POPULATION AND AUTECOLOGICAL ASSESSMENT

OF *ZIZANIA TEXANA* HITCHC. (POACEAE)

IN THE SAN MARCOS RIVER

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ABSTRACT

Historically a thriving aquatic plant species, _Zizania texana_ is being reduced to a remnant population in the uppermost reaches of the San Marcos River in Hays County, Texas. An investigation was conducted to identify the factors involved in and directly contributing to the dramatic decline and near extinction of the species. Currently, wildrice is only reproducing vegetatively and is confined to high velocity areas of the river. Under modified conditions wildrice is able to produce seed and grow successfully in a variety of microhabitats. Long- and short-term natural and man-made stresses are responsible for the population decline. The results of this study suggest that ideal growth conditions for Texas wildrice are no longer present in the San Marcos River. Supporting phenological and anatomical evidence is included.

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INTRODUCTION

Texas wildrice, _Zizania texana_ Hitchc. (Poaceae), is a large, perennial, aquatic grass which is endemic to the upper 2.4 km of the San Marcos River in Hays County, Texas. _Z. texana_ was first collected by G. C. Nealley in August, 1892 from the San Marcos River. Nealley's specimen was originally identified as _Zizania aquatica_ L.; it was first recognized as a distinct species in April, 1932 by W. A. Silveus, an attorney and amateur botanist from San Antonio, Texas and named by A. S. Hitchcock (Silveus 1932, 1933, Hitchcock 1933, Terrell, et. al. 1978). _Zizania texana_ is of special interest because of its endangered status and potential as a high quality grain crop (USFWS 1985).

The San Marcos River originates at Spring Lake, an 18 ha lake located in the Balcones fault zone at San Marcos, and flows 98 km to join the Guadalupe River below Gonzales. Approximately 3 km from Spring Lake, the Blanco River joins the San Marcos. The San Marcos River is warm, clear and fast flowing. It is 5-15 meters wide and up to 4 m deep in some areas. The river originates from natural springs in Spring Lake. The springs, which are fed by the Edwards Aquifer, discharge water from numerous openings, including fissures as long as 0.33 m (Beaty 1975).

Geologically, the surface rocks of the Balcones Fault Zone are of Cretaceous age. The aquifer-bearing strata belong to the Edwards formation and release water where they fault against the Pecan Gap chalk (Hill and Vaughan 1898). The springs discharge 208 million gallons of water a day into Spring Lake (Terrell et al. 1978) at a rate averaging 157 cfs.

The river bottom is composed of limestone sand and gravel over a Crawford black silt and clay. The major aquatic species which inhabit the river include Colocasia esculenta (L.) Schott, Ceratophyllum demersum L., Eichhornia crassipes (von Martius) Solms, Sagittaria platyphylla Engelm., Potamogeton illinoensis Morong., Egeria densa Planch.and Ludwigia repens Forst. Riparian tree species include Platanus occidentalis L., Carya illinoensis (Wang.) K. Koch., Populus deltoides Marsh, Quercus fusiformis Small, Sapium sebiferum L., Ulmus americana L., Celtis laevigata Willd., Taxodium distichum (L.) Rich. and Salix nigra Marsh.

Zizania texana was so abundant when first discovered that an irrigation company found it necessary to control its population size (Silveus 1933). Watkins (1930) and Devall (1940) reported Texas wildrice to be abundant in the channel above the dam and in Spring Lake. Wildrice was said to grow vigorously and to be constantly exposed to the current (Devall 1940). By 1976, however, the population of Z. texana had been drastically reduced in size with only 1,131 m2 of Texas wildrice occurring in the upper 2.4 km of the river and no plants occurring in Spring Lake (Emery 1977).

Little work has been done towards determining the factors responsible for the decline of _Z. texana_ in the San Marcos River. The cytology of sporogenesis, gametogenesis and early embryology of _Z. texana_ was studied by Emery and Guy (1979). Megasporogenesis and megagametogenesis of wildrice were determined to be similar in developmental sequence to that of other _Zizania_ species such as _Z. latifolia_ (Maheshwari 1950) and result in the production of a monosporic polygonium type embryo sac. Emery and Guy (1979) found that fertilization and embryo development were identical to that reported for _Z. aquatica_ by Weir and Dale (1960) and they concluded that the inability of Texas wildrice to produce normal, viable seed in the river was not a result of genetic, cytological or embryological factors.

Huang (1975) suggested that the two other North American species of wildrice, _Zizania aquatica_ and _Z. palustris_ originated from a putative common ancestor of the east Asia and China mainland varieties of _Z. latifolia._ He used evidence such as karyotype, writings of ancient historical Chinese documents, for example, _Chou Li_ from the Han dynasty (200-300 B. C.) and sediment radiocarbon technique. _Z. texana_ may be a remnant population of the gulf coastal varieties of _Z. aquatica,_ which has long been separated and modified from its original form.

Emery obtained data (Appendix 3) on the amino acid content in _Z. texana_ seeds. These data showed that Texas wildrice has great potential as an agricultural grain crop because important amino acids such as lysine and other proteins are higher in Zizania texana than any other rice species. In fact, its protein and lysine content is even higher than that of many other grains such as oats and wheat (Terrell and Wiser 1975).

The present study was undertaken to investigate factors responsible for the decline of Zizania texana. The specific objectives of the study were:

(1) to study the morphology, anatomy and phenology of the species.

(2) to monitor and evaluate its current population status.

(3) to determine its abiotic habitat requirements.

(4) to elucidate the factors responsible for its decline.

METHODS AND MATERIALS

Morphological and Anatomical Description

Morphological and anatomical observations were based on plant material obtained from clones grown in the Southwest Texas State University sluiceways. Root, culm and leaf material was preserved in FAA, dehydrated though an alcohol series, embedded in paraffin and sectioned on an AO Spencer 820 microtome following standard procedures for the preparation of botanical specimens (Johansen 1940). Dyes used include phloroglucinal, toluidine blue, safranin, fast green and neutral red.

Abiotic and Habitat Characteristics

Water temperature, pH and conductivity were measured with a Hydrolab Series 4000 with attachment 4041-110. Current velocity and dissolved oxygen were measured with a Teledyne-Gurley current meter (#665) and a YSI dissolved oxygen meter, respectively. Irradiance was measured with a Licor 188 quantum sensor and Licor UWQ 2583 underwater attachment. Measurements were taken seasonally in areas occupied by *Z. texana.* Air temperature and precipatation data were obtained from the National Weather Service in Austin, Texas.

Population Census and Mapping

Population measurements were taken at 3 month intervals from August 1983 to August 1986 with the floating meter-square procedure utilized by Emery (1967, 1977). Using this method, a 10-year comparison between the current results and those which Emery obtained could be made. The above-ground areal coverage was used to calculate total population area. Depths were also recorded in each section.

Environmental Growth Experiments and Statistics

Two growth rate experiments were conducted during the peak summer growing periods of 1984 and 1985. The experiments were designed to determine the annual growth rate of Texas wildrice and to observe flower development and seed-set capabilities. Two additional experiments to compare growth under various conditions were conducted in 1986. Small numbers of individuals were used in these experiments because of the endangered status of the species. Individual plants were collected from one area in the population to minimize experimental variation by ensuring homogeneity in the gene pool.

The first growth rate experiment was conducted from June to September 1984. Thirty uniformly-sized individuals were transplanted into sluiceways on the campus of Southwest Texas State University. Warm lotic conditions were present in the sluiceways to replicate the river environment. At the initiation of the experiment, clumps were thinned to a uniform diameter of 3 cm and clipped to 5 cm in length. Individuals were then transplanted into 15-cm diameter pots containing Crawford silt and Quarternary limestone alluvium from the river bottom. Plants were placed in water 50 cm deep and grown for 3 months. The plants were then clipped and wet weights and leaf lengths measured and recorded. Harvested plant material was sorted and dried in a forced-air oven at 85^{o}C until constant weight was achieved. Temperature, dissolved oxygen, pH and conductivity of the water in the sluiceways were monitored and recorded every 15 days. Measurements were taken with a portable Hydrolab Series 4000.

The experiment was replicated with a larger number of individuals from May to November 1985 and was terminated after the first freeze. Initially, fifty plants were clipped to 25 cm above the soil level to ensure good growth rates of individuals and to decrease mortality. Half of the individuals were harvested on 30 August and individual leaf and culm lengths and wet and dry weights were obtained. Twenty-five individuals were allowed to continue to grow through autumn. These individuals were harvested and measured on 30 November 1985.

A third growth experiment was conducted in Spring Lake to test the effects of depth and irradiance on biomass production. Spring Lake was selected because its environmental conditions once supported a large wildrice population. The experiment was conducted from February to July 1986. Thirty individuals of uniform size were placed at 30-cm depth increments from 30 cm to 180 cm in depth using an variable angle growth platform. The apparatus was specially designed to provide easy access and quantification of wildrice growth in water less than three meters in depth. Leaf lengths and weight measurements were obtained at the initiation of the experiment and again at its termination. Again, a mid-period harvest was conducted. Harvested plant material was dried to constant weight and recorded.

A fish-culture pond was selected for the fourth growth experiment because of its similarity to a marsh environment. This lentic environment was chosen to help determine the effects of soil and differing water regimes on Texas wildrice. The pond was located at the U. S. National Fish Hatchery in San Marcos, Texas. The pond was partially filled and provided with a constant flow of water. One hundred sixty individuals were placed in four water-inundation regimes. Individuals were organized into five size classes and segregated by soil type. The four regimes were: intermittant wet terrestrial, constant moist, emergent, and submerged. These regimes were designed to determine the effects of increasing water inundation on growth and survivorship of *Z. texana.* Two types of soil from the San Marcos River, Crawford silt clay from the river bank and Quarternary limestone gravel and silt sediment from mid-river were utilized. At the initiation of the experiment, the plants were clipped to 25 cm in height, they were then allowed to grow from 1 June to 30 July 1986. Plants were harvested every two weeks until the termination of the experiment. The leaf length and wet weight of each plant was recorded and the harvested material dried at 85°C until a constant weight was reached and recorded.

The data from the depth/light growth experiment were analyzed by a 2-way analysis of variance (ANOVA). This was done between harvest and within harvests. The data from the water regime/soil experiment were analyzed by a 3-way analysis of variance using the Statistics II module/program from the IBM Statpro statistical package. Multiple comparisons were done using the Student-Newman-Keuls multiple range tests (Zar 1974).

Phenology and Measurement of Seed Set

Inflorescences were randomly harvested from clones in the sluiceways in August 1984 and 1986. Potential numbers of seeds per inflorescence were determined by counting the number pistillate flowers on each panicle. Three quadrats (0.25 m^2) were selected in the sluiceway population to determine inflorescence/m2 from August to October.

