SALT TOLERANCE, PROPAGATION AND PROVENANCE EVALUATION OF 
TAXODIUM AS A LANDSCAPE AND COASTAL WETLAND TREE

By

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Presented to the Faculty of the Graduate School of
Stephen F. Austin State University
In Partial Fulfillment
Of the Requirements
For the Degree of
Master of Science in Agriculture

STEPHEN F. AUSTIN STATE UNIVERSITY
May, 2007
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ABSTRACT

Baldcypress, Montezuma cypress, and T302 (a baldcypress X Montezuma cypress cross) were evaluated for salt tolerance at four levels of salt rates (0, 1, 3.5, and 6 ppt for 13 weeks and then 0, 2, 7, and 12 ppt for another 12 weeks). The salinity treatments did not have significant effect on growth rate. There were significant differences of growth rate among the genotypes. T302 produced higher wet weights than the others. However, Montezuma cypress exhibited the greatest increase in height. Na concentration in *Taxodium* leaves increased as sea salt concentrations increased. Of three genotypes, baldcypress exhibited the highest leaf content of Na, Ca, S, and Fe; Montezuma cypress had the lowest leaf content of Na, Ca, S, and Fe; and the cross T302 was in between.

Cutting propagation of T302 was investigated with different treatments – 1) wounding, 2) rates of rooting hormone, and 3) RegalCrown®. Results indicated rooting ability improved with increasing root hormone rates and wounding. RegalCrown® treatments had no significant effect on rooting capacity of the cuttings.

Seventeen *Taxodium* genotypes were evaluated for growth performance. The results indicated T302 had the greatest growth rate of all genotypes.
ACKNOWLEDGEMENTS

The author is especially thankful to Dr. David L. Creech for his help and encouragement. I would like to thank Drs. Kenneth W. Farrish, Donald B. Pratt, and David L. Kulhavy for serving on my graduate committee. Dr. Dean Coble's assistance with the salt experiment design is gratefully appreciated.

My deepest thanks go to my family and friends for their support and assistance.
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INTRODUCTION

Wetlands are an important component of forested systems in the southern United States (Dickson et al. 1965). Along the Louisiana Gulf Coast, portions of these forests are under increasing stresses associated with flooding and saltwater intrusion (Williston et al. 1980). Degradation of coastal forests and associated wetland habitats by excessive flooding and saltwater intrusion is dramatically high, especially in the Mississippi River Delta (Allen, 1992; Earles, 1975; Krauss et al. 1999).

*Taxodium* is an important wetland species of river and coastal floodplains of the southern USA. This long-lived and generally pest-free deciduous conifer is popular in southern landscapes and quite tolerant of flooding, salt, alkalinity and hurricanes (Arnold 2002). There remains great opportunity to find superior genotypes and clones that fit particular site requirements.

The objectives of this thesis:
1. **Salt Tolerance**: Test the salt tolerance of three *Taxodium* genotypes [Baldcypress, Montezuma cypress, and T302 (a baldcypress X Montezuma cypress hybrid developed in China)] to acute applications of four rates of salt solution.
2. **Cutting propagation**: Test factors for their influence on T302 cutting propagation success (rooting hormone rates, rooting stimulants, wounding).
3. Germplasm evaluation: Evaluate the growth rate of 17 *Taxodium* genotypes representing a wide range of provenances. To augment the collection of superior clones of *Taxodium* at Stephen F. Austin State University and to plant them along La Nana Creek in a documented and mapped collection.
LITERATURE REVIEW

Description of *Taxodium*

*Taxodium* is a deciduous conifer in the family of Cupressaceae, one of several genera in the family commonly known as cypresses. Previous literature often refers to three species: 1) *Taxodium distichum* (baldcypress), *T. ascendens* (pondcypress), and *T. mucronatum* (Montezuma cypress). However, current taxonomy places *Taxodium* as one species with three botanical varieties (Arnold and Denny 2007).

*Taxodium distichum* (L.) Rich.var. *distichum* (Baldcypress - BC)

*Taxodium distichum* var. *imbricarium* (Nutt.) Croom (Pondcypress - PC)

*Taxodium distichum* var. *mexicanum* (Carriere Gordon) (Montezuma cypress - MC)

For the purpose of brevity, baldcypress, pondcypress, Montezuma cypress, and *Taxodium distichum* ‘Nanjing Beauty’ (a cross of Baldcypress X Montezuma cypress) will be referred to in this thesis as BC, PC, MC and T302 respectively.
While BC and PC ranges certainly overlap in many areas across the south, the nature of overlap of BC and MC ranges is less well defined (Figure 1).
**Baldcypress (BC)** - BC is native to much of the southeastern United States, from Delaware to Texas and inland up the Mississippi River to southern Indiana (Figure 1). It occurs mainly along rivers with silt-rich flood deposits. BC is a durable, long-lived deciduous conifer particularly well-adapted to wetland habitats (Cox and Leslie 1988). The tree is pollution-tolerant and excels in compacted, low-oxygen or swampy conditions. It stands strong in the face of hurricanes, is amazingly long lived (1000+ years) and, with time, can become quite large. BC is easy to grow from seed and is relatively free of pests and diseases. The prevalence of knees (pneumatophores) is considered a negative in most landscaping circles as they interfere with routine maintenance programs.

While superior clones have been available for years, they have rarely captured a large portion of the baldcypress market. Most plants sold by nurseries are seedlings and there is considerable diversity in form, shape, and salt and alkalinity tolerance. Propagation by cuttings can be successful with vigorous shoots as the cutting source, particularly if the clone is young. According to Larry Hatch’s extensive list ([http://www.raretrees.org/taxodium.html](http://www.raretrees.org/taxodium.html)) there are over 45 cultivars of *Taxodium* including clones that are pendulous, contorted, dwarf, salt tolerant, of good form, superior foliage color, etc. Many are not readily available or are lost to the garden world. As might be expected by its wide range, BC has the most varieties, some easier to find than others. The SFA Mast Arboretum, Nacogdoches, Texas, USA has a long history of collecting and planting a wide range of cultivars and genotypes (Appendix A). In addition, the
SFA Mast Arboretum includes seedling trees representing a wide range of provenances from across the southern USA.

