maximum local erosion rate of 0.75 ft/yr was calculated for Black Walnut Point, over a period of approximately 132 years. This rate is less than half the local erosion rate calculated for the same area over the past 32 years (Table 36). Similar trends, though not quite so dramatic, are evident for both Bluff Point and Sandy Point. These data indicated that the local erosion rates have accelerated recently.

Table 36. Comparison of Calculated Long-Range Erosion Rates with 30-Year Erosion Rates Based on Aerial Photographs

<u>Black Walnut Point</u>		<u>Sandy Point</u>		<u>Bluff Point</u>	
m/yr	ft/yr	m/yr	ft/yr	m/yr	ft/yr
0.67	2.23	0.62	2.07	1.90	6.33
0.64	2.13	0.38	1.27	0.59	1.97
0.07	0.23	0.41	1.37	0.55	1.83
0.41	1.37	0.76	2.53	0.50	1.67
0.06	0.20	0.30	1.00	0.09	0.30
0.15	0.50	0.24	0.80	0.36	1.20
0.17	0.57	0.42	1.40	0.23	0.77
0.12	0.40	0.45	1.50	0.21	0.70
0.11	0.37	0.37	1.23	0.15	0.50
0.22	0.73	0.53	1.77	0.30	1.00
0.33	1.10	0.46	1.53	0.28	0.93
0.18	0.60	0.32	1.07	0.26	0.87
0.05	0.17	0.29	0.97	0.12	0.40
0.14	0.47	0.20	0.67	0.19	0.63
0.06	0.20	0.38	1.27	0.11	0.37
0.24	0.80	0.15	0.50	0.25	0.83
0.19	0.63	0.39	1.30	0.25	0.83
		0.24	0.80	0.46	1.53
				0.36	1.20
				0.15	0.50
				0.07	0.23
$\bar{x} = 0.22$	0.75	0.38	1.28	0.35	1.17

Table 36. continued.....

<u>Black Walnut Point</u>	<u>Sandy Point</u>	<u>Bluff Point</u>
Calculated Erosion Rates Based on Average Minimum Age of Bald Cypress Trees		
0.75 ft/yr (132 yr)*	1.28 ft/yr (104 yr)	1.17 ft/yr (113 yr)
30-Year Erosion Rates Based on Aerial Photographs (USDA Soil Conservation Service, 1975)		
1.60 ft/yr (32 yr)**	1.62 ft/yr (31 yr)	1.62 ft/yr (31 yr)

* Average minimum age of bald cypress trees found offshore at each site

** Period of time covered by USDA-SCS study

Diameter vs Annual Rings

Since there was no significant difference between mean diameters of the three study sites, all diameter values were pooled. The linear correlation between diameter and annual ring count of the offshore bald cypress trees (Table 37) was low ($r = 0.42$), but highly significant ($p < 0.001$). That the correlation coefficient was not higher may be attributed to the fact that diameter was correlated with the number of annual rings actually counted rather than actual age. The space in the centers of the rotten trees with no rings present was not accounted for.

Theoretically, it should be possible to go to a specific site, core a few offshore bald cypress trees, measure several cypress tree diameters and corresponding distances from the shoreline, and then calculate a maximum erosion rate for the area. Using a regression line and baseline age data from the cored trees, minimum ages could be calculated from diameter values. Dividing these values into the corresponding distances from the shoreline would give an average value roughly comparable to the maximum local erosion rate over the average number of years determined from the diameters. This value, when compared to published 30 year erosion rates for the area, would approximate the maximum erosion rate to be expected in the given area. Understandably, the calculated figures are

Table 37. Linear Regression Analysis of the Correlation between Diameter and Annual Ring Count of the Offshore Bald Cypress Trees

Variable	Corr. coef. r	r^2	Level of significance	Intercept A	Slope B	n
Diameter	0.42	0.17	0.001	2.85	0.01	57

overestimates due to peculiarities of technique. It should be emphasized that calculated figures should only be used as an estimate for a restricted area.

Wind and Waves

Offshore stands of bald cypress trees with broad, flared bases, flared crowns, and lateral growths of roots and knees dampen wind velocity and wave amplitude. Depending on the density of the cypress trees, wind velocity may be reduced below levels of detection both within the cypress fringe and on the beach behind (Table 38). The average wind velocity reduction for the three study sites within the cypress fringe was 62.9% while that on the beach was 53.2% (Table 38). Beach values, and mid-fringe values to a lesser extent, were greatly affected by wind direction. Offshore bald cypress trees provided good protection to the beach from winds approaching perpendicular to the shoreline but were less effective when the wind approached from other directions. Due to the configuration of the cypress fringe (and shoreline), the wind energy was dampened to a greater or lesser extent depending on the wind direction and number of trees between direction of wind front and site of measurement. A larger number of trees provided more buffering of the wind as compared with fewer trees (Figure 20).

Table 38. Wind Velocity Measurements (mph) taken along a Transect at Three Different Study Sites on Albemarle Sound, N.C.

Study Sites	Trial No.	MPH		
		Albemarle Sound	Middle of Cypress Fringe	Beach Behind Cypress Fringe
BWP*	1	7.0	0.0	3.5
BWP	2	5.0	0.0	0.0
BWP	3	9.0	3.0	0.0
BWP	4	12.0	5.0	6.0
BWP	5	3.0	0.0	8.0
BWP	6	5.0	1.0	3.0
SP**	7	6.0	2.0	0.0
SP	8	6.0	2.0	2.0
BWP	9	5.0	0.0	3.5
SP	10	6.0	2.5	2.5
BWP	11	8.0	3.0	5.0
SP	12	12.0	4.0	8.0
SP	13	7.0	2.0	5.0
BP***	14	9.0	5.0	3.0
BP	15	11.0	5.0	2.0
BP	16	6.0	3.0	0.0
BP	17	5.0	0.0	0.0
BP	18	10.0	3.0	4.0
BP	19	18.0	5.0	9.0
BP	20	11.0	3.0	7.0
SP	21	8.0	5.0	5.0
SP	22	15.0	4.0	9.0
		$\bar{x} = 8.4$	$\bar{x} = 2.6$	$\bar{x} = 3.4$

* Black Walnut Point

** Sandy Point

*** Bluff Point

Fig. 20. Diagram of wave amplitude experimental design.