RESULTS

Morphology and Anatomy

Texas wildrice is a coarse, monoecious, perennial aquatic grass with long culms and blades which are completely immersed in fast flowing water (Figure 1a). The inflorescence is typically the only emergent part (Figure 1b). The numerous, elongate, decumbent, geniculate culms range from 3 to 5 m in length and 3 to 15 mm in thickness (Correll and Johnston 1979). They are stoloniferous and root only at the lower nodes (Figure 2a, b). The basal sheaths are straw-colored. The leaf blades are 12 to 110 cm long and 5 to 25 mm broad with ligules which are basally dark and distally whitish. The panicle is 20 to 30 cm in length, the lower, spreading branches bearing staminate spikelets, the upper, ascending, appressed branches bearing pistillate spikelets (Gould 1975). The staminate spikelets are pendulous at maturity and are 7-9 mm long and 1-2 mm broad; awns are absent. The pistillate spikelets are erect, terete, approximately 10 mm long and 1 mm broad. The bare awns, which are on the pistillate spikelets, are 10 to 25 mm long. Glumes are absent from both staminate and pistillate spikelets (Correll and Correll 1972). The pistillate lemmas have few microhairs and no stomata. The pistillate awns have microhairs and stomata. Stamens are white. Staminate lemmas are white or pink and have microhairs, stomata, and few siliceous papillae and pits. Silica bodies are suborbicular, sometimes four-lobed to C-shaped. Scattered prickle hairs are also present. The chromosome number is 15 (Terrell and Wergin 1981).

The leaf epidermis consists of short cells arranged in rows parallel to the veins (Figure 3). The epidermal cells have thin walls which are conspicuously sinuous. Epidermal appendages and components include prickle hairs (tapered barbs), macro-hairs, micro-hairs and silica bodies (Metcalfe 1960). The prickle hairs, macro-hairs and micro-hairs are thick walled and tend to be widest in the middle, tapering toward the apex and base. The hairs are less abundant on underwater parts. Few papillae are present on the epidermal cells. On aerial parts, papillae are abundant around stomata. The stomata have subsidiary cells which are triangular in shape (Figure 3).

The lamina has unpronounced ribs and furrows. Ribs are wide over vascular bundles and furrows are narrow and shallow between the bundles. Bulliform cells are in small, fan-shaped groups of 1-4. In transverse section, vascular bundles appear oval and widely spaced. The margins of the blade are slightly expanded with single large vascular bundles (Figure 3). Between the vascular bundles and epidermis of the lamina are thick-walled cells or girders. These are composed of sclerenchyma when proximal to well-developed vascular bundles. The girders range from 1-3 cells high and 4-14 cells wide. The abaxial median keel is lined with small sclerified cells. These cells surround the vascular tissue, which have large intercellular spaces. Stellate aerenchyma is present in lower regions of the midvein.

The leaf mesophyll consists of thin-walled parenchyma cells with abundant chloroplasts. Palisade and spongy layers are not well differentiated (Figure 4). The vascular bundles of the leaf have large xylary elements surrounded by tracheids and exhibit exarch maturation. Phloem is composed of sieve tube elements of moderate diameter. Each vascular bundle is surrounded by bundle sheath cells, usually 1-2 layers thick.

The culm contains internodal regions which have a narrow cortex of stellate aerenchyma for support, gas transport and storage. The aerenchyma surrounds a large central lacuna (Figure 5). Extensions of the cortical tissue form parenchymatous diaphragms partitioning the lacunae (Figure 5, 6a). The epidermis is lined on the inside with a sclerotic ring (Figure 6b). The culm is deeply furrowed. The ridges are composed of sclerenchyma cells surrounding small lacunae. The vascular bundles of the culm have the typical monocotyledon arrangement, with 2-3 large xylary elements surrounded by tracheids (Figure 6c). Vascular bundles are scattered in the cortex forming an atactostele. They are collateral and have reduced xylem and normal phloem. The xylem is occasionally just a cavity formed schizogenously in some mature bundles. Reduction is probably due to the aquatic habitat. Some bundles appear to be amphivasal in the nodal regions. There is an abundance of intercellular space in the culm.

The root and area of the root which joins the rhizomes have an abundance of intercellular space due to a stellate aerenchyma ground tissue (Figure 7, 8a). An endodermis is present and composed of round cells with suberized walls (Figure 8b). Centripetal to the endodermis is the pericycle which gives rise to secondary roots (Figure 9a) and surrounds the haplostele vascular cylinder (Figure 9b). Mature roots have a band of sclerenchyma between pith and cortex. Root epidermis has thin cell walls and few roothairs.

Habitat Characteristics

Water temperature at the origin of the river is a constant 21.5°C and ranges from from 25.5°C in August to 20.4°C in February at the lower end of the wildrice zone. The water has a reported pH of 6.9 to 7.9 (Texas Water Development Board 1969). I have found the pH to range from 7.1 at the origin of the river to 7.9 at the lower end of the population. Salinity of the river is 0% and the oxygen content is 5-6 ppm. Below the water release of Spring Lake, the water is 100% saturated with oxygen. A reduction in oxygen content occurs progressively toward the lower end of the river.

Population Census and Mapping

The total population of Texas wildrice in August 1986 covered an area of 454 m^2 (Table I). This is a decline of 676.5 m^2 from 1976 when the wildrice was monitored for the first time. The mean rate of decline from 1976, when the population covered 1131 m^2, has been 67.6 m^2/year or 6%. The areal extent of the population has been declining since it was first measured (Figure 10). Sections 1 and 10 exhibited the greatest decrease in total population (Figure 11, 12). The total percent decline since 1976 is 59.8% (Table II).

Growth of Experimental Populations.

Wildrice in the sluiceways exhibited a growth rate of 3.73 g/month for a bundle diameter of 3 cm. Annual biomass was quantified using two experiments. During the first biomass experiment in summer 1984, the mortality was unusually high (23.3%) and the growth rate (2.5 g/m) was below that of the other growth experiments. The loss of individuals resulted from the small amount of viable shoot vegetation at the initiation of the experiment. In the second experiment, 25 cm of photosynthetic shoot was retained initially rather than 5 cm as in the first experiment. The growth rate in experiment II was 4.9 g/month and mortality was only 5%. The results of experiments I and II also may exhibit lower growth because of the elimination of photosynthetic tissue. Wet weight to dry weight ratio of vegetative growth was 9:1.

The growth rates of the plants in the sluiceways (Experiment II) may be slightly higher than rates in the river because of the increased amount of light from the highly reflective concrete walls. Evidence to support this idea is provided by the observed correlation between the mortality rate and the placement of individuals in the sluiceways. Mortality was higher in individuals placed in sections of the sluiceways which had more shading. The growth rate may be higher because of the slightly warmer water temperature (25.1 ± 3.5) in the channels. The warmer temperature was caused by algal growth which darkened the water allowing additional heat absorption.

Results of the third growth experiment indicate that individual plants in the upper sections of the growth apparatus grew at a higher rate and produced more biomass. Irradiance and depth during growth had significant effects on the growth rate of the plants (Table III). The initial size of the plants had a slight effect on growth rate. Survivability of the plants was also affected by initial size. The dry-weight to wet-weight ratios were relatively constant at each irradiance level (Figure 13). The dry-weight to wet-weight ratio averaged 13.8% (Table III). The differences in total dry weight at each depth were insignificant ($P>0.05$). Relative growth rates were significantly higher ($P<0.05$) at the upper four irradiance levels (Figure 14). The first harvest had a growth rate of 2.03 g/week for a six week period. The shoot growth produced was 122.4 cm/week or 734.3 cm for the six week period. Plants grew at a rate of 1.75 g/week during the second six weeks. Shoot growth for the second harvest was 105.8 cm/week or 634.6 cm for the total six weeks.

At irradiances of 59.0 $uEm^{-2}s^{-1}$ and 51.0 $uEm^{-2}s^{-1}$, plants grown in the deepest zones had growth rates of 1.35 and 1.40 g/week, respectively. Mean shoot length averaged 469.2 cm/week. The growth rates increased significantly as depth decreased and irradiance increased (Figure 14). Mortality was 16.7% during the three months. Mortality occurred mainly at lower depths where lower growth rates were exhibited. The variation in growth between the six sections is attributed to the differences in the amount of light at each depth. Some variation of the growth rate occurred due to shading of the wildrice by faster growing species occurring in the lake. Also some individuals were lost due to disturbance by turtles, ducks and nutria. Survivorship among the plants was greatest for initially larger individuals.

Experiment IV was designed to determine the effects of different soil types and water regimes on the growth of _Z. texana_ (Table IV). One hundred percent mortality occurred within the first two weeks in the dry regime (Regime I), demonstrating the dependence of wildrice on water. Mortality in the moist regime (Regime II) was 57%. Mortality in all regimes increased over time. In the moist regime, mortality increased from 10% in the first harvest to 30% in the second harvest. Mortality in harvests three and four was 90% and 100%, respectively. Mean mortality for the emergent regime (Regime III) and the inundated regime (Regime IV) was 5% and 0%, respectively. Inundation, therefore, must play an important part in the survival of wildrice. Irradiance and inundation during growth had significant effects on growth of Texas wildrice. Differences in the growth rates and biomass were all highly significant ($P<0.05$). Individuals grown in regimes with more than 20 cm of water were significantly larger ($P<0.05$) than those in depths less than 20 cm. Overall means for harvests 1 and 2 were significantly greater than those of the last two harvests. This was due to changes in the experimental environment, primarily decreasing irradiance by algal growth. The growth rate in Regime IV was highest and decreased proportionally as water became more of a limiting factor. There was no significant difference in growth rates and survivorship rates between the two soil types, Crawford silt clay and Quarternary limestone sediment (Figure 15).

Phenology and Seed-Set

Zizania texana flowers intermittently from April to December and occasionally during warm winters (Hitchcock 1950). Anthesis peaks in late July and ends in early September. Most florets set viable seed, although approximately 10 to 40% never mature. The majority (90%) of individuals in the sluiceways produced one inflorescence and potential seed production averaged 76 ± 21 seeds/individual. Measurements of actual seed production in the field is difficult because the pistillate flowers and seeds are often prematurely eaten or dislodged. Shattering of mature seeds occurs at irregular intervals and seed maturation is often disturbed by floods and herbivory. On average, 82 ± 24 seed producing stalks were produced per m^2 in the experimental sluiceway population.

DISCUSSION

Certain activities have been proposed from past observations as the cause for the population decline of Texas wildrice (Emery 1967). These are:

1) Regular mowing of aquatic vegetation in Spring Lake for commercial and esthetic reasons.
2) Periodic dredging of the river by the city government recreational use.
3) Commercial enterprises that introduce and harvest exotic aquatic plants for profit.