**Central and West Texas Baldcypress** - BC in the western regions of its range is more salt and alkalinity tolerant, and is less prone to produce knees than its more eastern types. Eastern genotypes of *Taxodium* planted in San Antonio, Texas, USA often turn chlorotic and sometimes fail to survive. Botanists and horticulturists are convinced that Central to West Texas BC are perhaps commingled with MC and represents transitional genetics.

**Pondcypress** - PC occurs in the southern portion of the range of BC and only on the southeastern coastal plain from North Carolina into Louisiana, and to our observation, perhaps into southeast Texas (Shangrila Botanical Gardern, Orange, Texas) (Figure 1). It occurs in still blackwater rivers, ponds, bayous and swamps, usually without silt-rich flood deposits. PC is relatively easy to distinguish via the nature of its feathery foliage which is ascendant, rather than more splayed and flat as in BC, but this may not always be consistent. Hardin (1971) was first to speculate on the nature of intermediates where BC and PC ranges overlap. Landscapers often use PC as a specimen particularly when moist soil conditions exist – and a smaller stature is desired.

**Montezuma cypress** (MC) - Less well known in southern USA landscapes, MC is native to Mexico, the tip of South Texas and remnant populations near Las Cruces, New Mexico (Figure 1). MC differs from BC and PC in being substantially evergreen, produces smaller seed, never produces distinct knees,
and is generally more salt and alkaline tolerant. It is less likely to survive extended periods of flooding. Where adapted, usually in Zones 8 and 9, MC has a much faster growth rate than BC and PC. MC forces new growth early in the spring and continues to grow late into the fall. Observations of MC in Zone 8 and lower suggest that there may be hardiness and winter damage issues, particularly with trees derived from lowland, tropical Mexico genotypes. These may fail in Zones 7 and lower in the U.S. This may be a seed source provenance problem and there is good reason to believe that MC can be grown much further north if the proper genotypes are selected as seed sources. A genotype from near Las Cruces, New Mexico shows great promise. This disjunct population is reported to have endured -31.7 °C. MC is not usually considered a superior landscape tree; it often fails to form a strong central leader and can develop a somewhat wild and unbalanced form. Landscapers in Texas and Louisiana often report that MC “fails to grow old gracefully”. However, there are many exceptions to this rule and MC can be quite balanced and uniform. MC can become huge, and live for thousands of years. A MC near Oaxaca, Mexico, the famous 2500 year-old “Arbole de Tule”, features a trunk over 17 m in diameter and is estimated to be over 2500 years old. It is often referred to as the world’s largest tree.

Nurserymen rarely grow MC and there only a few varieties have been named. Paul Cox of the San Antonio Botanical Garden has introduced ‘Sentido’ (Spanish for crying), which is modestly weeping and a beautiful tree. Cedar
Lodge Nursery in New Zealand has a form they have named ‘McClaren Falls’, a mounding weeper of unknown proportions at maturity. Unfortunately, five grafted plants of that variety failed to survive at SFA for unknown reasons. At the SFA Mast Arboretum, there are several MC specimens worth noting. One particular tree, first planted in 1988, survived the December 23, 1989 freeze (-17.8°C) with no damage. In the SFA Mast Arboretum, MC withstood droughts of considerable magnitude. The SFA Montezuma cypresses lost their foliage in summer droughts several times, but each time they quickly pushed new growth when rains or irrigation finally arrived. Vigorous trees often keep their foliage through most of the winter.

**Value of *Taxodium***

*Taxodium* has numerous attributes that qualify it as a supreme urban landscape tree and as a species to mediate harsh coastal wetlands and floodplains of major rivers in the South. Riverine swamps of BC cause floodwaters to spread out, slow down, and infiltrate the soil. Thus, these stands reduce damage from floods and act as sediment and pollutant traps. The tree once dominated large areas of the southern USA and had a fascinating history in early American forestry. The species was heavily cut in the late 1800s and early 1900s. Only a few patriarchs survived. Even second and third growth cuts have not prevented the species from being quite resilient when environmental conditions fit its preference. The wood has long been valued for its resistance to
rot and warp once cured. In addition, cypress bark is very popular in landscaping circles as a long-lived mulch that doesn’t wash away in rains.

**Genetic Variation in *Taxodium***

Genetic variation in *Taxodium* has received limited attention in the USA and most trees planted in the USA are seedlings from a wide range of seed sources. Very little attention has been paid to superior genotypes as a seed source and horticultural varieties are rarely encountered outside of botanical gardens and arboreta. While most studies conclude that BC and PC are not distinctly different enough to be a separate species, researchers note that there is considerable variation in characteristics and the genetic foundation for improvement is quite broad (Lickey and Walker 2002). In many landscapes across the southern USA, a “line” of uniform bald cypress at planting almost always evolves into varied forms, growth rates, foliage color, limb structure, etc.

Tsumura et al. (1999) found very little genetic differentiation between BC and PC, but their study included only 20 individuals from each of six populations of BC and seven populations of PC in Florida and extreme southern Georgia. Beilman (1947), Flint (1974), McMillan (1974), and Sharma and Madsen (1978) reported on seed source and provenance variation. Faulkner and Toliver (1983) found seed source effects for cone size and seed weight, but failed to find geographic variation for number of insect galls per cone, height, and diameter, but they concluded that because the scope of their work was rather limited they were unable to detect geographic variation. In another study, the seed
characters and young seedling growth of BC from 11 locations in six U.S.A. states were studied in China and the results indicated there were significant differences among 34 progenies concerning the measured variables that included seed length, 1000-seed weight, seed vigor, the length of leaves of 60-day-old seedlings, height growth of young seedlings, diameter growth, and biomass of seedlings (Cao F et al. 1995). In another study, seed origin of MC had no effect on cumulative germination percentage for two seed sources from New Mexico (St. Hilaire 2001).