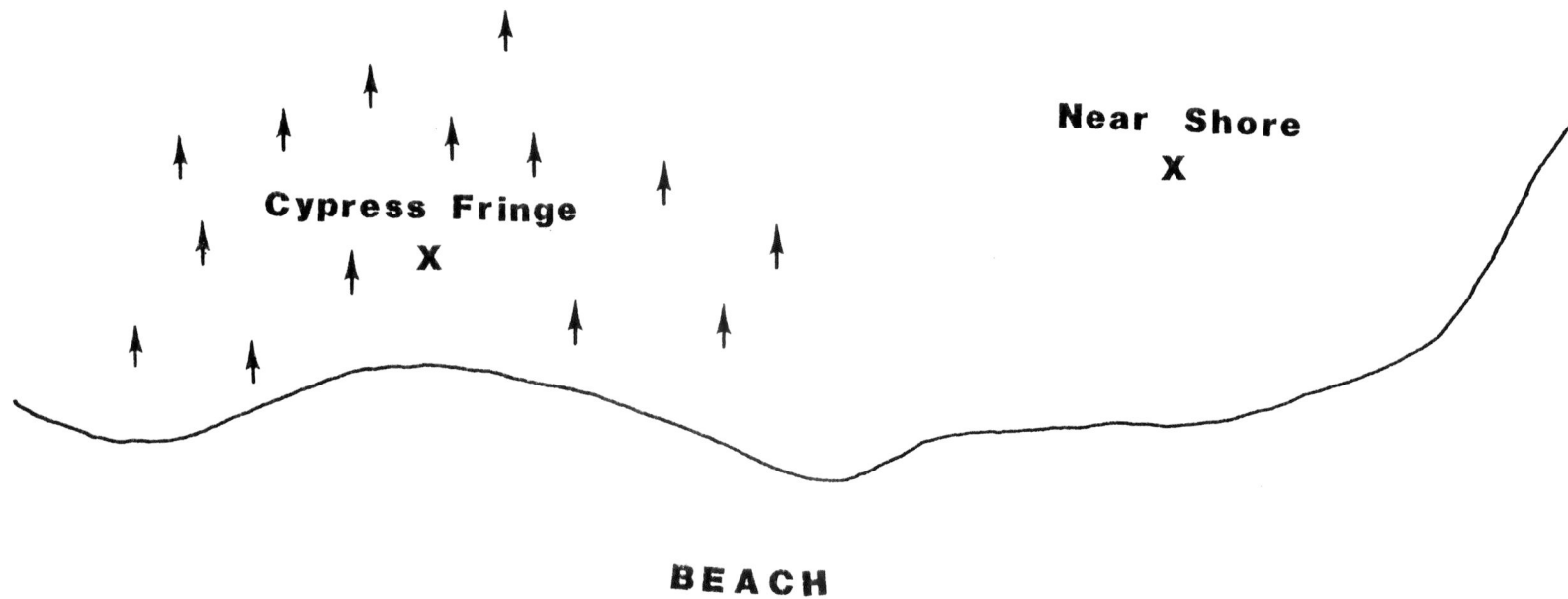
ALBEMARLE SOUND

Site 1

Open Sound
X

Site 2

Open Sound
X



Wave amplitude was altered by the cypress fringe. Measurements were taken at the same water depth both in the middle of the fringe and in an open area near the shore (Table 39). Wave amplitude was affected by distance from the shore and the water depth change from the measurement site to the shore. Therefore it was deemed necessary to obtain measurements from the unprotected "near shore" area in order to provide a profile of wave action in the absence of interaction with the cypress fringe. The difference in wave amplitude between the open sound value and the mean of both the cypress fringe site values and the unprotected near shore site value was calculated for each trial. The average difference at each site for the 25 trials was termed "mean wave reduction". Mean wave reduction from the control site (unprotected near shore area) was subtracted from the cypress fringe mean wave reduction. This gave a mean wave amplitude value of 4.3 cm for the fringe area (33.5% wave amplitude reduction due to the cypress fringe) (Table 39). In every case, the near shore (unprotected) wave amplitude value was higher than the wave amplitude value within the cypress fringe (Figure 21). The Student's t-test for Paired Data revealed that wave amplitude was significantly reduced ($p \leq 0.001$) in the cypress fringe area (Table 40). Cypress knees, as well as the exposed root system and trunk, function in disrupting wave pattern and dampening wave height.

Table 39. Comparison of Near Shore and Mid-Cypress Fringe Wave Amplitude Measurements (cm) at Three Study Sites on Albemarle Sound, N.C.

Trial No.	Water Depth (cm)		Wave Amplitude (cm)***			Wind Velocity in Sound (mph)
	Open Water*	Near Shore*	Open Water**	Near Shore		
				Site 1 (Fringe)	Site 2 (Open)	
1	76	38	11.0	6.5	9.5	5
2	76	36	12.0	8.0	10.0	5
3	76	36	10.0	4.5	9.0	5
4	76	37	10.0	4.0	8.0	5
5	82	41	13.0	7.5	12.0	7
6	79	40	13.5	7.0	11.5	7
7	84	42	15.0	7.5	13.0	10
8	83	39	27.0	18.0	23.5	20
9	76	35	25.0	15.0	24.0	17
10	78	37	10.0	2.0	7.0	5
11	80	38	11.0	3.5	5.0	7
12	75	33	13.0	6.5	10.5	8
13	76	34	9.0	1.0	4.0	4
14	77	34	5.0	1.0	5.0	3
15	77	34	18.0	7.5	11.5	12
16	81	36	9.0	3.5	7.5	5
17	83	39	11.5	6.5	10.5	5
18	79	37	8.5	6.0	6.5	4

Table 39. continued.....

Trial No.	Water Depth (cm)		Wave Amplitude (cm)***			Wind Velocity in Sound (mph)
	Open Water*	Near Shore*	Open Water**	Near Shore		
				Site 1 (Fringe)	Site 2 (Open)	
19	76	35	12.0	5.5	8.0	6
20	78	33	10.0	3.0	7.5	5
21	79	34	23.5	10.5	18.5	16
22	82	38	17.0	9.0	13.5	9
23	83	38	7.0	3.0	6.0	5
24	78	38	20.5	9.5	17.0	13
25	78	38	11.0	5.0	8.5	7
			$\bar{x}$ 13.0	6.4	10.7	
% Wave Amplitude Reduction			0.0	52.0	20.0	
Actual Wave Amplitude Reduction			0.0	6.9	2.6	
6.9 cm Site 1 Wave Amplitude Reduction						
<u>-2.6 cm Site 2 Wave Amplitude Reduction</u>						
4.3 cm Wave Amplitude Reduction Due to Cypress Fringe						

*Site 1 and Site 2 were adjacent sites measured simultaneously. Since the mean values for water depth were always the same, they are reported in a single column

**Site 1 and Site 2 Mean Wave Amplitude values recorded in the open water of the Sound were identical.

***Mean Wave Amplitude values were calculated following each 5 min trial

Fig. 21. Wave height as a function of wind velocity
measured in Albemarle Sound, N.C.