Mowing and dredging destroyed wildrice and the other native vegetation. It also interfered with the aerial pollination and seed production of Texas wildrice by causing large masses of cut vegetation to float downstream. Nonnative species introduced to the river may have outcompeted wildrice and other natural species. Mowing, dredging and the introduction of nonnative plants are only partially responsible for the population decline of Texas wildrice. Currently other factors affect the population of *Zizania texana* . These are:

1) Runoff and sewage from storm drainage and sewage leaks and spills release toxins, herbicides, pesticides, fertilizers, raw human sewage and other chemical compounds into the river (Chandler 1976). This has a continual effect on the wildrice and its environment. *Z. texana* no longer exists, as reported previously by Emery (1967), below the San Marcos sewage plant outlet.

2) Competition by introduced and native species of plants and animals. These plants include *Colocasia* , *Elodea, Hydrilla, Sagittaria, Potomogeton* and *Ludwigia* (Akridge and Fonteyn 1981). Recent fauna introductions include

Myocaster coypus (nutria), a South American mammal which feeds on rice and other river vegetation (Esminger 1955, Kebbe 1959, Chapman and Feldhamer 1982). Esminger (1955) reported that "eat outs" commonly occurred in marshes occupied by nutria. Also introduced is the popular aquarium snail *Marissa,* which can completely defoliate ponds (Murray and Roy 1968). *Marissa* is a recent addition to the river and is increasing in number.

3) Recreational use of the river. The inflorescence of the wildrice must be emergent for pollination and development of seeds. Inflorescences are knocked over and broken during recreational use of the river, such as tubing and canoeing.

The one factor, however, which is most responsible for the decline of *Zizania texana,* is the implacement of dams along the San Marcos River at numerous locations. These dams have two major effects on the wildrice.

Damming of the river raises the mean water depth preventing rice from receiving optimum light and carbon dioxide. This study indicates that water depth influences biomass production. *Z. texana* has an optimum level of irradiance and water inundation for greatest growth and survivability. Water depth has been commonly attributed to the viability of other *Zizania* species (Chambliss 1940, Steeves 1952, Simpson 1966, Weber and Simpson 1967, Thomas and Stewart 1969). In the light/depth experiment, greatest growth was exhibited by plants in the upper four depths. At lower depths, significant decreases in light availability occurred, which inhibited the growth of the wildrice. This was partially caused by shading of the wildrice by other aquatic plants which grew faster in Spring Lake.

Seed production was also affected by water depth. Texas wildrice produces seed at depths ranging from 20-60 cm in an artificial sluiceway environment. Seed production by individuals in the river has not been observed for many years. Potential seed production was estimated from plants grown in the sluiceways, by multiplying the average number of seeds/plant by the mean number of seed-producing inflorescences. Seed mortality and number of unfertile seeds were higher than those reported for Z. aquatica by Whigham and Simpson (1977). They also recorded similar but higher seed production potentials for northern wildrice, Z. aquatica. Germination of other species of wildrice also require very shallow water depths (Thomas and Stewart 1969, Ferren and Good 1977, Whigham and Simpson 1977).

Soil type had a minimal effect whereas water regime had a significant effect on growth, development and viability of Zizania texana. Wildrice exhibits more growth and less mortality when water is abundant and the level constant. Relative growth rates increased significantly with increasing inundation. In all regimes, there was less mortality and greater growth by plants in submerged and emergent regimes. Yamasaki (1981) found that Z. latifolia exhibited better growth in flooded (0-60 cm depth) plots than in dry or constantly moist (0 to -60 cm) plots. Water depths of 0-40 cm were best for biomass production (Yamasaki and Tange 1981). The results suggests that Texas wildrice is adapted to specific inundation levels. Larger individuals exhibited less mortality and significantly better growth than did smaller individuals. Other species of <u>Zizania</u> are adapted to a wide variety of environmental extremes. Wildrice species are found in brackish coastal marshes (<u>Z. aquatica</u>) and warm inland freshwater rivers and lakes (<u>Z. texana</u>). Species are also found in near anaerobic conditions (<u>Z. latifolia</u>) and aerated waters (Yamasaki and Saeki 1976). One species <u>(Z. palustris)</u> is even adapted to the permafrost of northern Saskatchewan (Archibold and Weichel 1986).

Additionally, anthesis and seed production are stimulated by higher light and shallower depths. Culms and inflorescences must be aerial for pollination, fertilization, seed maturation and dispersal. Few areas, however, are now suitable for such events. Constant immersion eliminates the sexual mode of reproduction, thereby preventing wide dispersal of the wildrice. <u>Zizania texana</u> excels in marsh environments and is not adapted to "deep" water (120+ cm). Texas wildrice, therefore, can only reproduce asexually by rhizomes, stolons and plantlets.

Second, in the marsh environment which historically existed in the Spring Lake and San Marcos River area, <u>Z. texana</u> developed a complex system for aeration of its submerged organs. Many plants tolerant to water inundation meet their aeration requirements by developing special anatomical features such as lacunae in the culm and roots (Kaufman 1959, John 1977). These allow the passage of oxygen by diffusion and bulk flow to the submerged organs (Armstrong 1978, Raskin and Kende 1985). Texas wildrice also has special lacunae (Figure 6a).

Oxygen enters the plant through a low resistance pathway provided by airlayers trapped between the hydrophobic surface of the leaves and the water (Raskin and Kende 1983). The need for oxygen is a direct result of oxygen consumption in metabolism. The need is compensated by a process involving a reduction of pressure in the air conducting system. This is caused directly by oxygen consumption (Yamasaki and Saeki 1976) and solubilization of carbon dioxide into the surrounding aquatic environment. At 25°C and pH 7, carbon dioxide is 140 times more soluble in water than is oxygen (Raskin and Kende 1985). This causes a vacancy due to loss of carbon dioxide. The oxygen diffusion capacity through shoots is found to be extremely high in other species of _Zizania_ (Yamasaki 1981, 1984).

In summary, _Zizania texana_ , significant because of its unique status and its potential as a beneficial grain crop, is rapidly declining in population. The decline has been attributed to numerous factors, the most significant of which is the long-term affects from implacement of dams on the river.

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FIGURE LEGENDS

Figure 1. Growth forms of Texas Wildrice; a) Zizania texana exhibiting emergent growth; Individual taken from sluiceway; b) Z. texana exhibiting submerged, decumbent growth in river (view from above).

Figure 2. Vegetative growth of Z. texana; a) Texas Wildrice clump taken from the river; b) Plantlet formation from lower nodes.

Figure 3. Feature illustrations of Z. texana leaf anatomy. Lamina l.s., stamata and leaf c.s. are included.

Figure 4. Leaf anatomy; a) Photograph of leaf c.s; b) Leaf c.s., undifferentiated mesophyll, chlorenchyma, abaxial and adaxial epidermis are shown.

Figure 5. Feature illustrations of Z. texana culm anatomy. Culm l.s., lacunae, culm c.s., sclerotic ring and exarch vascular bundles are included.

Figure 6. Anatomy of Z. texana culm; a) Z. texana culm l.s. showing lacunae; b) Cross-section of culm showing epidermis, chlorenchyma, and sclerenchyma surrounding the inner cortical parenchyma; c) vascular bundles in culm.

Figure 7. Feature illustrations of Z. texana root anatomy. Root l.s. and c.s exhibiting pericycle, endodermis, aerenchyma and sieve tube elements.

Figure 8. Anatomy of Z. texana root; a) Stellate aerenchyma in cortex; b) endodermis, pericycle and vascular tissue in stele.

Figure 9. Anatomy of Z. texana root; a) Development of secondary root from pericycle; b) stele l.s. with sieve tube elements exhibiting type III simple sieve plates.

Figure 10. Annual population of Z. texana (m^2) from 1976 to 1986. Net total population change (%) by year.

Figure 11. Population of Z. texana by river quadrant. Population of 1976 and 1986 and population of 1983 through 1986 exhibited. Quadrant 2, 6 and 7 contained no wildrice plants.

Figure 12. Population quadrant map of the upper 2.5 km of the San Marcos River.

Figure 13. Net growth comparison by irradiance ($uEm^{-2} s^{-1}$), biomass (g) and length (cm).

Figure 14. Net biomass (g) comparison by depth (cm) and harvest.

Figure 15. Net biomass production (g) by harvest and regime in Crawford silt clay and Edwards limestone sediment. Four harvests shown for two month period in summer 1986.