All of the above-mentioned studies dealt with *Taxodium* as a forest tree and not as an ornamental for the nursery and landscape industry. Denny et al. (2006) are currently screening genotypes for salt tolerance and good landscape form at Texas A and M University (Appendix B). They have reported that there is influence of seed source on tolerance to salt, high pH and alkalinity, and Mexico MC and western BC were generally less adversely affected by higher alkalinity levels than more eastern populations (Denny et al. 2006). Rockwood in Florida is evaluating *Taxodium* seed sources and field trials are underway (Rockwood, personal communication, 2006). Finally, Krauss at the Wetlands Research Center is evaluating a wide range of salt-tolerant BC from various provenances in the coastal south (Krauss, personal communication, 2006).
**Hybrids**

Chinese scientists are convinced that controlled *Taxodium* hybridization promises to combine the best characteristics of superior parents. In 1988, clones T302 (BC X MC), T401 (PC X MC), and T202 (PC X BC) were selected in China primarily for growth rate and tolerance to alkaline and salt-rich coastal floodplains. All hybrids are intermediate types as far as photosynthetic activities are concerned and the genetic influence of the male parent was greater than that of the female. The height and breadth of the hybrids have positive correlation with photosynthetic intensity (Wu S et al. 1990). The mean annual increment and current annual increment curve of volume indicate that T302 grows well under alkaline soil condition (pH ≤ 8.5), while BC would be comparatively inhibited (Zhou K et al. 2000). T302 is recommended in China for soils with pH 8.0~8.5 and salt concentrations < 2 ppt (34 moles⋅m$^{-3}$). T301, T401, and T302 have higher salt tolerance than BC and PC. Other attributes of T302 included 159% faster growth than BC, good columnar form, and longer foliage retention in fall and early winter, and no knees (Chen Y et al. 1987).

In one Chinese study, growth rate (height and root diameter), and biomass above-ground as well as twig structure of the first backcrossed generations of (BCF$_{1}$) *Taxodium* ‘Zhongshansha 302’ X MC were monitored during the first three years after planting. The results indicated that “the average growths of height and biomass above ground of BCF$_{1}$102, BCF$_{1}$118, BCF$_{1}$61 and BCF$_{1}$149 were significantly higher than the mother plant T302. Experiments in saline-alkali
soil (pH 8.5) indicated that the growth rates of BCF\textsubscript{1}102, BCF\textsubscript{1}118 and BCF\textsubscript{1}149 were superior to T302 except the growth of BCF\textsubscript{1}61 was slightly less. The relationships between twig structure and tree height were concluded by path analysis, it indicated that twig number was a determinative factor to the growth of height” (Yin Y et al. 2003). Yin X et al. (2002) analyzed the isohyets of peroxides (POD) and super oxide disputes (SOD) in leaves of MC, T302 and four strains of their hybrids. The result indicated that “SOD expressed only in May and POD isohyets had a certain difference among of six samples in May and July, but notable differences existed in September and POD isohyets were a suitable enzyme system to distinguish the various hybrids.”

Li H (2006) completed a genetic analysis of 18 *Taxodium* genotypes and found considerable diversity using RAPD (Random Amplified Polymorphic DNA). According to the cluster analysis, the results indicated that “the genetic relationship between *Taxodium distichum* Rich. and *T. ascendens* Brongn. is nearer; the genetic relationship of first crossed generation (F\textsubscript{1}) *Taxodium ‘zhongshansha 302’* [*Taxodium distichum* (Linn.) Rich. X *T. mucronatum* Tenore] is closer to the female parent *Taxodium distichum* (Linn.) Rich.. When the threshold is 5.0, the first backcrossed generations (BCF\textsubscript{1}) belong to 3 groups: BCF\textsubscript{1}149 is the first group; BCF\textsubscript{1}102 is the second group; BCF\textsubscript{1} 1, 27,118,140, 86,136 formed the third group, the clustering results were in consistence with that of the analysis of morphology. BCF\textsubscript{1}149 might be used as the type of fast-
growing ornamental forest. BCF₁₁₁₈ and BCF₁₀² might be used as the type of fast-growing timber forest”.

T3₀₂ has been in the USA since January 2002 and is currently under evaluation in over 30 locations in southern USA. The clone was named ‘Nanjing Beauty’ in 2004 as a cooperative introduction of the SFA Mast Arboretum and Nanjing Botanical Garden. In March 2005, the SFA Mast Arboretum received two new clones from Professor Yin Yunlong’s program at the Nanjing Botanical Garden; T₁₄₀ and T₂₇ are considered more evergreen than T₃₀₂ and both demonstrate strong salt tolerance. The clones were selected from a field population of T₃₀₂ X MC – with strong MC characteristics and improvements in growth rate, salt tolerance, form and vigor. T₁₄₀ grows faster than T₂₇, which produces a wider profile. Nanjing scientists believe they have selected another clone, T₁, that may be superior to both T₁₄₀ and T₂₇, but more genotype X environment studies are needed. The foundation of the most recent selections comes originally from crosses made by Professor Chen and Liu in 1992 at the Nanjing Botanical Garden. Pollen from MC was applied to a female T₃₀₂ and fifteen selections were made in 1995. The main characteristics for selection were 1) fast growth rate, 2) dark green color during the growing season and a red-orange leaf color in the autumn, and 3) evergreen leaves. In 2006 or 2007, the results from T₁₄₀ and T₂₇ will be reported and registered with the Chinese Forestry Department. It will be at least five years before T₁₄₀ and T₂₇ enter commerce. In June, 2005 there were less than 100 each of these two clones.
T118, T120 and T149 have already been registered with the Chinese Forestry Department at the provincial level, while T302 has been registered at the national level.