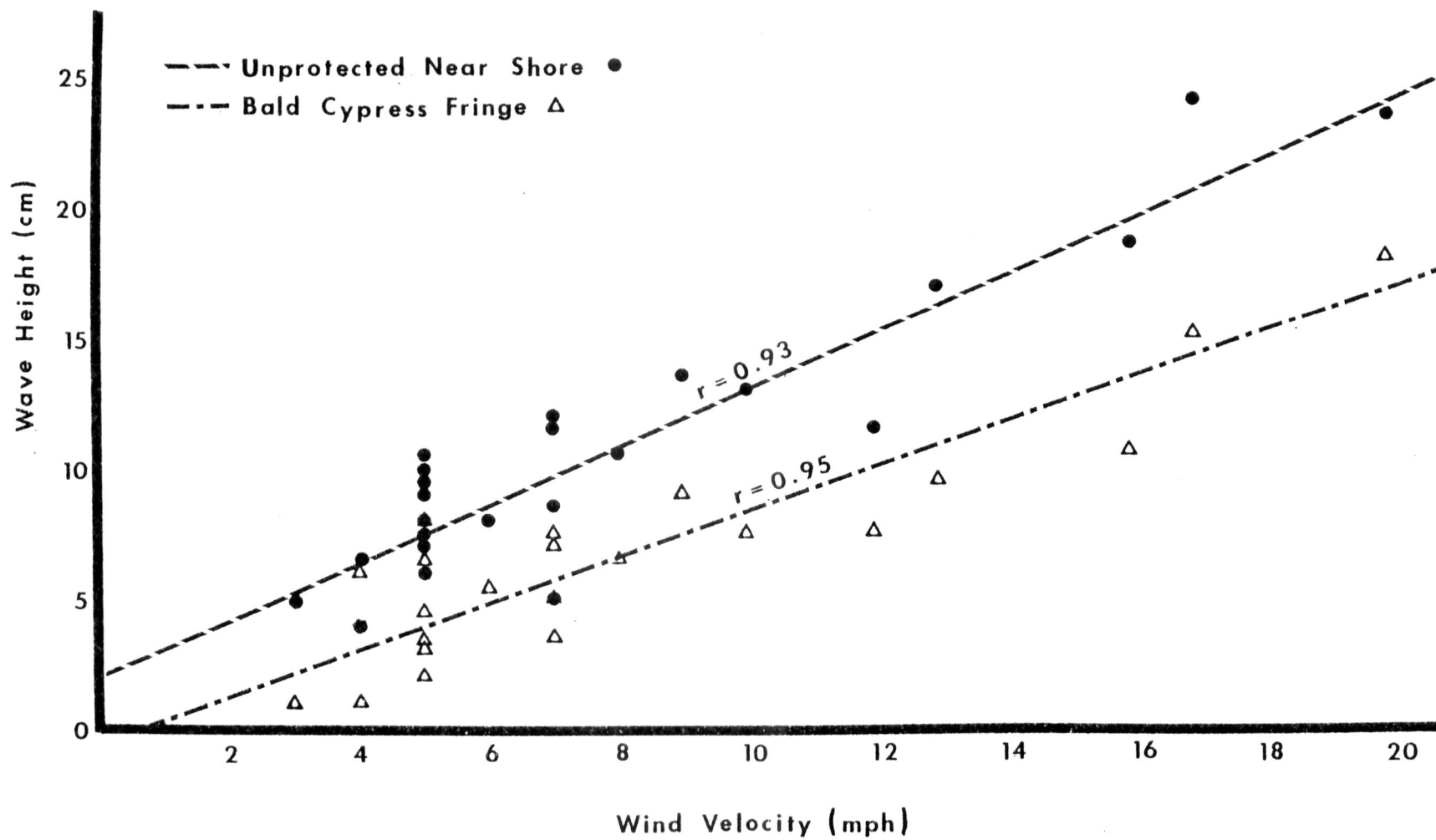


Table 40. Statistical Comparison of Near Shore and Mid-Cypress Fringe Wave Amplitude Measurements through Use of the Student's t-test with Paired Data

Variable	Mean $\bar{X}$	Corr. coef. r	t Value	Degrees of freedom	2-Tail Prob.
Fringe	6.44	0.96	-11.16	24	0.0001
Near Shore	10.68				

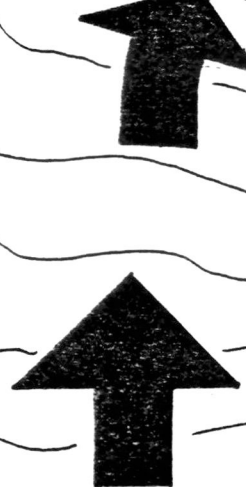
Wave pattern disruption results in loss of wave energy and loss of suspended sediment load. In the first case, one edge of a wave actually contacts the obstacle (for example, the base of a cypress tree). As the wave continues its motion, the edge of the wave in contact with the tree trunk travels more slowly than the free edge of the wave. The drag, caused by the cypress trunks, results in the bending of the wave front as much as 90° in some instances (Figure 22). Thus the angle at which the incoming wave contacts the beach (or shoreline) is altered and the force of the wave is redirected. Even in those instances where the wave front is actually directed to the beach, the wave has already been slowed down and some energy has been lost on impact with the stump or tree trunk.

When a segment of a wave collides with a cypress trunk, the outer edges of the wave front are both bent toward the bald cypress trunk and the wave "wraps" itself around the tree (Figure 22). As the opposing segments of the wave collide, energy is lost. Sand and sediment carried by the waves are deposited as the wave drags around the tree trunk, as well as upon impact of the leading wave edges. Over a period of time, accumulation of sand behind the tree results in a sand bridge connecting the tree trunk to the shore. Moreover, an offshore stand of bald cypress, fallen trees, old stumps and the anastomosing lateral root system of bald cypress all serve to trap

Fig. 22. Wave pattern disruption by bald cypress trees
results in redirection of wave, loss of wave energy
and loss of suspended sediment load.

Shoreline

Accumulated Sand



Wave Force

sediment, logs, and debris carried into the cypress fringe by longshore drift. Thus not only is erosion slowed but short term accretion may occur (Figure 23).

Fig. 23. An offshore stand of bald cypress traps sediment, logs and debris carried into the cypress fringe by longshore drift. (Bellis et al. 1975)



DISCUSSION

Germination, Photosynthesis and Growth

Germination

Early attempts to germinate bald cypress seeds were based on the assumption that they undergo a period of embryonic dormancy (Barton 1930, USDA 1948, 1961, 1974). More recently it has been shown that the major obstacle to bald cypress seed germination is the extremely hard seed coat (Murphy and Stanley, 1975). Little detailed information is available concerning germination of bald cypress seeds following partial or complete removal of the seed coat. Preliminary results from this study (Table 4) show that 1 hour soaking of cypress seeds in concentrated sulfuric acid yielded a higher percent germination than a similar 4 hour treatment. However the 4-hour treatment seeds germinated 3 weeks sooner than the 1-hour treatment seeds. This supports the idea that the seed coat presents a physical barrier to bald cypress seed germination. However, extensive digestion in some way may harm the embryo and thus lowers percent germination.

Both bald cypress and tupelo gum seeds germinated best at the higher experimental temperatures (30/20°C and 35°C) (Tables 41 and 42). These findings may partially explain the essentially southern coastal plain distribution of both species (Figure 24). Seed germination was extremely poor for bald cypress and negligible for tupelo gum

Table 41. Comparison of Germination of Bald Cypress Seeds and Tupelo Gum Seeds at Various Temperatures

Temp (°C)	Seed Type	Overall Germination	Germination Percentage (corrected for seed viability)
10	Bald Cypress	0.0	0.0
	Tupelo Gum	0.0	0.0
15	Bald Cypress	0.0	0.0
	Tupelo Gum	0.0	0.0
20	Bald Cypress	4.0	6.0
	Tupelo Gum	0.0	0.0
25	Bald Cypress	24.0	33.3
	Tupelo Gum	16.0	20.0
25/15*	Bald Cypress	38.0	52.7
	Tupelo Gum	16.0	20.0
30	Bald Cypress	34.0	47.2
	Tupelo Gum	22.0	27.5
30/20	Bald Cypress	46.0	63.8
	Tupelo Gum	--**	--
35	Bald Cypress	28.0	52.0
	Tupelo Gum	52.0	65.0