FIGURE

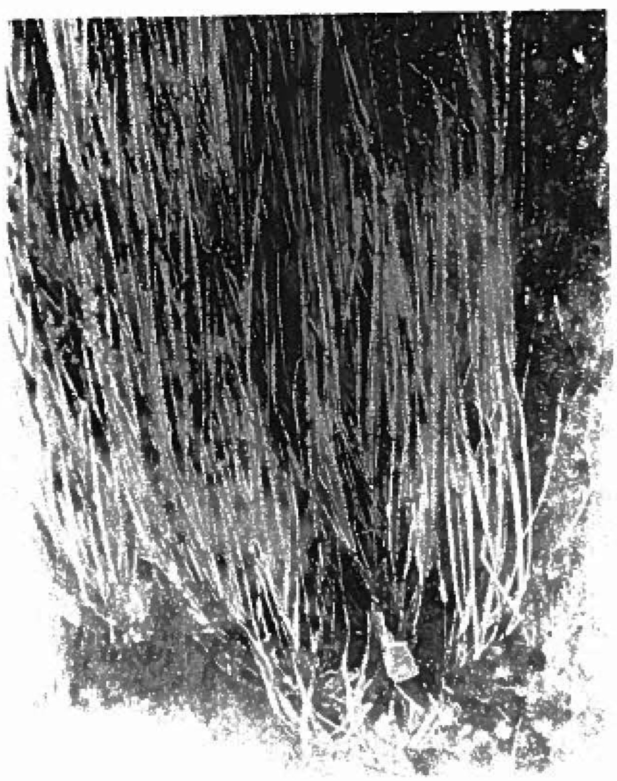


FIGURE 2

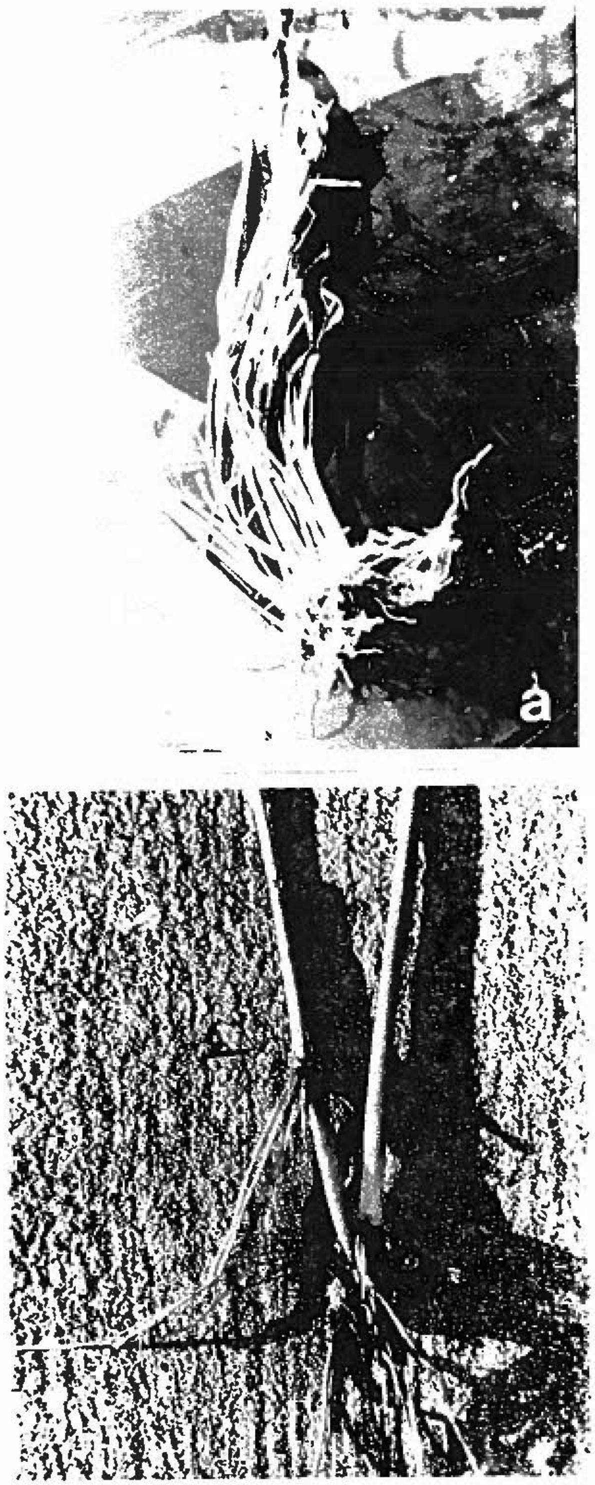


FIGURE 3

<u>Zizania texana</u>
LEAF SECTIONS