An interesting intergeneric hybrid $X$ *Taxodiomeria peizhongii* Z.J.Ye, J.J.Zhang et S.H. Pan (a cross between MC and *Cryptomeria fortunei* Hooibrenk ex Otto et Dietr.) was reported to have been created in Nanjing, China in 1963. The hybrids are semi-evergreen, grow fast, hold up to strong winds, have no butswells and buttresses. The trunk is usually divided at a height of 5-8 m into two or more primary branches. They thrive in wetlands and saline sea-shores with a soil pH ranging from 6.5 to 8.6. The trees can grow in saline soil with 4 ppt (68 moles·m$^{-3}$) salt. They are useful for landscape planting as well as for large-scale windbreaks in reverie and coastal regions (Zhang J et al. 2003).

Chen Y et al. (2002) conducted RAPD analyses on genetic polymorphisms of twelve fir genotypes to identify their relationships. These genotypes included eight suspected hybrid MC forest samples, the hybrid female parent—MC, and the same class of hybrid male parent—*Cryptomeria fortunei* Hooibrenk and sugi *C. Japonica* (L.f.) D.Don. The results revealed that “the genetic relationship of sample No.11 in three *Cryptomeria* genotypes is the closest to the original male-parent; samples No.1, 4 and 9 are most possibly the true hybrid MC populations; sample No.5 may be the false hybrid.”

Recently, the authenticity of the new intergeneric hybrid ($X$ *Taxodiomeria peizhongii* Z. J. Ye, J. J. Zhang et S. H. Pan) has been questioned by Chinese
scientists at the Shanghai Botanical Garden. To confirm the authenticity of the intergeneric hybrid, scientists analyzed the rbcL gene and the internal transcribed spacer (ITS) of 26S–18S ribosomal RNA gene of the three species using polymerase chain reaction-restriction fragment length polymorphism (PCR-RFLP) and arbitrarily primed PCR (AP-PCR), and obtained the following results: “(1) *Taxodiomeria peizhongii* had the same RFLP maps of the rbcL gene and the ITS as MC, but was different from *C. fortunei*; (2) a 311-bp PCR amplification product was obtained in *C. fortunei* by AP-PCR of ITS, but was not found in *Taxodiomeria peizhongii*. Their results have demonstrated that *C. fortunei* did not provide any genome for *Taxodiomeria peizhongii*, implying that *T. peizhongii* is not an intergeneric hybrid between the two species” (Ling Y et al. 2006).

**Salt Tolerance**

Many coastal wetlands of the southeastern United States are threatened by increases in flooding and salinity as a result of both natural processes and man-induced hydrologic alterations (Allen 1992; Conner and Toliver 1990; Craig et al. 1979; Templet and Meyer-Arendt 1988; Wicker et al. 1981). If predicted climate changes occur, the consequent rise in sea level will cause flooding and salt water intrusion in many coastal areas (Daniels 1992; Kerr 1991; Smith and Tirpak 1989; Titus 1988; Wigley and Raper 1993). Salt-tolerant trees can withstand concentrations up to 40,000 parts per million (ppm) of salt water. Wahome et al. (2001) define salt tolerance as “the ability of a plant to maintain growth and metabolism under saline conditions”.
Salt can damage trees in two ways. Salt in the soil can adversely affect soil structure and damage a tree’s roots, causing the crown to thin; however, aerial deposition of salt on the above-ground parts of a plant causes the most damage and ocean spray is the primary culprit. The average concentration of the ocean water is as high as 34.9 parts per thousand (ppt). During extreme conditions, such as hurricanes, salt spray can affect plants as far as 50 miles inland, although most damage occurs within 1,000 feet of the shore. Salt damage may take various forms: delayed bud break, reduced leaf size, desiccated leaf margins and tips, premature fall coloration and leaf fall, bud and stem dieback, and reduced shoot growth. Salt produces these symptoms by altering osmotic pressure and, where soil is salty, upsetting the mineral nutritional balance. Damage to trees can be minimized by avoiding the use of salt around landscape plants, but, obviously, the salt content of ocean spray or storm-caused inundations can not be changed. It is therefore essential that species selected for landscape planting in areas exposed to ocean spray be able to survive and remain attractive in such environments.

Pezeshki et al. (1995) found salt tolerance differences among populations of BC. In that study, populations from freshwater provenances had greater height growth, net shoot biomass, and net root biomass, when compared to brackish populations. They identified a need for further investigation to explore population variations in performance to identify plants tolerant of environmental stresses. In another study, the salt tolerance of BC from different provenances was varied
and individuals exhibited good pollution tolerance (Wang G and Cao F 2002). In another study, compared to *Nyssa aquatica*, BC seedlings were able to grow unaffected by fly ash concentrations up to 10% in sand, concluding that BC was highly recommended for wetlands containing fly ash (McLeod et al. 1997). In Louisiana, Krauss et al. (1996, 1998, and 1999) studied intraspecific variation of salinity tolerance in BC and found genotypes with significantly improved tolerances.

Wang G and Cao F reported the effects of salt stress on growth and uptake of nutrients of BC under varying soil water content. The results indicated that “there were significant effects of soil water contents (W1, flooding; W2, 75% of field water capacity; W3, 25% of field water capacity) and soil salt (NaCl) contents (0, 0.15%, 0.3% and 0.45% of dry weight of soil) on growth and uptake of nutrients of BC. The relative height growth, relative ground diameter growth, and biomass increment decreased with increase of soil salt content and decrease of soil water content. The total N, P and Na content in root, stem and leaf and the total Ca and Fe content in leaf increased with increase of soil salt content under the soil condition of flooding, while the total Fe, Ca and Mg content in stem and root had little significant difference. The total N, Na, Ca and Fe content in root, stem and leaf and the total P, K and Mg content in stem and leaf increased differently with increase of soil salt content under the soil condition of W2 (75% of field water capacity), while the total P, K and Mg content in stem decreased under higher soil salt content. The total N, P and K content in leaf,
the total Ca and Mg content in stem and leaf and the total Na content in root, stem and leaf increased differently with increase of soil salt content under the soil condition of W3 (25% of field water capacity), while the total N, P and K content in stem and root and the total Fe content in root, stem and leaf decreased with increase of soil salt content” (Wang G and Cao F 2004 a and b).