* 12/12 h day/night alternating temperature regime

** Data was not collected

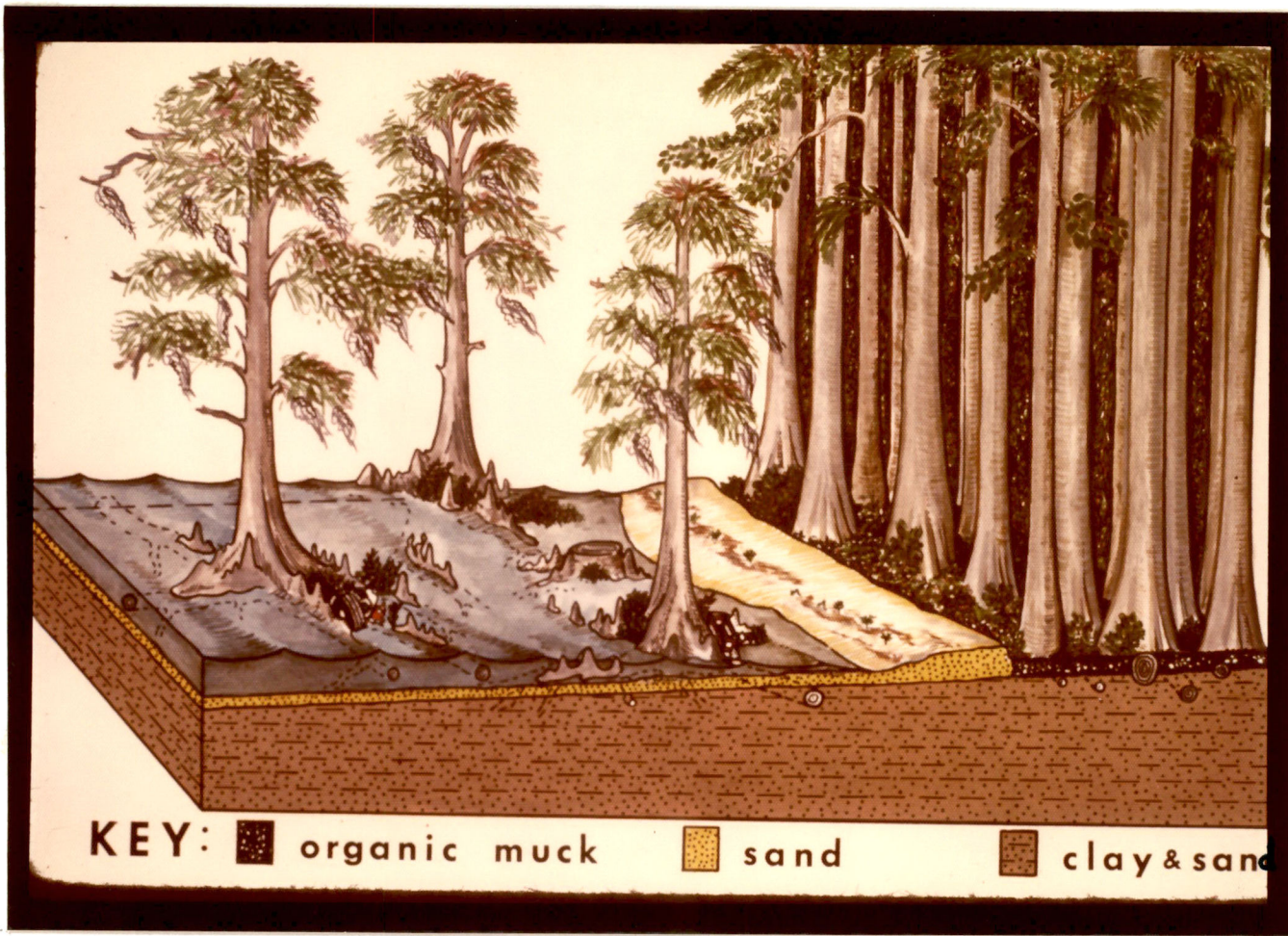
Table 42. Comparison of Germination of Bald Cypress Seeds and Tupelo Gum Seeds as a Function of Temperature and Light Conditions

Temp. (°C)	Overall Germination Percentage	Germination Percentage (corrected for seed viability)	Dark Germination Percentage	Dark Germination Percentage (corrected for seed viability)	Light Germination Percentage	Light Germination Percentage (corrected for seed viability)
30						
Bald Cypress	--*	--	--	--	--	--
Tupelo Gum	31.4	36.6	--	--	31.4	36.6
35						
Bald Cypress	--	--	--	--	--	--
Tupelo Gum	39.4	53.5	36.0	58.1	40.9	51.8
30/20**						
Bald Cypress	27.2	62.9	30.0	57.6	26.5	64.5
Tupelo Gum	50.0	55.5	--	--	50.0	55.5
Overall						
Bald Cypress	27.2	62.9	--	--	27.2	62.9
Tupelo Gum	34.6	42.4	--	--	34.6	42.4

* Not applicable

** 12/12 h day/night alternating temperature

Fig. 24. Map of the distribution of bald cypress and tupelo gum in the United States. (Adapted from USDA 1972a, 1972b)



KEY:  organic muck  sand  clay & sand

below 25°C. It is of interest that absence of light did not significantly affect seed germination for either species (Table 42).

Photosynthesis

Total leaf area per seedling increased with increasing PAR for bald cypress seedlings ($r = 0.81$) (Table 8). The mean total leaf area for the PAR-1000 bald cypress seedlings fell between the means of treatment groups PAR-308 and PAR-641 and could not be statistically distinguished from these groups (Table 8). This might reflect the absence of uniform high light intensity for the seedlings in the greenhouse (PAR-1000). However, photoinhibition of leaf expansion may occur at extremely high light intensities in bald cypress seedlings.

In contrast to bald cypress, tupelo gum seedlings showed no trend toward increased leaf area per seedling with increasing PAR. In fact, there was no statistical difference between treatment groups PAR-27, PAR-308 and PAR-641 (Table 23). Under the highest light intensity (PAR-1000), however, tupelo gum seedlings produced a significantly higher leaf area (Table 23). Even when no corrections are made for leaves removed from tupelo gum seedlings by topping at the 6th week, seedlings in the lowest light intensity (PAR-27) produced more leaf area ($\bar{x} = 479.01 \text{ cm}^2$) than the mean maximum total leaf area (PAR-641, $\bar{x} = 415.16 \text{ cm}^2$) of untopped bald cypress seedlings

Acetone extraction values indicate bald cypress seedlings average significantly higher concentrations ($p < 0.01$) of both chlorophyll a and

b and total chlorophyll per unit leaf area than did tupelo gum seedlings. This was consistent under each PAR treatment (Table 43), with treatment group PAR-1000 chlorophyll ratio as the only exception. This is not surprising, since PAR-1000 seedlings produced such small mean concentrations of chlorophyll b. This resulted in higher chlorophyll a/b ratios.

Although photosynthetic capacity and respiratory activity are known to be species dependent, these rates are neither uniform nor constant throughout the life of a plant. Developmental stages as well as seasonal, diurnal, and temperature changes affect metabolic rates. These factors and the conditions for growth must be kept in mind when evaluating data from this study. Plants were young seedlings grown at 30°C, supplied with 400 ppm CO₂, and provided with controlled light intensity and duration. The short-term CO₂ gas exchange within the plexiglass chamber was interpreted as net photosynthetic rate; an average rate was calculated for the entire seedling without measuring sun and shade leaves separately.