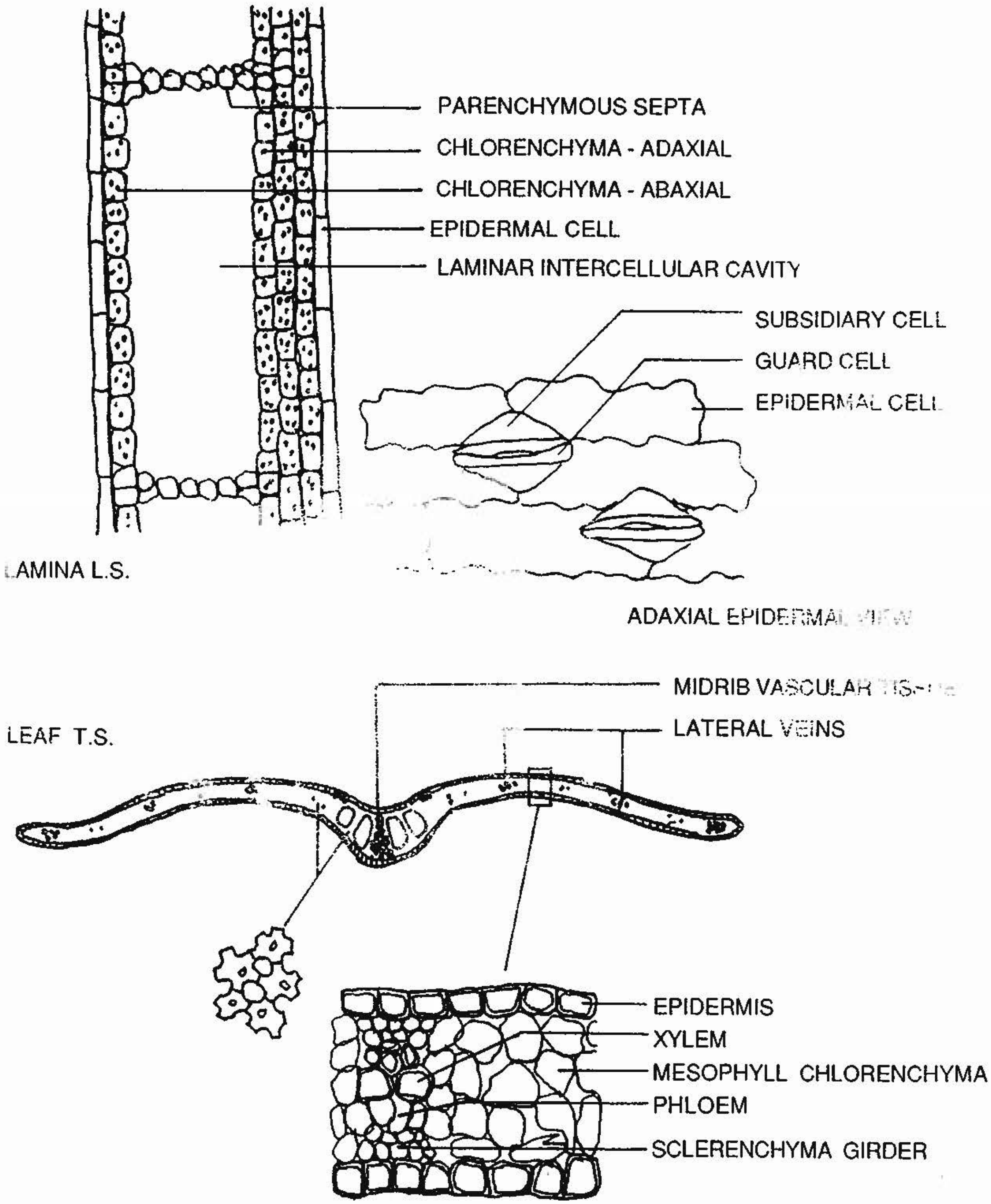


FIGURE 4

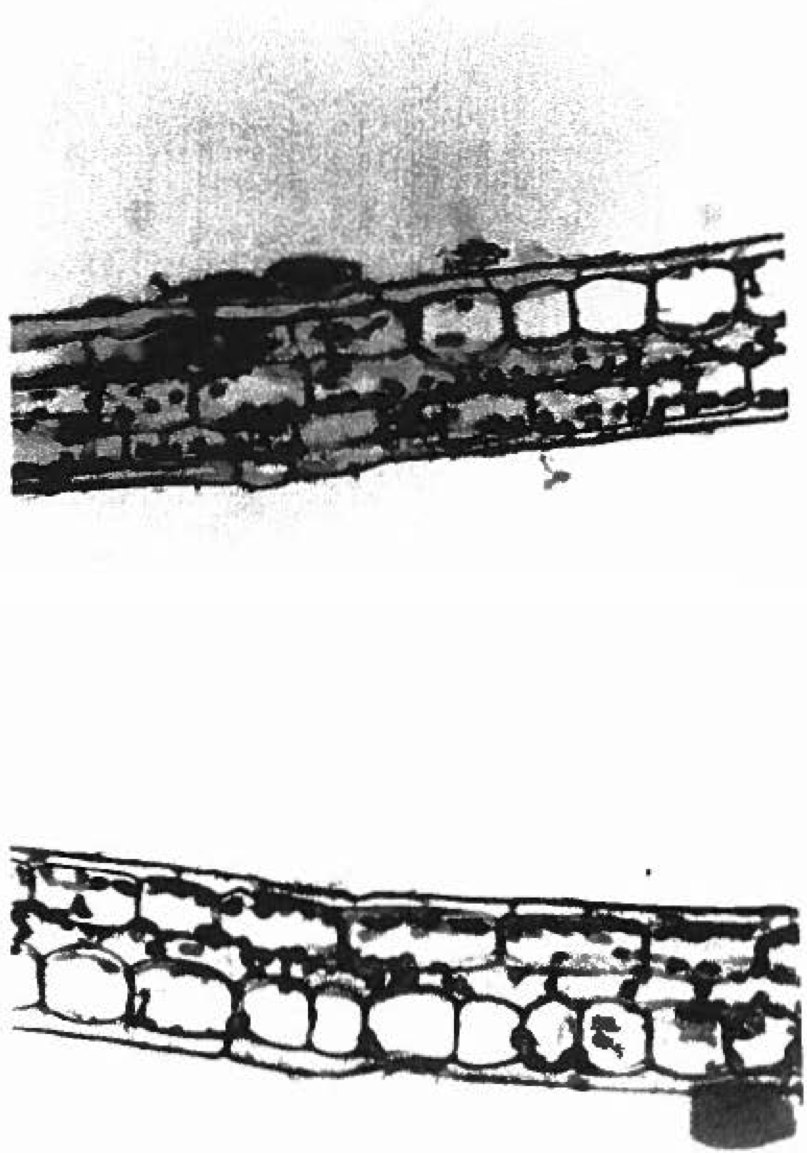
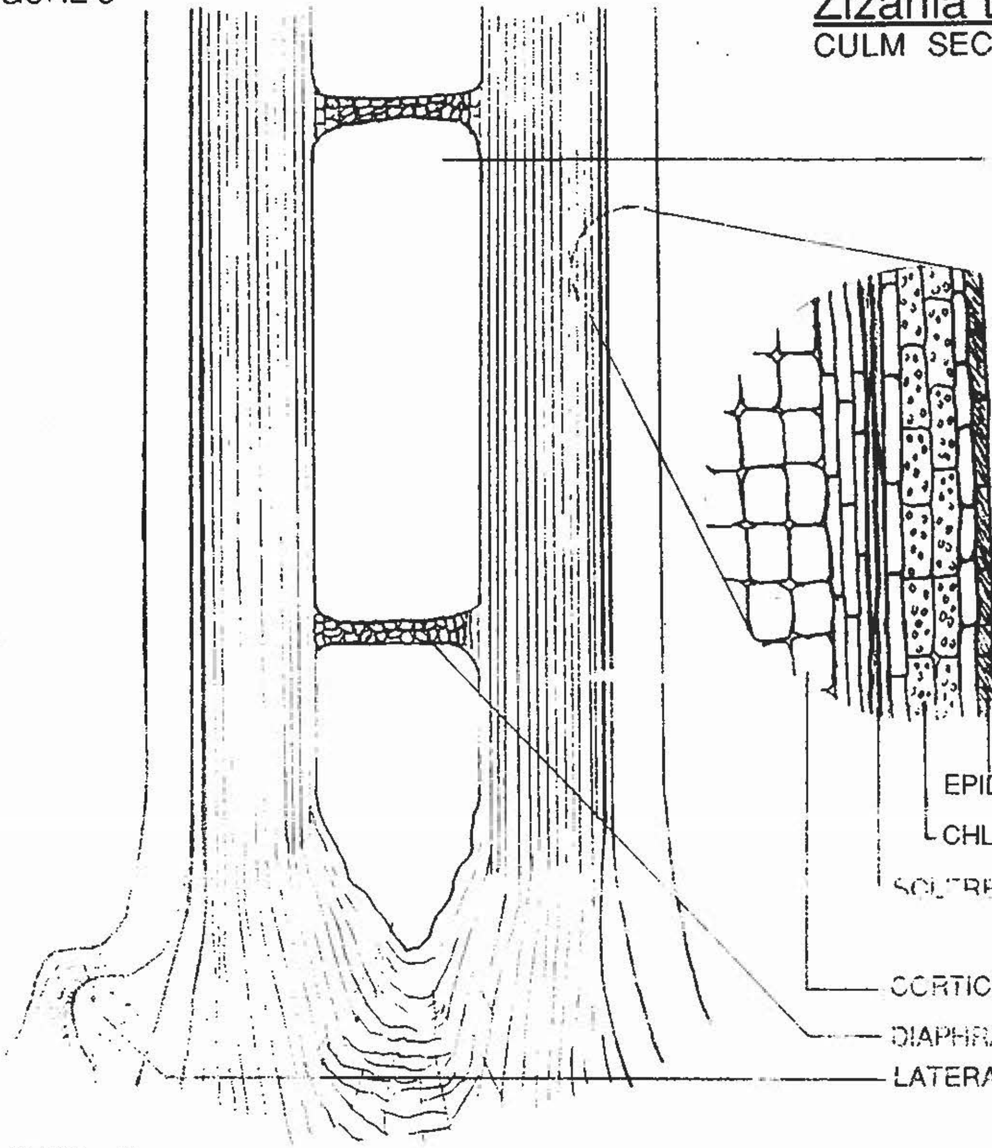
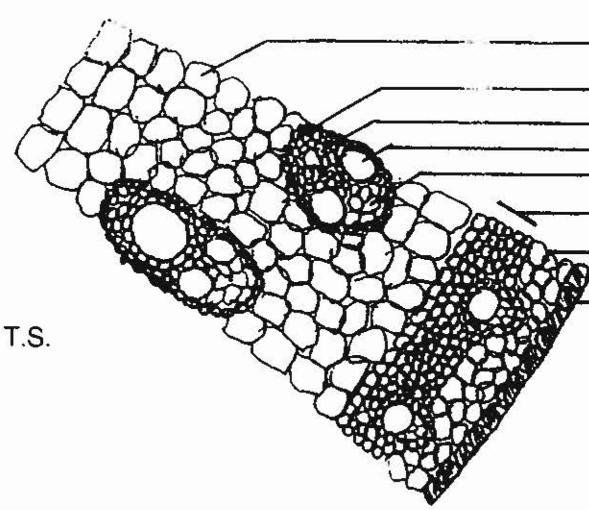