Wang G and Cao F reported the effects of soil water and salt content on photosynthetic characteristics. The results indicated that “the net photosynthetic rate, stomatal conductance, chlorophyll a concentration, chlorophyll b concentration, and chlorophyll content decreased with increasing of soil salt (NaCl) contents (0, 0.15%, 0.3% and 0.45% of dry weight of soil) at varying soil water contents (W1: flooding; W2: water logging; W3: 75% of field water capacity; W4: 50% of field water capacity; W5: 25% of field water capacity), but transpiration rate and respiration rate had different changing tendency; The net photosynthetic rate decreased with decreasing of soil water content at varying soil salt contents, and the water treatment of W3 among five soil water levels had a highest intercellular CO$_2$ concentration, chlorophyll a concentration and chlorophyll content, but stomatal conductance, transpiration rate, respiration rate, chlorophyll b concentration and chlorophyll a/b had different changing tendency” (Wang G and Cao F 2004 c).

While not directly a salt-tolerance study, Wang G and Cao F reported the effects of soil water contents on nutrient uptake, including Na, and allocation nutrients in the leaves, stems, and roots of BC. The results are as follows:
“(1) The total N concentration of root, stem and leaf of BC increased with increasing of soil water contents, and the total P concentration of root, stem and leaf of W3 among five water treatments (W1, flooding; W2, water logging; W3, 75% of field water capacity; W4, 50% of field water capacity; W5, 25% of field water capacity) was the lowest, flooding or drought stress increased the total P concentration, and the total Ca, K, Na, Mg, and Fe concentration in root, stem and leaf had different changing tendency; (2) The order of total N, P, Ca, K, Na, Mg, and Fe concentration in root, stem and leaf was in the order of leaf>root>stem; (3) The total accumulation of nutrients in BC decreased with decreasing of soil water contents, and the allocation ratio of root and stem increased with decreasing of soil water contents, while the allocation ratio of leaf decreased significantly with decreasing of soil water contents” (Wang G and Cao F. 2004 d).

Wang G, Cao F and Wang Q reported the effects of soil salt contents on uptake of nutrients of BC. The results are as follows: “(1) The total N, Ca, Na, and Fe concentration of root, stem and leaf increased with increasing of soil salt content (0, 0.15%, 0.3% and 0.45% of dry weight of soil), and total P, K, and Mg concentration of root decreased with increasing of soil salt content, and total P, K, and Mg concentration of stem and leaf increased with increasing soil salt content; (2) Ca/Na of root increased with increasing soil salt content, and Ca/Na of stem and leaf, K/Na, Mg/Na and Fe/Na of root, stem, and leaf decreased with increasing of soil salt content; (3) The order of total N and P concentration of
root, stem, and leaf was leaf > root > stem, and total Ca concentration was leaf > stem > root, and total Fe concentration was root > leaf > stem, and the order of total K, Na, and Mg concentration of root, stem and leaf was different with varying soil salt contents” (Wang G, Cao F and Wang Q. 2004).

Krauss et al. (2000) reported the effect of salinity treatment on growth and nutrition of BC. The results indicated that the survival, height, diameter, and leaf biomass differed significantly among salinity treatments in the field sites. Leaf Na, and Cl increased with the increase of site salinity; the mean K/Na ratios decreased as the salinity levels increased. In another study, BC seedlings were subjected to flooding with salinity levels ranging from 0 - 8.3 ppt (0-140 moles · m⁻³) NaCl. The effect of salt water on leaf tissue ion concentrations and subsequent changes in net photosynthesis were measured. The result indicated leaf concentrations of Na, K, Ca, and Mg increased as salinity of floodwater increased. The net photosynthesis decreased as the salinity increased (Pezeshki et al. 1988).

**Propagation**

It is a common propagation experience that mature BC seeds freshly harvested from dried cones in the late fall or early winter will germinate at high percentages, with most seeds emerging in 21 – 28 days depending on temperature. Some propagators recommend a brief soak in rubbing alcohol...
followed by a water rinse which removes the oily resin on the surface of the seed, and this can improve germination.

In the USA, the vast majority of BC trees used in the landscape trade are from seed and the variation is often quite distinct when the tree reaches five to ten years of age. Variation includes tree size, tree form, foliage color, branching, density of branching, and other visual characteristics. Superior varieties are generally grafted and thus more costly to produce. Cutting propagation offers a robust method to quickly multiply a clone to significant nursery numbers but rooting percentages are often low and the species is considered “difficult to root”.

Yunlong reports that T302, selected in 1988, is no longer easy to root, a condition attributed to chronological and physiological age factors. To counter lower rooting percentages, a strict protocol for achieving success has been developed. Chinese nurserymen encourage one year old clones to produce vigorous cutting wood in the second year. T302 plants are field planted at close spacing. The plants are grown one year and then cut back in the winter to 1’ – 3’ (0.31 – 0.91 m) tall. This severe pruning results in vigorous upright shoots that provide cuttings that root in good percentages, and produce upright growing plants of better form than trees produced from side branches (plagiotropic growth). Cuttings are rooted under part shade using intermittent mist and a well drained mix in rooting beds. While rooting hormones are utilized, cutting wood quality and maintaining good turgor are recognized as critical for high rooting percentages. One upright shoot is left on the stock tree to grow for the rest of the
season which produces a tree that can then be dug for sale as a straight 6 – 8’ (1.86 - 2.48 m) tree at the end of the second year.