The net photosynthetic rates for tupelo gum (0.05-0.15 mg CO₂ · cm⁻² h⁻¹) are similar to the ranges published for the shade leaves of winter-deciduous trees (0.05-0.10 mg CO₂ · cm⁻² h⁻¹) (Larcher 1975). Rates for bald cypress (0.12-0.30 mg CO₂ · cm⁻² h⁻¹) approximate those of sun leaves of winter-deciduous trees (0.10-0.20 mg CO₂ · cm⁻² h⁻¹) and agricultural C₃ plants (0.20-0.40 mg CO₂ · cm⁻² h⁻¹). The

Table 43. Mean Chlorophyll Concentration ($\text{mg}\cdot\text{cm}^{-2}$) of Bald Cypress and Tupelo Gum Seedlings Under Selected Light Intensities

PAR Treatment Group	Bald Cypress	Tupelo Gum
Chlorophyll <u>a</u>		
27	136.95	49.78
308	96.51	50.58
641	92.18	52.67
1000	94.61	46.85
Chlorophyll <u>b</u>		
27	81.64	33.88
308	61.83	45.60
641	60.06	40.10
1000	85.80	32.86
Total chlorophyll (<u>a</u> & <u>b</u>)		
27	222.66	80.83
308	158.34	95.99
641	153.68	92.76
1000	177.42	79.77
Chlorophyll Ratio (a/b)		
27	1.68	1.47
308	1.58	1.11
641	1.55	1.31
1000	1.12	1.43

elevated net photosynthetic rates from this study could be a result of using young seedlings; younger plant shoots respire more rapidly than do those of older plants (Larcher 1975). Moreover growth of these plants at high temperatures may allow more complete opening of the stomata and an increase in the rate of diffusion of CO_2 to chloroplasts (Bannister 1976).

The higher net photosynthetic rate for bald cypress seedlings as compared to tupelo gum seedlings is not surprising when the higher chlorophyll concentration of the bald cypress seedlings is considered. Characteristics of understory or shade-tolerant plants which only receive small quantities of light are high chlorophyll concentrations, thin leaves, no obvious etiolation under low light intensities, and a large amount of chlorophyll b (Bannister 1976). Cypress seedlings in this study had all of these characteristics. However the following shade-tolerant characteristics not exhibited by bald cypress seedlings were evident in the tupelo gum seedlings: etiolation under low light conditions, large leaves, lower maximum photosynthetic rates and not much increase in leaf area with increased light intensity. Perhaps both species are intermediate with respect to shade tolerance as Mattoon (1915) indicated.

Growth

One of the difficulties in comparing species is the selection of the parameters used. Although growth is often used, it could be

misleading where patterns of growth are inherently dissimilar. No single growth pattern alone provides a complete picture of the effect of light intensity upon seedlings. As stated earlier, rapid vertical growth may be manifested by both healthy seedlings and etiolated seedlings. Diameter measurements add another dimension to the picture. However, both of these parameters ignore vital underground structures such as the roots. Dry weight or biomass measurements may include all structures, yet merely describe total net primary production without indicating distribution. Biomass partitioning probably presents the best isolated physical description of a plant. Nevertheless only a combination of these parameters yields a good overall summary of a seedling's response to light intensity.

An interesting phenomenon noted during this study is that although the bald cypress study seedlings contained both a higher chlorophyll concentration and a higher net photosynthetic rate than the tupelo gum seedlings, the latter species surpassed bald cypress in most growth parameter values. Both bald cypress and tupelo gum grew best at PAR-641 (See Figures 7 and 13). In both cases, PAR-27 seedlings grew least during the course of the experiment. In each treatment chamber, tupelo gum seedlings grew faster and taller than bald cypress seedlings. PAR-1000 bald cypress seedlings grew taller than PAR-308 bald cypress seedlings, although this was not the case for tupelo gum (Tables 7 and 13). Still, it must be

remembered that the tupelo gum height data ends at the end of the 6th week of exposure time and, at that point, tupelo gum and bald cypress seedlings paralleled each other. Had tupelo gum been able to continue growth intact, the PAR-1000 seedlings might have overtaken the PAR-308 seedlings.

Although early reports (USDA 1948) indicate that cypress is a slow growing tree, and Mattoon (1915) has reported a maximum annual increase in height of approximately 104 cm per year, the mean heights of cypress seedlings at PAR-641, PAR-1000, and PAR-308 indicate that, under the controlled conditions of this experiment, bald cypress manifests a growth rate comparable to many hardwoods (USDA 1974). A comparison of growth rate under experimental conditions (76.8 cm/4 mo i.e., 140 cm/9 mo growth season) with the reported slower growth rates (104 cm/yr) under field conditions (Mattoon 1915) suggests that perhaps bald cypress is not usually found growing under optimal conditions, or even favorable conditions.

The correlation between light intensity and dry weight produced was slightly higher in tupelo gum seedlings ($r = 0.94$) than in bald cypress seedlings ($r = 0.86$) and was significant at the 0.001 level of probability for both species (Tables 13 and 20). As in fresh weight, the smallest biomass produced was found in treatment group PAR-27 while the largest mean biomass produced was found in treatment group

PAR-641. However, there was a notable difference in proportions (Table 44). While tupelo gum seedlings at PAR-641 produced only slightly more biomass than tupelo gum seedlings at PAR-1000, their mean value was 1.5 times greater than tupelo gum seedlings at PAR-308. This is compared to PAR-641 bald cypress seedlings, whose mean biomass value was two times greater than either PAR-1000 or PAR-308 bald cypress seedlings. Thus it appears that bald cypress seedlings were more adversely affected by the higher natural light intensity (PAR-1000) than were tupelo gum seedlings. These data appear to support the results of Browder et al. (1974) who reported that seedlings achieve maximum biomass at 80% available sunlight. This could indicate either some level of shade adaptation of bald cypress seedlings, or photoinhibition of cypress seedlings at an extremely high light intensity.

Biomass partitioning revealed some interesting differences between bald cypress and tupelo gum seedlings (Table 45). Tupelo gum seedlings in each treatment consistently produced more biomass (gram dry weight) in the stem compartment than in either the leaf or root compartments. Bald cypress seedlings also followed this trend with the exception of treatment group PAR-1000 which accumulated the majority of its biomass into leaf production ($\bar{x} = 2.59$ g). Tupelo gum seedlings in each PAR treatment produced significantly more

Table 44. Comparison of Mean Bald Cypress and Tupelo Gum Total Dry Weight Per Plant (g) under Selected Light Intensities

PAR Treatment Group	Bald Cypress	Tupelo Gum
27	0.52	2.60
308	6.21	11.07
641	12.03	16.29
1000	6.30	14.09

Table 45. Biomass Partitioning (gram dry weight) of Bald Cypress and Tupelo Gum Seedlings under Selected Light Intensities

PAR Treatment Group	Bald Cypress	Tupelo Gum
Leaves		
27	0.16	0.55
308	1.73	1.24
641	2.64	1.37
1000	2.59	1.87
Roots		
27	0.13	0.48
308	1.77	2.64
641	3.02	3.57
1000	1.67	3.18
Stems		
27	0.18	1.17
308	2.39	4.79
641	4.21	7.34
1000	1.47	5.47
Root/Shoot Ratio		
27	0.88	0.42
308	0.72	0.55
641	0.71	0.51
1000	1.28	0.58

biomass ($p < 0.01$) in both stems and roots than did bald cypress seedlings. The reverse was true for the leaf compartment values (with the exception of treatment group PAR-27).