FIGURE 5

Zizania texana
CULM SECTIONS



CULM L.S.



CULM T.S.

FIGURE 6

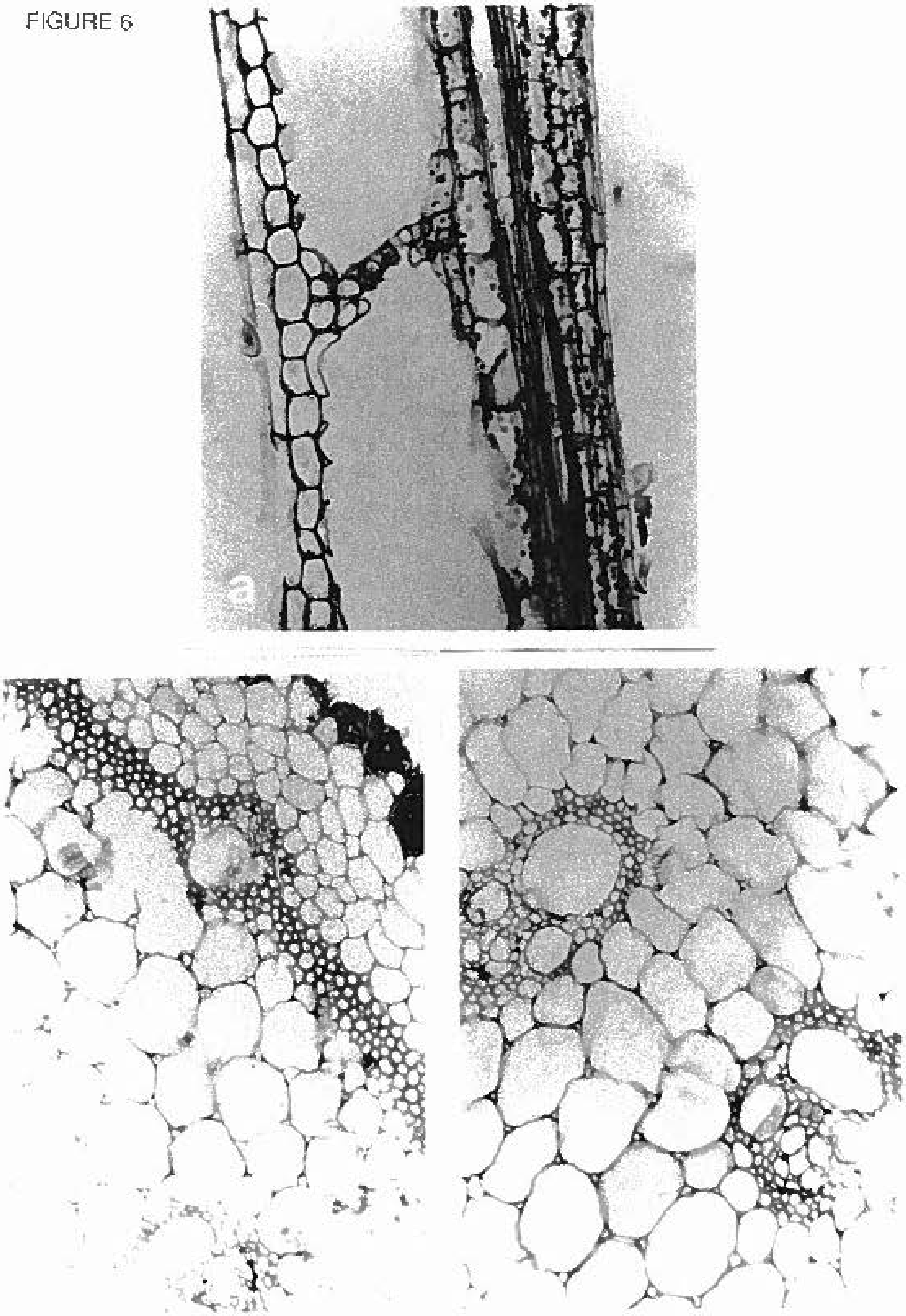


FIGURE 7

<u>Zizania texana</u>
ROOT SECTIONS

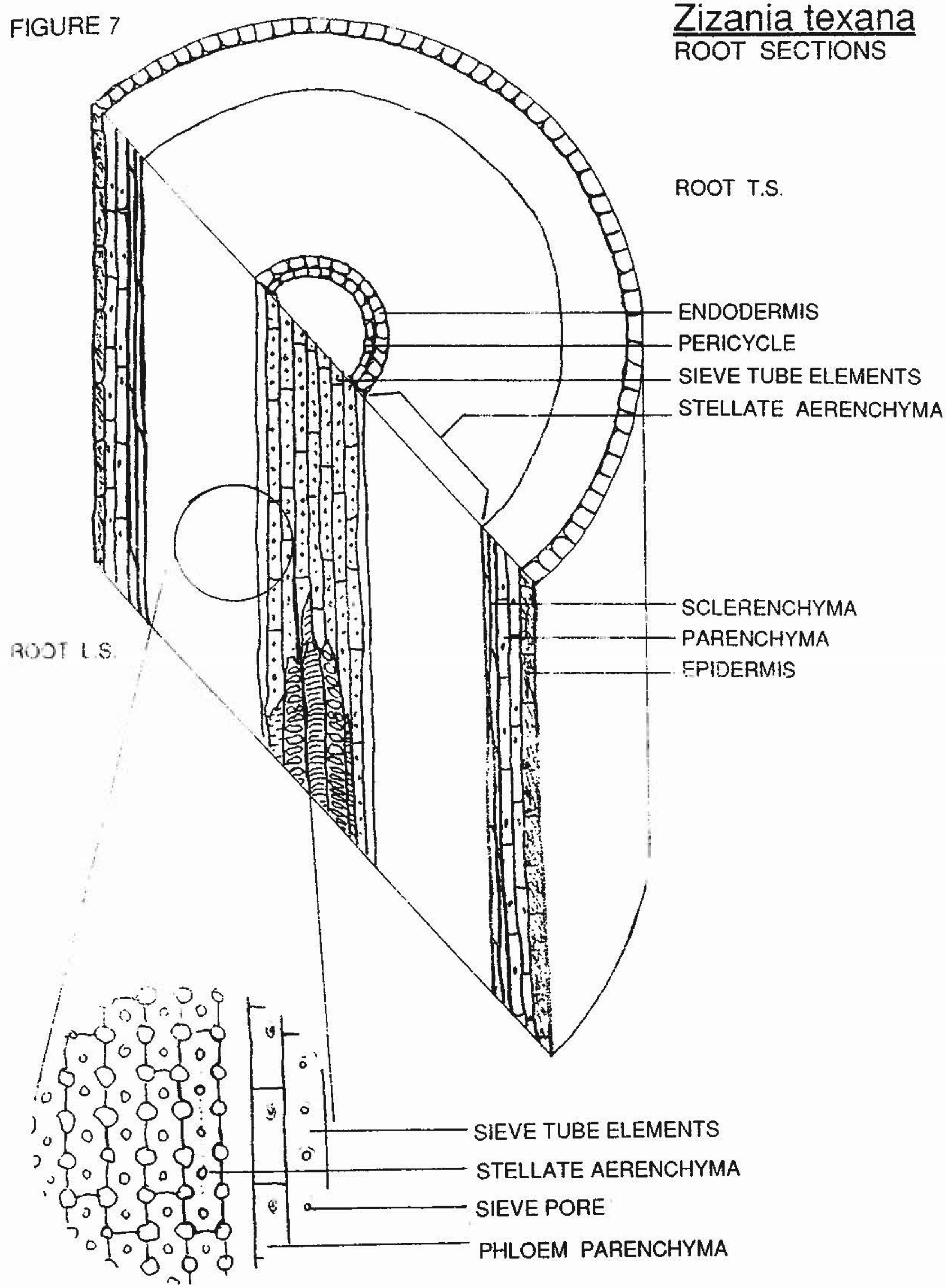


FIGURE 8

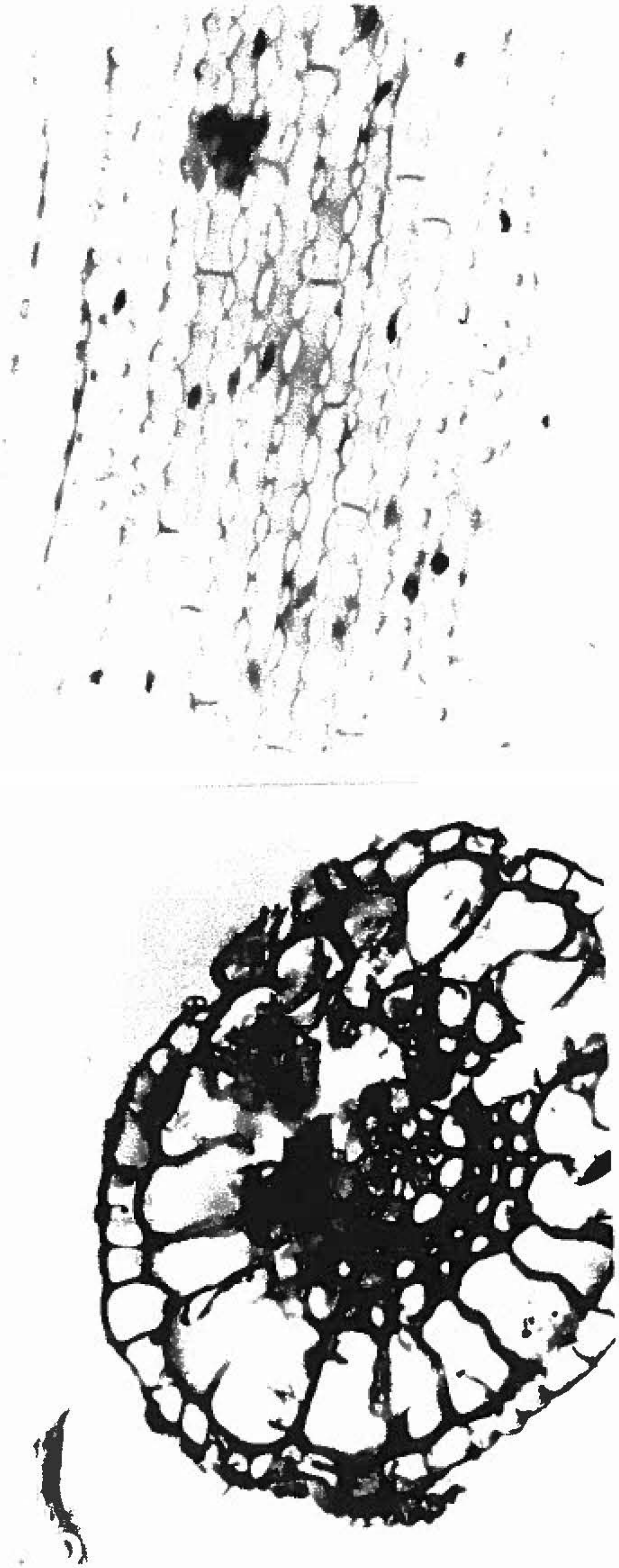
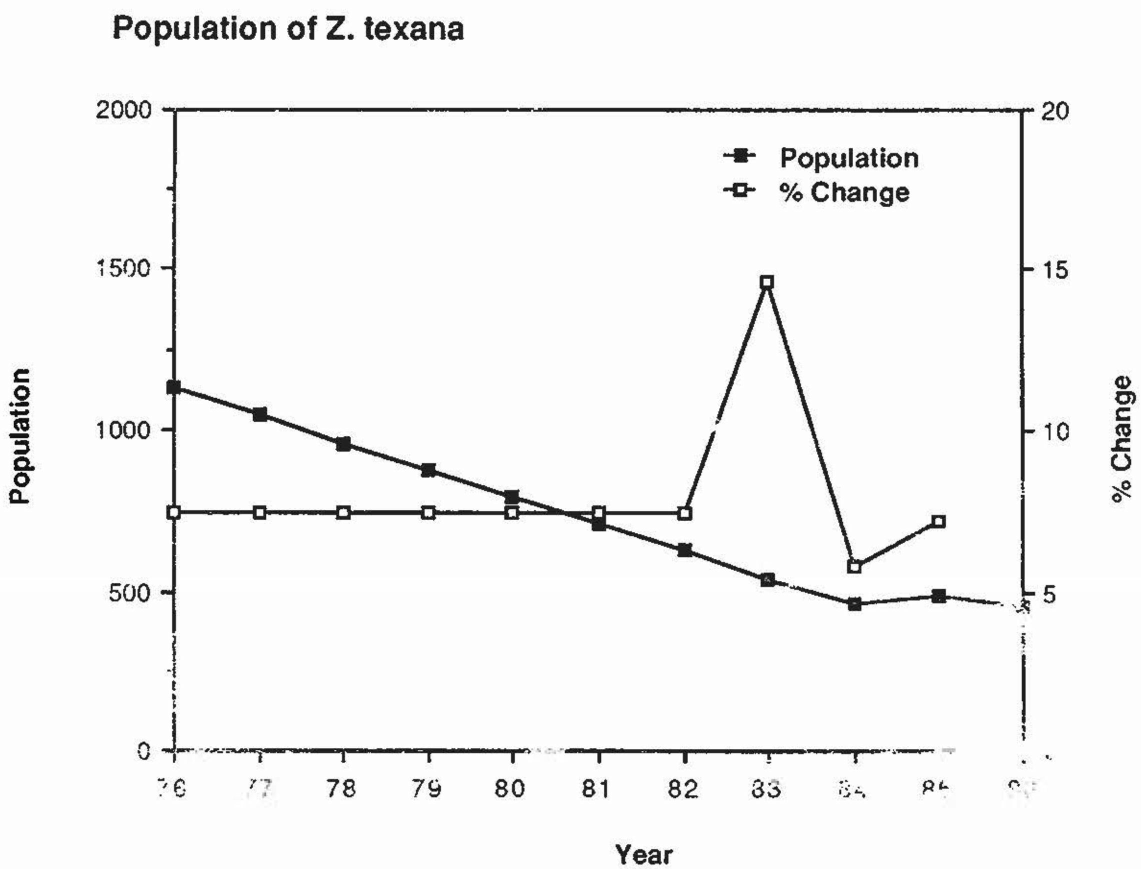


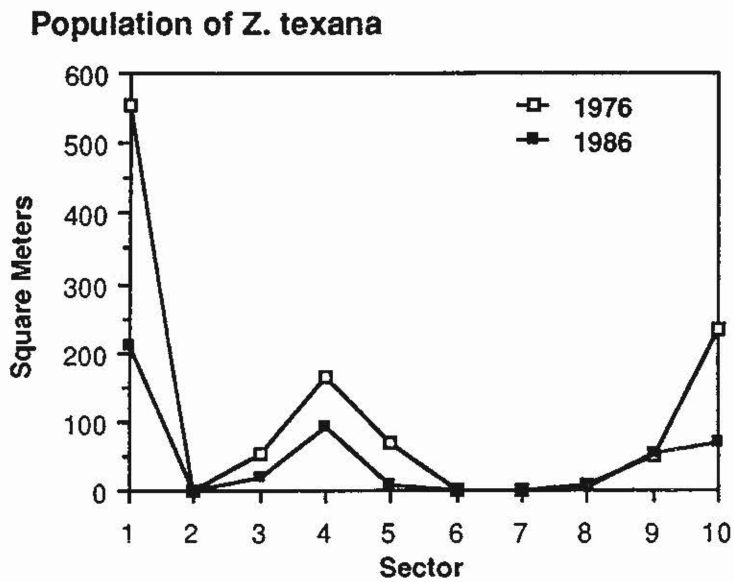
FIGURE 9

FIGURE 10



Population of Z. texana
Population
% Change
2000
1500
1000
500
0
20
15
10
5
78
79
80
81
82
83
Year

FIGURE 11


Population of Z. texana
600
500
400
300
200
100
0
Square Meters
1976
1986
1
2
3
4
5
6
7
8
9
10
Sector