In a Chinese article, the selection of *Taxodium ‘zhongshansha’* cutting substrate, cutting of wood and maintenance of three main ecological factors (temperature, moisture and illumination after cutting cultivation), and their effects on taking root were provided. The result indicated that T302 had higher rooting percentage (52.4%) using sandy loam as the cutting medium in a plastic shed than using sandy alkaline soil (pH 8) as cutting medium or using a 75% yellow soil / 25% sand substrate (Lu X et al. 2004). In another Chinese study, the 1-2 – year – old branches of T302 with higher resistance and superior characters were used as experimental materials, plant ash + soil as cutting medium, and 1.5 mg/L NAA X IAA as the rhizogenic accelerant, the rooting percentage was about eighty-seven percent (Dong B 2005). Huang L et al.(2000) found that significant variation existed among the provenances and families in Genus *Taxodium* in six rooting characteristics (survival rate, rooting rate, sum of adventitious roots, total length of adventitious roots, rooting perform indexes, and length of terminal shoots).
MATERIALS AND METHODS

Salt Tolerance Study

Plant materials

Three genotypes (BC, MC, and T302) were used in this study. 96 plants per genotype were planted in 2-gallon plastic nursery pots containing Woods #2 substrate. Substrate analysis is shown in Table 1. It must be noted that plants appeared to adapt poorly at first to this substrate. Slight chlorosis was present but cleared up a month into the study. The containers were placed on the nursery pad in the sun container yard at the Pineywoods Native Plant Center (PNPC), SFASU, Nacogdoches, Texas.

Table 1. Potting substrate analysis, based on saturated extract with deionized water.

<table>
<thead>
<tr>
<th>pH</th>
<th>Mg (ppm)</th>
<th>Na (ppm)</th>
<th>E.C. (dSm⁻¹)</th>
<th>Fe (ppm)</th>
<th>Na Adsorption Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.01</td>
<td>47.60</td>
<td>110.99</td>
<td>2.10</td>
<td>1.03</td>
<td>1.92</td>
</tr>
<tr>
<td>1.00</td>
<td></td>
<td></td>
<td>10.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.07</td>
<td></td>
<td></td>
<td>1.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The experimental design

The experiment followed a two-way factorial design with three Taxodium genotypes and four levels of sea salt concentrations. A completely randomized block design was utilized. Three genotypes with 6 plants per genotype were
randomly assigned to each treatment for a total of 24 plants per genotype in one block, with four replications, for a total of 288 plants in this study.

**Experimental procedures**

The treatments included a control with no sea salt, a low sea salt concentration - 1ppt (17 moles⋅m$^{-3}$), a medium sea salt concentration - 3.5ppt (60 moles⋅m$^{-3}$) and a high sea salt concentration - 6ppt (102 moles⋅m$^{-3}$). The chemical composition of the sea salt is shown in Table 2.

<table>
<thead>
<tr>
<th>Components</th>
<th>Typical Range (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium Chloride</td>
<td>99.50 - 99.88</td>
</tr>
<tr>
<td>Water</td>
<td>0.87 - 2.50</td>
</tr>
<tr>
<td>Calcium</td>
<td>0.02 - 0.06</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.01 - 0.05</td>
</tr>
<tr>
<td>Sulfate</td>
<td>0.05 - 0.21</td>
</tr>
</tbody>
</table>

Salt treatments application was initiated on May 22, 2006. 500 ml sea salt solution was applied to the substrate of each container every Monday afternoon, once per week (10-20% leach) for 13 weeks. After 13 weeks of salt application weekly, no salt damage symptoms were noticed in the appearance of the trees. For this reason, the salt concentration rates were doubled on August 19th. The salt rates were increased to 0, 2, 7, 12ppt (0, 34, 120, and 204 moles⋅m$^{-3}$). These new salt solutions were applied starting August 21, 2006. The same application procedure was followed every Monday afternoon, once per week, for another 12 weeks.
Salt solutions remained in containers for at least 24 hours after each salt application before irrigations with Nacogdoches city water. The plants were watered as needed with normal overhead sprinkler irrigations until the next week’s salt application. Plants were fertilized with ten mls of 18-6-12 osmocote as conductivities indicated. Three times during the course of the experiment, leachate was collected via the pour-through technique to monitor the changes of electrical conductivity.

**Tissue analysis**

Leaf samples were collected for tissue analysis on October 27, 2006. Six leaves were taken from each plant for a total of thirty-six leaves per genotype per treatment in each block. The plant samples were dried in a convention oven for 3 days at 60°C. The dried plant samples were then ground in a cyclone grinder and analyzed for plant nutrient concentration. A nitric acid (HNO₃) and 30% hydrogen peroxide wet acid digestion was used to prepare the samples for P, K, Na, Ca, and Mg analysis using Inductively Coupled Argon Plasma Spectroscopy.

**Heights and Wet weights**

Plant height was measured at the beginning and conclusion of the experiment. At the conclusion of the salt study, each plant was cut back to five cm above ground and the above-ground parts were placed in a paper bag to be weighed (wet weights).
Data analysis

The General Linear Models (GLM) procedures of SAS (Statistical Analysis System) were used to detect significant differences among the variable means for different genotypes and different treatments. A Tukey’s studentized ranged test ($\alpha = 0.05$) used to identify genotype groups and treatment groups.

Propagation Study

Starting from the summer of 2006, four different experiments were undertaken to test factors influencing rooting success of T302 cuttings. Across the four experiments, a total of 1728 cuttings were used. The cuttings were collected, trimmed and then subjected to different treatments. The treatments include wounding, hormone—K-IBA, CYT-1, and RegalCrown® (RC) treatments. The potassium salt of indole-3-butyric acid (K-IBA) is a root promoting substance. CYT-1 is a rooting hormone solution supplied by colleagues at the Nanjing Botanical Garden, Nanjing, China. RC is a plant growth stimulator for superior root and plant development. RC contains hormones (auxins, gibberellins, and cytokinins) and other undisclosed ingredients. It is reported to improve nutrient and water uptake, increase plant growth, enhance rooting, and improve plant quality and vigor.