The only compartment in which bald cypress seedlings had higher values than tupelo gum seedlings was the leaf compartment. However, this is almost certainly attributable to the fact that tupelo gum seedlings were topped after only 6 weeks under experimental treatment. The 3 tupelo gum seedlings (PAR-641) which were not topped produced a mean leaf dry weight of 5.11 g, which is three times as great as the value of the topped tupelo gum seedlings and two times greater than the PAR-641 bald cypress seedlings.

Bald cypress seedlings in treatment group PAR-27 produced a mean total gram dry weight of less than 0.50 g while similarly treated tupelo gum seedlings averaged a total gram dry weight of 2.20 g. Thus it appears that tupelo gum seedlings generally produced more stem biomass than root biomass, and more root biomass than leaf biomass. This was also true of bald cypress seedlings for the middle light intensities (PAR-308 and PAR-641). Moreover tupelo gum seedlings averaged two times each compartmental biomass of bald cypress seedlings and 1.5 times the total biomass produced.

These data indicate that tupelo gum seedlings increase in height significantly ($p < 0.01$) faster than bald cypress seedlings as indicated by comparing incremental growth rates. Leaf area, fresh weight, gram

dry weight and diameter measurements confirm that tupelo gum seedlings produced a greater biomass in a given length of time than did bald cypress seedlings. This is in opposition to what would be expected from cypress seedlings with a net photosynthetic rate that is higher than that of tupelo gum seedlings. Perhaps the cypress seedlings are less efficient in carbohydrate synthesis than are the tupelo gum seedlings. In any case, it would appear that tupelo gum seedlings would take up a greater volume of forest space and would have a decided advantage over bald cypress seedlings in competing for space and available light in a forest situation. Thus in a clear-cut mixed bald cypress-tupelo gum swamp or in an area where most of the bald cypress seed source has been removed, the bald cypress would be relatively slow to reforest and a faster growing competitor could become dominant.

Cypress Fringe Structure and Function

Mature bald cypress trees may be found as co-dominants with tupelo gum in swamp forests. The swamp floor is characterized by low light intensity and periodic flooding. It has been demonstrated that bald cypress seeds require moist unflooded soil for germination (Barton 1930, Demaree 1932). Following germination, there must be sufficient sunlight to produce an increase in height great enough, to permit the short stems of the bald cypress seedlings to remain above water level during periodic flooding (Welch 1931, Demaree 1934). Only

with this combination of factors can a bald cypress seedling survive its first season.

Whenever a cypress fringe (offshore stand of cypress trees) is present, its buttressed trunk bases and anastomosing root systems appear to form an effective natural bulkhead. Wave amplitude may be lowered or the incoming wave may wrap itself around a tree, thus changing the wave direction (and energy impact) from parallel to perpendicular to the beach. Suspended sediments dropped along this line may form a sand bridge between the tree and the shoreline. Fallen trees not only function as natural groins but also trap sediment and debris carried into the cypress fringe by longshore drift.

Offshore bald cypress trees serve as a unique habitat for plants and animals. Insects such as spiders, mosquitos and flies can be found within the cypress fringe. Birds forage and nest within the cypress fringe, with ospreys utilizing the flat crowns typical of offshore bald cypress. Raccoons often consume their fare on the roots of bald cypress. Small snakes sun on branches while larger snakes such as water moccasins coil up on stumps, roots, or between the knees of bald cypress trees.

The anastomosing root system of bald cypress often results in the formation of small "islands" at the base of the trees. Sediment trapped there provides soil for the growth of other vegetation. Swamp-rose, poison ivy, small shrubs and vines are typical of the plant

coverage found on these "islands". Occasionally small wild flowers are also present. Aquatic macrophytes have been reported to utilize submerged stumps and lateral roots of bald cypress as colonization sites (Vicars 1976, Blanton 1976). Thus it may be seen that a bald cypress fringe significantly protects the shoreline while offering a greater habitat diversity for local flora and fauna.

In this field study, no bald cypress seedlings were observed in the swamps at the three study sites. However, seedlings were observed germinating and growing on the storm tide driftline on the beach directly behind the cypress fringe. Presumably the driftline of organic material provides enough moisture and nutrients to support bald cypress seed germination and early growth of the seedlings, whereas sand alone is too hot and dry for germination. Although numerous seeds were observed, no tupelo gum seedlings were ever observed on the beach.

The question remains however: why were there no bald cypress seedlings in the swamp? There are several possible answers:

- 1) Light intensity may be insufficient to support seedling growth. According to laboratory experiments reported here low light intensity is a plausible explanation. The PAR-27 chamber simulated typical light intensity conditions found in the swamps of the study sites. Although growth conditions in the laboratory were otherwise optimal (with the exception of light intensity), cypress seedling growth was extremely

poor in chamber PAR-27. Poor growth under otherwise "optimal" conditions may indicate that light intensity under general field conditions was simply too low to support cypress seedling growth in the swamp.

2) Water level was too high to allow germination of the seed. During the study period, June, 1975 to August, 1976, dry ground was only observed at the periphery of the swamp. However, scattered through the swamps were raised points or fingers of land that drained in the summer. These fingers could have supported bald cypress germination. Presumably channels connecting the swamp and the sound are responsible for the prolonged hydroperiod.

3) The combination of light intensity and water level is insufficient to sustain bald cypress seedlings. In other words, although there may be adequate germination conditions, and enough light for limited growth of the bald cypress seedling, flood waters drown the seedling before an adequate height is achieved. This may occur any time before the bald cypress seedling reaches a vertical growth sufficient to permit its leaves to remain above the flood waters.

4) Competition. Tupelo gum seedlings may be outcompeting bald cypress for available light and nutrients after clearcutting. Laboratory studies showed that tupelo gum seedlings achieved a greater overall growth at all light intensities than did bald cypress seedlings. Thus the tupelo gum seedlings could grow taller in a shorter period of

time and overshadow the smaller bald cypress seedlings. Also the root systems of the tupelo gum seedlings were much more developed than those of their bald cypress counterparts. Tupelo gum seedlings could possibly tap a larger reservoir of nutrients.

It must be remembered that the tupelo gum seedlings in PAR-27 required staking. It is not known how the seedlings would have fared without this additional support. In contrast to chamber lighting conditions, however the sporadic light flecks which reach the forest floor in the field, probably result in large pulses of photosynthetic activity and "hardening" of tupelo gum stems. Allelopathy under field conditions has also not been explored. Thus it would be inappropriate to accept competition as the most reasonable explanation for the absence of bald cypress seedlings in the swamp.