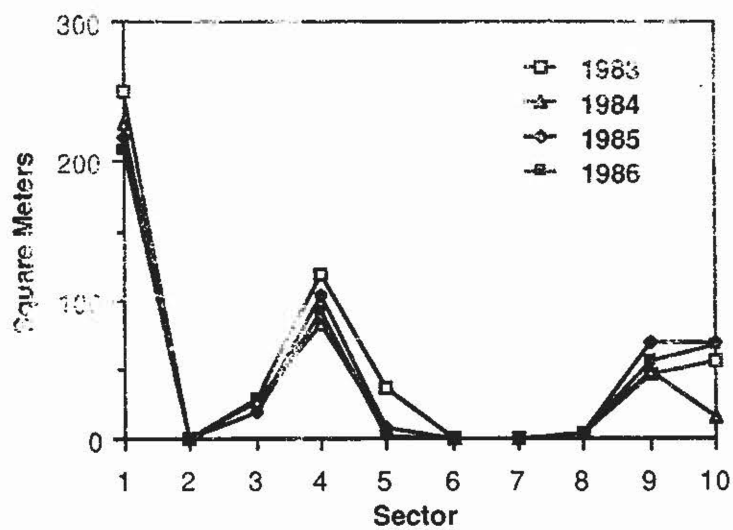
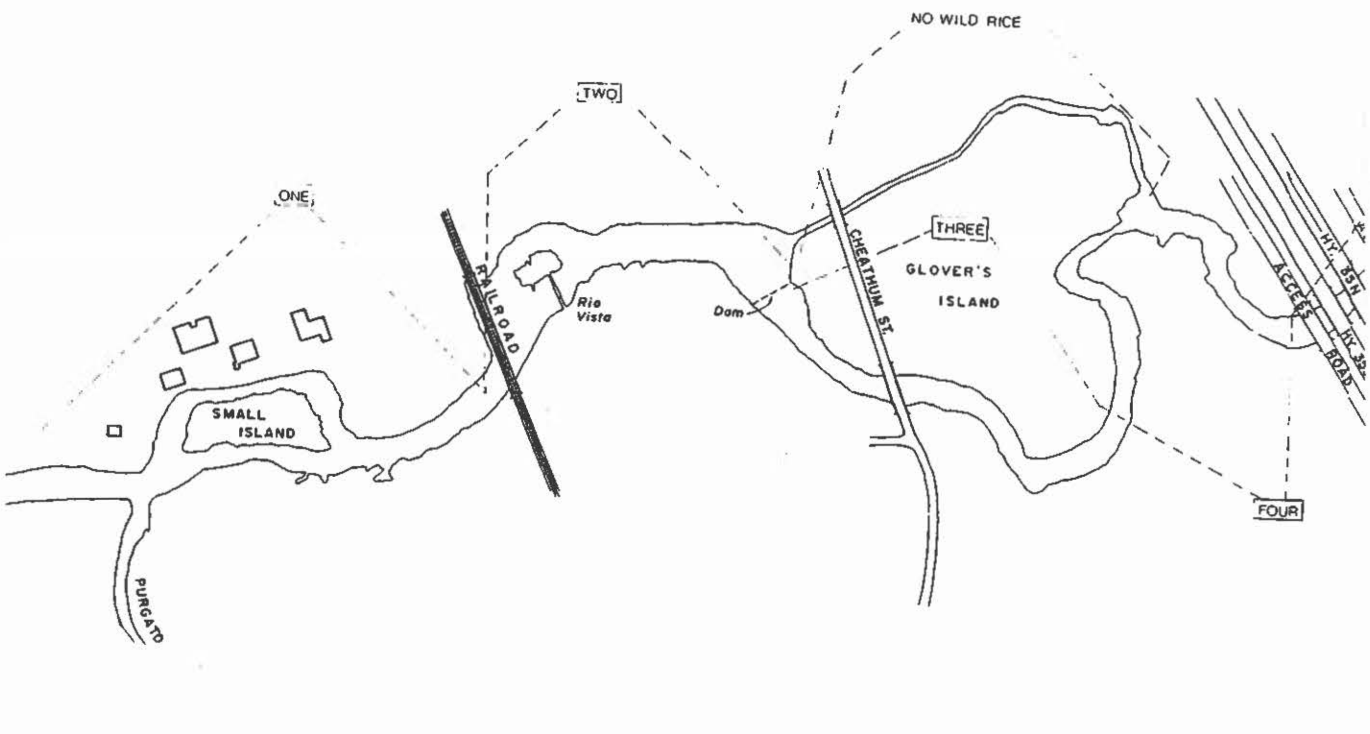
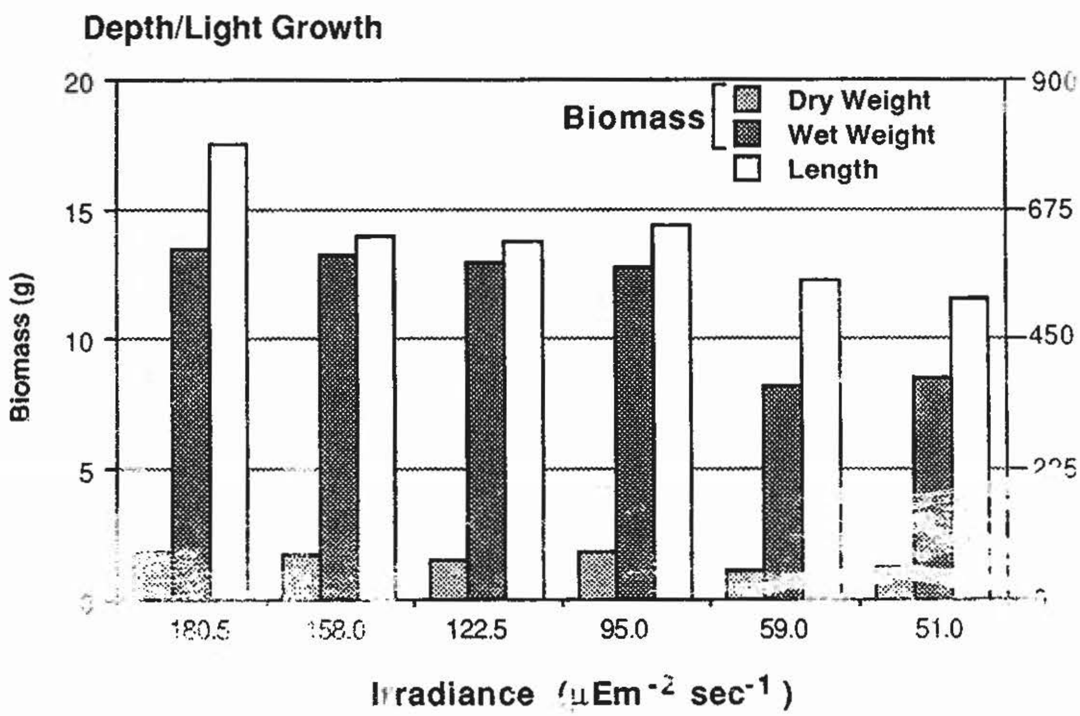

300
200
0
Square Meters
1984
1985
1986
1
2
3
4
5
6
7
8
9
10
Sector

FIGURE 12



NO WILD RICE
TWO
ONE
THREE
RAILROAD
Rio Vista
Dam
CHEATHUM ST.
GLOVER'S ISLAND
HY. 35N
ACCESS ROAD
SMALL ISLAND
FOUR
PURGATO

FIGURE 13



Depth/Light Growth
Biomass
Dry Weight
Wet Weight
Length
Biomass (g)
Length (cm)
20
15
10
5
900
675
450
180.5
158.0
122.5
95.0
59.0
51.0
Irradiance (µEm⁻² sec⁻¹)

FIGURE 14

Depth/Light/Harvest

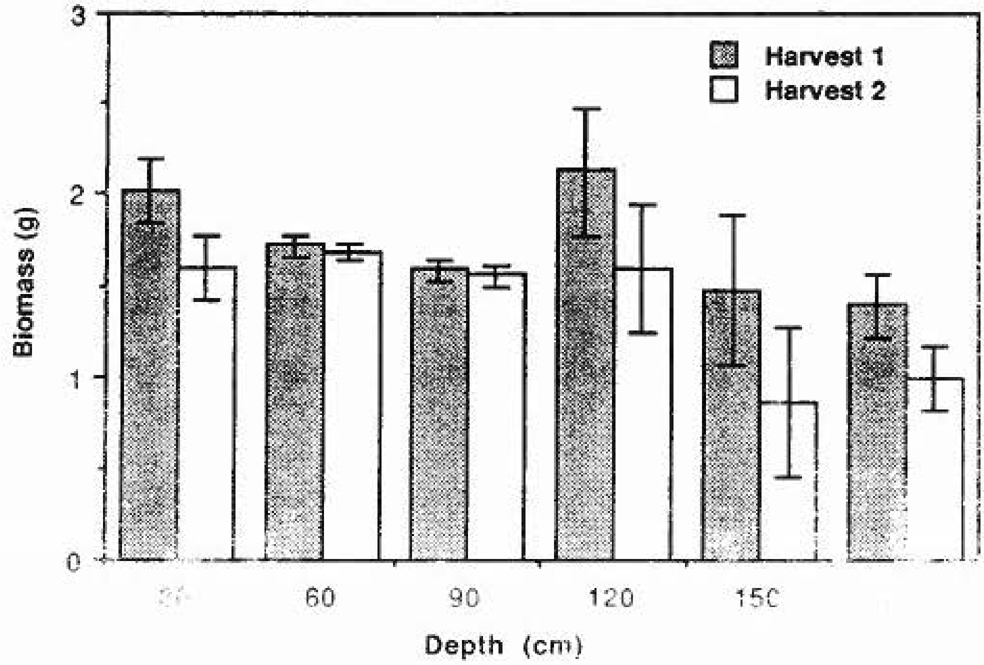
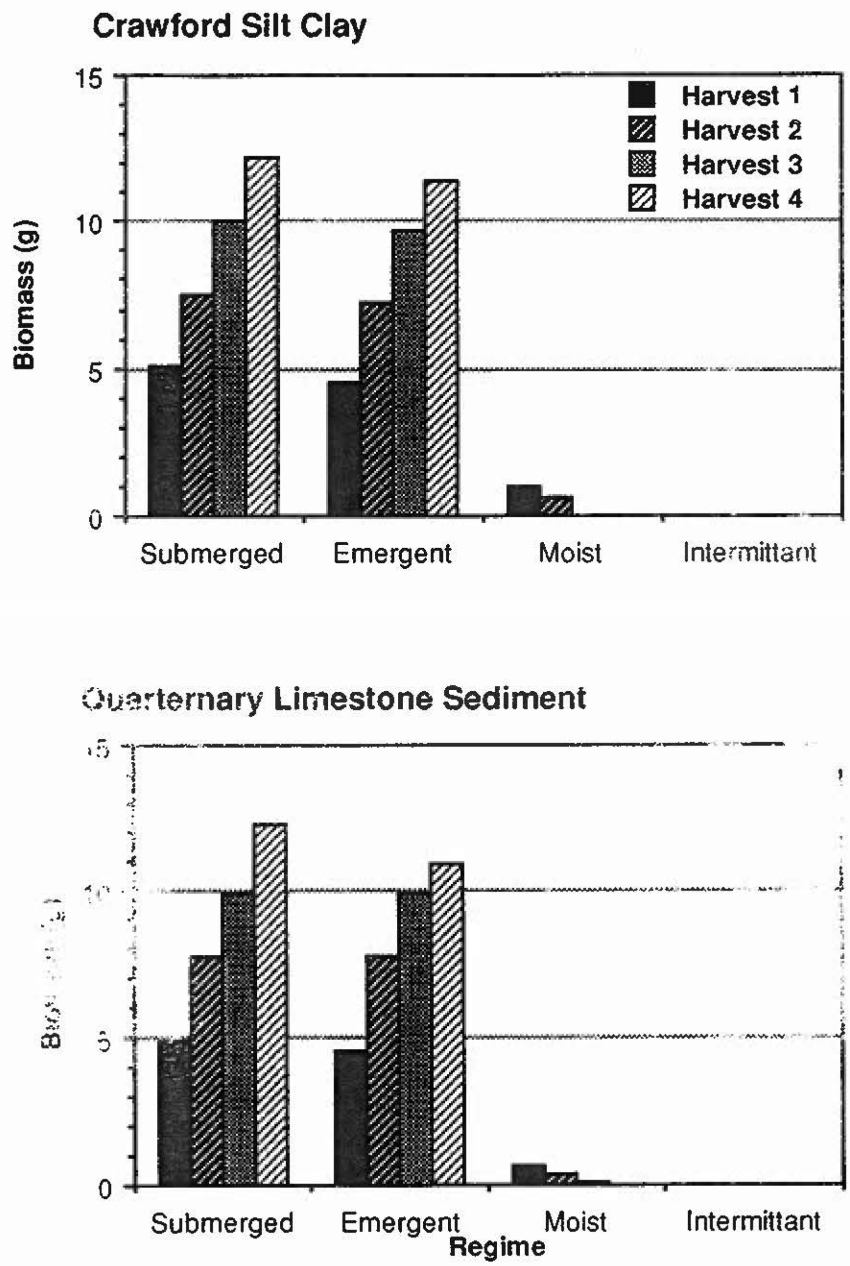


FIGURE 15



Crawford Silt Clay
Harvest 1
Harvest 2
Harvest 3
Harvest 4
Biomass (g)
15
10
5
0
Submerged
Emergent
Moist
Intermittant
Quarternary Limestone Sediment
0
Submerged
Emergent
Moist
Intermittant
Regime

Table 1. Population areal coverage (m2) of *Zizania texana* from 1976 to 1986 for the ten river sections. Data from 1976 and 1978 are from Emery (unpublished).