The cuttings were placed into 24-cavity flats with a 50% perlite/50% promix substrate. Perlite is a mineral, which when expanded by a heating process, forms light granules. Perlite is used as a substrate amendment to improve
aeration and drainage. Promix is a planting substrate which contains peat moss, pine bark, endomycorrhizal inoculum, limestone, and wetting agent. All the flats were placed on a mist bench in the greenhouse for about twelve weeks. An intermittent mist spray was operated for a period of 8 seconds in a 16-minute cycle during the daytime. The average temperature of the rooting media was 24°C.

Experiment One

The first experiment was initiated July 6, 2006 and ended Oct.18, 2006. 720 Taxodium ‘Nanjing Beauty’ cuttings were divided into three uniform groups of 240 cuttings each. 48 cuttings per group were dipped into each hormone treatment for five seconds. The treatments included 0, 2500, 5000, 10000 ppm K-IBA and 5% CYT-1. Two flats per treatment were utilized for a total of 10 flats per group. One flat of cuttings per hormone treatment in each group was sprayed with the RC solution.

The experiment was carried out in a completely randomized block design with 3 repetitions of 24 cuttings per replication, a factorial 5 X 2 design, hormone treatment factor having 5 levels (0, 2500, 5000 and 10000 ppm K-IBA and 5% CYT-1) and RC treatment factor having 2 levels (RC spray, no RC spray).

Experiment Two

The second experiment was started on August 3, 2006 and ended on November 9, 2006. 288 Taxodium ‘Nanjing Beauty’ cuttings were divided into three groups of 96 cuttings each. 48 cutting bases per group were incision
wounded along the axis at length of about 1 cm. The other cuttings per group were not subjected to this procedure. All cuttings were dipped into 5000 ppm K-IBA for five seconds. There were two flats of wounded cuttings and two flats of non-wounded cuttings in each group. One flat of wounded cuttings and one flat of unwounded cuttings in each group were sprayed with RC solution.

The experiment was carried out in a completely randomized block design with 3 repetitions of 24 cuttings per replication, in a factorial 2 X 2 design, wounding treatment factor having 2 levels (wound, no wound) and RC treatment factor having 2 levels (with RC spray, without RC spray).

Experiment Three

The third experiment was started on October 12, 2006 and ended on January 8, 2007. 360 *Taxodium* ‘Nanjing Beauty’ cuttings were divided into three uniform groups of 120 cuttings each. The experiment consisted of RC treatment and hormone treatment. The RC rates include 0, 0.25, 0.5, 1, and 2 ounces per gallon. 24 cuttings were given a 20-second soak in each rate of RC solution prior to 5000 ppm K-IBA dip or no hormone dip. 12 cuttings treated with each rate of RC solution were dipped into 5000 ppm K-IBA for five seconds.

A 2-way factorial experimental design with three randomized blocks involving 10 variables was employed. (RC treatment [0, 0.25, 0.5, 1, and 2 oz/gallon]; hormone treatment [hormone, no hormone], i.e. 5 X 2 = 10). Three replicates of 12 cuttings were randomly assigned to each treatment.
Experiment Four

The fourth experiment was started on November 12, 2006 and ended on February 6, 2007. 360 cuttings were divided into 2 uniform groups. In one of them the cutting bases were incision wounded along its axis at the length of about 1 cm. The other cuttings were not wounded. The cuttings were dipped for 20 seconds into RC solution, at concentrations of 0, 0.25, 0.5, 1, and 2 ounce per gallon and then were dipped into 10000 ppm K-IBA for 5 seconds.

A 2-way factorial experimental design with three randomized blocks involving 10 variables was employed. (Five rates of RC treatments [0, 0.25, 0.5, 1, and 2 oz/gallon]; wound treatment [wound, no wound], i.e. 5 X 2 = 10). Three replicates of 12 cuttings were randomly assigned to each treatment.

Data recording

At the conclusion of each experiment, the cuttings were gently removed from the substrate. The rooting percentage and root density ranking (RDR) (0 to 5 scale; none to heavy) were determined. The GLM procedures of SAS was used to detect significant differences among the variable means of rooting percentages and RDR in the study.

Genotype Growth and Performance

Thirteen genotypes acquired from Florida, three genotypes from Louisiana, and T302 from SFA were planted in 2-gallon plastic nursery pots on January 20th, 2006 (Table 3). Six plants per genotype were placed on the nursery pad in the
sun container yard at PNPC for 10 months. Heights at the base of each plant were measured at the beginning and end of the study to evaluate plant growth rate. A randomized block design was utilized with two plants per genotype per block for a total of thirty-four plants per block and one hundred and two plants (three blocks) in this study. These *Taxodium* genotypes were planted along La Nana creek at SFASU in December 2006. The GLM of SAS was used to detect significant differences of plant height increase among genotypes.

Table 3. Genotypes from Florida and Louisiana.