Given these possibilities, it appears that a combination of prolonged hydroperiod and low light intensity is responsible for the absence of bald cypress seedlings in these bald cypress-tupelo gum swamp forests. This explanation is supported by the fact that very few tupelo gum seedlings were observed in the swamps. If tupelo gum seedlings were out-competing bald cypress seedlings, there should be more of the successful species present in the swamp. Perhaps the conditions are too harsh for both species. This is entirely possible since, in a preliminary experiment in August

of 1976, all healthy bald cypress seedlings that had been transplanted into the swamps either died or had disappeared (washed away?) within three months.

Although these bald cypress-tupelo gum swamps apparently do not offer adequate environmental conditions for the establishment of bald cypress seedlings, the bald cypress fringe appears to provide the environment necessary for its own regeneration. Bald cypress seed germination was observed along storm tide driftlines; however, these seedlings are often washed away during severe storms. Survival of bald cypress seedlings appeared most frequently along the protected sand berm behind the cypress fringe. The offshore bald cypress trees function to reduce wave energy reaching the beach while cypress seedlings survive along the sand berm formed from accreted sediments.

Bald cypress seedlings appear to flourish only at those locations on the sand berm where the tree canopy does not completely shade the area. This was expected, since laboratory studies indicated that bald cypress seedlings respond best to high light intensity. Nutrients for the young seedlings are also enhanced by the bald cypress fringe which traps debris that is later deposited on shore by storm driven winds. Thus the bald cypress fringe creates the seed-bed required by its successor.

Shoreline erosion with accompanying longshore sediment movement is a natural process which has occurred at least periodically throughout

the last 17,000 years. Any practice, such as bulkheading, which disrupts longshore sediment equilibrium would prevent the natural re-establishment of the bald cypress fringe. This vegetative type forms a natural bulkhead which, in itself, retards erosion. Thus it would appear expedient for man to protect the bald cypress fringe. Bald cypress might even be utilized as an inexpensive and aesthetically pleasing means for controlling estuarine shoreline erosion. Under this premise, young bald cypress would be planted at the edge of a property line behind a low wooden or concrete bulkhead. Theoretically, by the time the bulkhead needed replacement, the bald cypress trees would be established enough to function alone in retarding shoreline erosion. Not only would bald cypress serve as an inexpensive, natural bulkhead, but the trees should outlast artificial bulkheads while providing natural beauty that would blend with its environment.

Competition between bald cypress and tupelo gum may exist on a larger scale than is first evident. A trend becomes apparent when the geographical distribution of bald cypress and tupelo gum are superimposed on a map (Fig. 22). It may then be seen that the ranges of the two species are almost identical, with the exception of the Florida area and parts of Texas.

As is well known among foresters, when a co-dominant swamp forest of bald cypress-tupelo gum is logged, tupelo gum comes back

as the clearly dominant species. Thus with angiosperm competition within the swamp, erosion evident along the coast, and rising sea level killing bald cypress trees (as indicated by the hollow, rotten trunks of the offshore trees), it appears that perhaps this system is in tertiary succession: that is, the replacement of one species by another, not a mere generation scale, but on an evolutionary scale. If these premises are correct, this would result, in time, in bald cypress being replaced over most of its range by tupelo gum.

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APPENDIX

Table A. Statistical Analyses of Fresh Weight (g) of Bald Cypress and Tupelo Gum Seedlings by PAR Treatment Group

PAR Treatment Group	Mean $\bar{x}$	Min value	Max value	Standard deviation	Standard error	n
Bald Cypress						
27	2.87	0.53	6.03	1.62	0.51	10
308	30.00	8.26	47.04	13.51	4.50	9
641	46.14	17.64	60.54	15.59	5.19	9
1000	28.76	14.04	38.77	9.31	4.15	5
Tupelo Gum						
27	11.82	8.29	14.95	2.03	0.67	9
308	36.56	27.63	50.83	7.46	2.48	9
641	46.87	35.50	59.22	7.78	2.59	9
1000	47.04	34.67	58.92	6.54	1.96	11

Table B. Net Photosynthetic Rates ($\text{mg CO}_2 \cdot \text{cm}^{-2} \cdot \text{h}^{-1}$) of Bald Cypress and¹ Tupelo Gum Seedlings under Selected Light Intensities

	PAR Treatment Group			
	27	308	641	1000 ²
Seedling				
Bald Cypress				
1	0.04	0.19	0.31	off upper scale
2	0.02	0.20	0.36	off upper scale
3	0.04	0.20	0.35	off upper scale
Tupelo Gum				
1	0.01	0.10	0.11	NA
2	0.01	0.16	0.15	NA
3	0.01	0.13	0.11	NA

¹All seedlings were grown at PAR - 1000, then acclimated at a specific PAR condition, and the net photosynthetic rate was recorded. This was repeated with the same seedling for each successive PAR treatment, beginning with PAR - 27

²The light intensity in the controlled greenhouse (PAR - 1000) was not constant

Table C. Statistical Analyses of Chlorophyll Concentrations
($\text{mg}\cdot\text{cm}^{-2}$) of Bald Cypress Seedlings by Methanol
Extraction Method

PAR Treatment Group	Mean $\bar{x}$	Min value	Max value	Standard deviation	Standard error	n
Chlorophyll <u>a</u>						
27	100.89	64.13	182.95	33.96	10.74	10
308	87.78	73.41	119.60	15.13	5.04	9
641	85.82	53.94	112.46	21.12	7.04	9
1000	54.94	52.84	56.77	1.46	0.65	5
Chlorophyll <u>b</u>						
27	41.06	12.41	76.59	16.53	5.23	10
308	35.10	27.29	48.75	7.29	2.43	9
641	33.95	17.13	49.32	10.49	3.49	9
1000	20.15	19.57	20.53	0.37	0.16	5
Total Chrlorophyll <u>a</u> & <u>b</u>						
27	142.16	76.74	260.04	50.04	15.83	10
308	123.34	100.56	154.85	18.87	6.29	9
641	119.21	71.36	149.96	30.33	10.11	9
1000	75.15	72.40	76.76	1.72	0.76	5
Chlorophyll Ratio (<u>a/b</u>)						
27	2.67	2.18	5.16	0.86	0.27	10
308	2.59	1.68	3.44	0.50	0.17	9
641	2.65	1.97	3.34	0.49	0.16	9
1000	2.72	2.68	2.73	0.14	0.06	5

Table D. Statistical Analyses of Bald Cypress Seedling Incremental Growth Rates (cm) under Selected Light Intensities

PAR Treatment Group	Mean $\bar{x}$	Min value	Max value	Standard deviation	Standard error	n
Total Height at 0 Wks ¹						
27	10.7	1.5	18.6	5.10	1.61	10
308	11.0	1.3	18.6	5.84	1.95	9
641	11.5	2.0	20.3	5.69	1.90	9
1000	11.8	8.7	15.4	2.54	1.13	5
Difference in Height 0-2 Wks						
27	3.8	2.1	6.9	1.81	0.57	10
308	10.0	5.3	13.6	3.82	1.11	9
641	15.8	6.4	23.5	6.96	2.32	9
1000	6.6	3.6	7.1	1.16	0.52	5
Difference in Height 2-4 Wks						
27	2.9	1.1	6.7	3.82	1.21	10
308	9.7	4.2	12.8	5.04	1.68	9
641	15.7	7.1	22.3	9.13	3.04	9
1000	2.7	1.8	3.5	1.62	0.72	5
Difference in Height 4-6 Wks						
27	2.2	1.2	3.5	0.70	0.22	10
308	8.5	2.4	12.9	3.68	1.23	9
641	6.9	1.9	17.2	4.15	1.38	9
1000	12.8	9.6	16.0	3.06	1.37	5
Difference in Height 6-8 Wks						
27	1.0	0.2	2.6	0.93	0.29	10
308	6.9	1.6	10.5	3.32	1.11	9
641	9.4	3.9	15.5	4.08	1.36	9
1000	15.4	10.3	21.3	4.63	2.07	5

Table D. continued.....