SECTION	YEAR						% CHANGE
	1976	1978	1983	1984	1985	1986	1976 - 1986
ONE	554.0	463.5	251.0	228.0	217.0	209.0	-62.3
TWO	0	0	0	0	0	0	0
THREE	55.0	26.0	29.0	27.0	19.0	19.0	-65.4
FOUR	164.0	-	119.0	83.0	103.0	92.5	-43.6
FIVE	68.0	33.0	37.0	8.0	8.0	7.5	-88.9
SIX	0	0	0	0	0	0	0
SEVEN	0	0	0	0	0	0	0
EIGHT	9.0	-	4.0	3.0	4.5	4.0	-55.5
NINE	49.0	-	46.0	48.0	68.0	55.0	+10.9
TEN	233.5	-	55.0	15.0	69.5	67.0	-71.3
TOTAL	1130.5	-	541.0	462.0	489.0	454.0	-59.8

Table 2. Annual population area changes of *Zizania texana* from 1976 to 1986. Values indicate total change (+) in square meters and by percentage.

SECTION	YEARS 1976-1978	1978-1983	1983-1984	1984-1985	1985-1986
ONE	-90.5/16.3%	-212.5/45.8%	-23.0/9.2%	-11.0/4.8%	-8.0/3.7%
TWO	0	0	0	0	0
THREE	-29.0/52.7%	+3.0/11.5%	-2.0/6.9%	-8.0/29.6%	0
FOUR	-	-	-36.0/30.3%	+20.0/24.1%	-10.5/10.2%
FIVE	-35.0/51.5%	+5.0/15.1%	-29.0/78.4%	0	-.5/6.2%
SIX	0	0	0	0	0
SEVEN	0	0	0	0	0
EIGHT	-	-	-1.0/25.0%	+1.5/50.0%	-.5/11.1%
NINE	-	-	+2.0/4.3%	+20.0/41.7%	-13.0/19.1%
TEN	-	-	+10.0/18.2%	+4.5/6.9%	-1.5/2.2%
TOTALS	*	*	-79.0/14.6%	+27.0/5.8%	-35.0/7.2%

* From 1976 to 1983, the population decline was -589.5 m2 or 52.1%. This was 7.4% per year or 84.2 m2 per year.

Table 3. Mean dry weights of *Zizania texana* for each harvest from April to July 1986. Mean dry weight for each harvest, mean percent of wet weight, and mean shoot lengths (cm) are included.

DEPTH (cm)	DRY WEIGHT (g) HARVEST ONE	DRY WEIGHT (g) HARVEST TWO	DRY MEAN (g)	MEAN PERCENT OF WET WEIGHT	MEAN LENGTH
30	2.013	1.602	1.81	13.70	817.96
60	1.721	1.683	1.70	12.15	799.63
90	1.595	1.563	1.58	12.20	781.40
120	2.135	1.596	1.87	14.60	769.40
150	1.485	0.858	1.17	14.40	493.29
180	1.403	0.991	1.20	16.22	445.05
MEANS	1.725	1.382	1.55	13.88	684.45

Table 4. Total weight (g) for 160 *Zizania texana* plants grown in forty regime-soil-size levels for a two month period in summer 1986. Soils used are Crawford silt (soil 1) and Quarternary alluvial gravel (soil 2).

SIZES		REGIMES / SOILS							
	HARVEST	SUBMERGED		EMERGENT		MOIST		WET/DRY	
		1	2	1	2	1	2	1	2
LARGE	1	4.91	5.64	6.43	6.20	0.67	1.41	0	0
	2	9.46	8.05	7.93	9.12	1.15	0.32	0	0
	3	13.11	12.75	10.91	12.23	0	0.11	0	0
	4	15.87	15.16	13.82	13.44	0	0	0	0
MEDIUM	1	6.01	4.62	5.01	6.77	0.72	0.60	0	0
LARGE	2	3.48	7.78	8.25	8.17	0.22	0.08	0	0
	3	10.27	10.91	12.47	9.85	0	0	0	0
	4	13.69	14.84	13.16	11.34	0	0	0	0
MEDIUM	1	4.90	5.55	4.57	3.86	1.49	0.26	0	0
	2	6.85	8.05	6.72	6.04	0.65	0.57	0	0
	3	9.48	9.13	8.81	9.29	0	0	0	0
	4	11.64	12.77	11.26	11.39	0	0	0	0
MEDIUM	1	6.11	4.47	3.16	2.89	0.86	0.99	0	0
SMALL	2	8.28	8.16	7.45	7.68	0	0.47	0	0
	3	10.62	9.77	9.15	10.21	0	0	0	0
	4	12.07	10.10	0	10.99	0	0	0	0
SMALL	1	3.23	4.21	3.24	3.08	0	0.14	0	0
	2	6.57	6.64	5.71	0	0	0	0	0
	3	6.78	7.05	7.13	7.97	0	0	0	0
	4	7.78	8.55	7.26	7.34	0	0	0	0
MEANS	1	5.03	4.90	4.48	4.56	0.96	0.68	0	0
	2	7.53	7.74	7.21	7.75	0.67	0.36	0	0
	3	10.05	9.92	9.69	9.91	0	0.11	0	0
	4	12.21	12.28	11.38	10.90	0	0	0	0

Appendix I.
Analysis of Variance Table: Depth/Irradiance/Harvest

Source of Variation	DF	SS	MS	F-stat
depth	5	0.9152	0.1830	5.7520
harvest	1	0.3533	0.3533	11.1027
Error	5	0.1591	0.0318	
Total	11	1.4275		

Depth Statistics

Group	N	Sum	U-SSQ	Mean S.E.	C.V. S.E. (CV)
[1]	2	3.6150	6.6186	1.8075 0.2055	16.0786 8.2445
[2]	2	3.4040	5.7943	1.7020 0.0190	1.5787 0.7896
[3]	2	3.1580	4.9870	1.5790 0.0160	1.4330 0.7167
[4]	2	3.7310	7.1054	1.1715 0.2695	20.4305 10.6331
[5]	2	2.3940	2.9505	1.1970 0.3135	37.8452 21.4623
[6]	2	2.3940	2.9505	1.1970 0.2060	24.3382 12.8698

Harvest Statistics

Group	N	Sum	U-SSQ	Mean S.E.	C.V. S.E.(CV)
[1]	6	10.3520	18.2899	1.7253 0.1196	16.9822 5.0417
[2]	6	8.2930	12.1073	1.3822 0.1466	25.9860 7.9920

Appendix II.
Analysis of Variance Table: Regime/Soil/Harvest

Source	df	SS	Mean Square	F-Statistic
Method 1 - Consistent Model Includes Interaction Terms				
A	2	464.9811	232.4906	56.7289
B	3	169.3012	56.4337	13.7701
C	1	0.4945	0.4945	0.1207
AB	6	103.0056	17.1676	4.1890
AC	2	2.1367	1.0684	0.2607
BC	3	0.9200	0.3067	0.0748
ABC	6	9.1631	1.5272	0.3726
Error	96	393.4343	4.0983	
Total	119	2601.8385		
Method 2 - Additive Model Includes No Interaction Terms				
A	2	1683.4348	841.7174	205.3834
B	3	290.1417	96.7139	23.5987
C	1	0.5922	0.5922	0.1445
AB	6	103.0056	17.1676	4.1890
AC	2	2.1367	1.0684	0.2607
BC	3	0.9200	0.3067	0.0748
ABC	6	9.1631	1.5272	0.3726
Error	96	393.4343	4.0983	
Total	119	2601.8385		
Method 3 - Additive Model Includes Interaction Terms				
A	2	1683.4348	841.7174	205.3834
B	3	290.1417	96.7139	23.5987
C	1	0.5922	0.5922	0.1445
AB	6	103.0056	17.1676	4.1890
AC	2	2.1367	1.0684	0.2607
BC	3	0.9200	0.3067	0.0748
ABC	6	9.1631	4.0983	
Error	96	393.4343		
Total	119	2601.8385		

Appendix III. Comparison of amino acid composition of dehulled Texas Wildrice, <u>Zizania texana</u> grain to Northern Wildrice, <u>Z. palustris,</u> spring oat groats and hard red spring wheat grain.

Amino acid	*Z. texana*	*Z. palustris*	Oat groats	Wheat grain
	g amino acid/100 g amino acids recovered			
Alanine	5.2	6.2	5.0	3.3
Arginine	8.5	8.2	6.9	4.0
Aspartic	10.0	10.6	8.9	4.7
Cystine,half *	0.6	0.2	1.6	2.6
Glutamic acid	18.1	19.5	23.9	33.5
Glycine	5.0	4.9	4.9	3.8
Histidine *	2.8	2.8	2.2	2.2
Isoleucine *	4.3	4.4	3.9	3.9
Leucine *	7.7	7.5	7.4	6.8
Lycine	6.9	4.5	4.2	2.3
Methionine *	2.7	3.1	2.5	1.7
Phenylalanine *	5.1	5.1	5.3	4.8
Proline	4.5	4.0	4.7	11.2
Serine	5.2	5.5	4.2	5.1
Threonine *	3.8	3.3	3.3	2.8
Tyrosine *	3.8	3.9	3.1	2.7
Valine *	5.8	6.2	5.3	4.5

* Essential amino acids.