PAR Treatment Group	Mean x	Min value	Max value	Standard deviation	Standard error	n
Difference in Height 8-10 Wks						
27	0.4	0.0	0.6	0.22	0.07	10
308	6.9	1.1	13.0	3.99	1.33	9
641	8.7	2.5	21.6	7.28	2.43	9
1000	13.7	10.3	16.3	2.17	0.97	5
Final Height ²						
27	20.8	9.5	34.5	8.08	2.56	10
308	54.1	40.0	67.5	10.22	3.41	9
641	76.8	70.6	84.7	4.03	1.34	9
1000	62.9	52.2	75.1	8.55	3.82	5
Total Difference ³						
27	10.4	6.1	18.8	4.22	1.34	10
308	43.1	32.2	51.2	6.49	2.16	9
641	65.3	54.7	74.8	6.43	2.14	9
1000	51.2	41.9	59.7	6.43	2.87	5

¹Time of placement in S.E.P.E.L. chambers. Age of seedlings = 4 wks

²"Final Height" refers to the height of the cypress seedling at harvest

³"Total Difference" refers to total incremental growth during treatment in S.E.P.E.L. chamber

Table E. Statistical Analyses of Data Gathered Following the Topping of Tupelo Gum Seedlings at the 12th Internode after 6 Weeks of Treatment

PAR Treatment Group	Mean $\bar{x}$	Min value	Max value	Standard deviation	Standard error	n
Length of Stem Removed by Topping (cm)						
27	5.25	0.0	16.80	5.70	1.16	24
308	30.31	10.80	41.30	8.95	1.83	24
641	34.92	23.20	48.50	7.07	1.66	18
1000	29.05	21.20	37.00	3.79	0.77	24
Height of Tupelo Seedlings Immediately after Topping (cm)						
27	51.84	34.60	63.70	8.58	1.75	24
308	56.56	46.70	64.60	4.54	0.92	24
641	57.38	49.50	62.30	3.46	0.81	18
1000	47.32	37.60	56.80	5.38	1.10	24

Table F. Statistical Analyses of Chlorophyll Concentrations
($\text{mg}\cdot\text{cm}^{-2}$) of Tupelo Gum Seedlings by Methanol
Extraction Method

PAR Treatment Group	Mean $\bar{x}$	Min value	Max value	Standard deviation	Standard error	n
Chlorophyll <u>a</u>						
27	45.60	37.62	61.84	8.46	2.82	9
308	48.98	33.38	69.03	11.03	3.67	9
641	44.68	37.45	56.08	5.85	1.95	9
1000	39.59	34.13	47.19	4.62	1.39	11
Chlorophyll <u>b</u>						
27	15.47	11.35	24.68	3.99	1.33	9
308	20.11	10.78	29.69	5.23	1.74	9
641	19.79	10.50	25.06	5.03	1.67	9
1000	20.03	13.99	25.44	4.67	1.40	11
Total Chlorophyll <u>a</u> & <u>b</u>						
27	61.07	50.97	86.62	11.68	3.89	9
308	69.29	49.83	98.72	14.38	4.79	9
641	64.51	49.93	81.32	9.81	3.27	9
1000	59.63	48.80	72.53	7.63	2.29	11
Chlorophyll Ratio (<u>a/b</u>)						
27	3.03	2.36	3.66	0.51	0.17	9
308	2.55	1.86	4.41	0.80	0.27	9
641	2.38	1.89	3.74	0.66	0.22	9
1000	1.97	1.21	2.96	0.53	0.16	11

Table G. Statistical Analyses of Total Dry Weight (g) of
Bald Cypress and Tupelo Gum Seedlings by PAR
Treatment Group

PAR Treatment Group	Mean $\bar{x}$	Min value	Max value	Standard deviation	Standard error	n
Bald Cypress						
27	0.52	0.07	0.92	0.29	0.09	10
308	6.21	1.42	10.06	3.16	1.05	9
641	12.03	4.83	16.76	4.28	1.42	9
1000	6.30	5.10	7.78	1.23	0.54	5
Tupelo Gum						
27	2.59	1.69	3.54	0.70	0.23	9
308	11.07	8.46	13.07	1.66	0.55	9
641	16.29	12.50	19.95	2.79	0.93	9
1000	14.09	10.56	16.72	1.80	0.54	11

Table H. Biomass Partitioning (gram dry weight) of Bald Cypress Seedlings by PAR Treatment Group

PAR Treatment Group	Mean $\bar{x}$	Min value	Max value	Standard deviation	Standard error	n
Leaves						
27	0.15	0.03	0.35	0.10	0.03	10
308	1.72	0.49	2.87	0.92	0.30	9
641	2.63	1.22	3.83	0.99	0.33	9
1000	2.59	1.73	3.18	0.58	0.25	5
Roots						
27	0.12	0.01	0.26	0.07	0.02	10
308	1.77	0.32	3.03	1.04	0.34	9
641	3.02	0.79	4.73	1.51	0.50	9
1000	1.66	1.00	2.84	0.71	0.31	5
Stems						
27	0.17	0.01	0.35	0.12	0.03	10
308	2.38	0.48	3.87	1.29	0.43	9
641	4.20	1.20	6.43	2.05	0.68	9
1000	1.46	0.03	3.05	1.24	0.55	5
Root/Shoot Ratio						
27	0.88	0.46	1.40	0.30	0.09	10
308	0.72	0.57	0.81	0.07	0.02	9
641	0.71	0.51	1.04	0.17	0.05	9
1000	1.28	0.58	1.85	0.48	0.21	5

Table I. Biomass Partitioning (gram dry weight) of Tupelo Gum Seedlings by PAR Treatment Group

PAR Treatment Group	Mean $\bar{x}$	Min value	Max value	Standard deviation	Standard error	n
Leaves						
27	0.54	0.40	0.75	0.11	0.03	9
308	1.23	0.76	1.74	0.34	0.11	9
641	1.36	0.69	2.44	0.55	0.18	9
1000	1.86	1.47	2.73	0.36	0.10	11
Roots						
27	0.47	0.35	0.60	0.09	0.03	9
308	2.63	1.92	3.47	0.47	0.15	9
641	3.57	2.37	4.98	0.72	0.24	9
1000	3.17	2.38	3.92	0.50	0.15	11
Stems						
27	1.16	0.73	1.66	0.31	0.10	9
308	4.79	3.25	6.21	0.85	0.28	9
641	7.34	4.85	9.56	1.64	0.54	9
1000	5.46	4.01	7.10	0.94	0.28	11
Root/Shoot Ratio						
27	0.41	0.33	0.48	0.04	0.01	9
308	0.55	0.45	0.68	0.07	0.02	9
641	0.51	0.41	0.67	0.10	0.03	9
1000	0.58	0.53	0.71	0.05	0.01	11