<table>
<thead>
<tr>
<th>Acc</th>
<th>Prog</th>
<th>Variety</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>61</td>
<td>E3</td>
<td>Bald</td>
<td>FL clone</td>
</tr>
<tr>
<td>108</td>
<td>P3</td>
<td>Pond</td>
<td>Blountstown, FL, tree</td>
</tr>
<tr>
<td>132</td>
<td>P8</td>
<td>Pond</td>
<td>Mayo, FL, tree</td>
</tr>
<tr>
<td>154</td>
<td>P10</td>
<td>Pond</td>
<td>Deland, FL, tree</td>
</tr>
<tr>
<td>172</td>
<td>B8</td>
<td>Bald</td>
<td>W FL Bulk</td>
</tr>
<tr>
<td>190</td>
<td>B8</td>
<td>Bald</td>
<td>E FL Bulk</td>
</tr>
<tr>
<td>263</td>
<td>P4</td>
<td>Pond</td>
<td>Desmore, FL, tree</td>
</tr>
<tr>
<td>327</td>
<td>P11</td>
<td>Pond</td>
<td>Deland, FL, tree</td>
</tr>
<tr>
<td>339</td>
<td>P15</td>
<td>Pond</td>
<td>Mayo, FL, tree</td>
</tr>
<tr>
<td>342</td>
<td>B15</td>
<td>Bald</td>
<td>FL Tree</td>
</tr>
<tr>
<td>AK</td>
<td>Bald</td>
<td>AK Bulk</td>
<td></td>
</tr>
<tr>
<td>BC</td>
<td>Bald</td>
<td>W FL Bulk</td>
<td></td>
</tr>
<tr>
<td>PC</td>
<td>Pond</td>
<td>W FL Bulk</td>
<td></td>
</tr>
<tr>
<td>SC</td>
<td>Bald</td>
<td>Waccamaw River, Georgetown</td>
<td>Dr. Krauss^w</td>
</tr>
<tr>
<td>GA</td>
<td>Bald</td>
<td>Lower Savannah River, Port Wentworth</td>
<td>Dr. Krauss</td>
</tr>
<tr>
<td>LA</td>
<td>Bald</td>
<td>Mash, cypress transition near Houma</td>
<td>Dr. Krauss</td>
</tr>
</tbody>
</table>

^Accessions 61, 108, 132, 154, 172, 190, 263, 327, 339, and 342 were in a seed orchard. For example, 108, one of approximately 480 trees in Dr. Rockwood's cypress seed orchard, was a seedling derived from seed collected from P3, a naturally occurring tree near Blountstown, Florida. SC and GA collections were from strongly tidal sites, while LA collections were from remnant microtidal sites that are now impounded from tidal activity.

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^Ken W. Krauss, Ph.D. Research Ecologist, U.S. Geological Survey, National Wetlands Research Center, 700 Cajundome Blvd, Lafayette, LA 70506 office: 337-266-8882; 337-266-8592 fax; Email: kkrauss@usgs.gov; http://www.nwrc.usgs.gov/
In another project, 988 small seedlings of MC (New Mexico provenance) were planted in SFA Mast Arboretum plots in early April 2006 and grown under drip irrigation. Twenty selections were made in February 2007 based on the presence of a strong central leader, branching, and good foliage color. The remaining trees were sold to TreesUSA, Lindale, Texas where they will be grown in 30 and 45 gallon containers. SFA will have right of first selection of this material.
RESULTS AND DISCUSSION

Salt Tolerance Study

Electrical conductivity

From electrical conductivity readings (Figure 2, 3), we concluded that from the second day on after each weekly salt application, the sea salt solution was rapidly leached from the container. When salt rates were doubled, essentially the electrical conductivities were doubled. During the twenty-four hour exposure periods, roots were subjected to conductivities approaching 20 decisiemens/m with the 12 ppt application rate.

![E.C. at various salt concentrations](image)

Figure 2. An example of conductivity readings taken during the early portion of the experiment.
Growth

1. The wet weights of *Taxodium* were not significantly different at various sea salt levels (Table 4), but were different by genotype (Table 4, Figure 4). The mean wet weight of T302 was significantly higher than that of BC and MC (Figure 4). Zhou K et al. (2000) reported the height and volume growth of T302 was 147% and 331% of BC, respectively, based on stem analysis of T302 and BC grown on alkaline low-land areas. Analysis of variance showed no interactive effects between the salinity treatments and the genotypes.

### Table 4. General linear model analysis of variance for mean wet weight of *Taxodium*.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity</td>
<td>3</td>
<td>14867.26</td>
<td>4955.75</td>
<td>2.65</td>
<td>0.1122</td>
</tr>
<tr>
<td>Genotype</td>
<td>2</td>
<td>464224.56</td>
<td>232112.28</td>
<td>32.72</td>
<td>0.0006</td>
</tr>
<tr>
<td>Salinity X Genotype</td>
<td>6</td>
<td>21670.38</td>
<td>3611.73</td>
<td>1.04</td>
<td>0.4339</td>
</tr>
</tbody>
</table>
Figure 4. Wet weights (± standard deviation) of three *Taxodium* genotypes exposed to four salt rates. Bars labeled with the same letter are not significantly different at the 0.05 level of probability according to Tukey’s studentized range test.

2. Significant difference in height change among genotypes was found in the salt study (Table 5, Figure 5). MC demonstrated the greatest height increase, followed by T302 and the least height increase was found with BC (Figure 5). There was no significant difference at various salt rates (Table 5). Analysis of variance showed no interactive effects between salinity treatments and genotypes.

Table 5. General linear model analysis of variance for mean height growth of *Taxodium.*

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity</td>
<td>3</td>
<td>69.15</td>
<td>23.05</td>
<td>0.69</td>
<td>0.5829</td>
</tr>
<tr>
<td>Genotype</td>
<td>2</td>
<td>9611.94</td>
<td>4805.97</td>
<td>51.68</td>
<td>0.0002</td>
</tr>
<tr>
<td>Salinity X Genotype</td>
<td>6</td>
<td>281.12</td>
<td>46.85</td>
<td>0.97</td>
<td>0.47</td>
</tr>
</tbody>
</table>
T302 had the highest wet weight, while MC had the most height increase. A likely explanation for this result lies in different growth habits. The cutting-grown hybrid exhibited plagiotropic growth and more branching, while MC quickly formed a strong central leader with less branching.

**Leaf tissue content**

There were significant differences of leaf tissue elemental concentrations among genotypes (Table 6). Of the three genotypes, BC had the highest content of Ca, Na, S, and Fe, while MC had the lowest values, and T302 was in between. Leaf K, Ca, Na, S, and Fe in BC and T302 were significantly higher than MC. Leaf P, Zn, and Mn in T302 and MC were significantly higher than BC. T302 had the highest content of P, Mg, Zn, and Cu.

Table 6. Leaf tissue elemental concentrations of three genotypes of *Taxodium* in salt study.
Significant differences of leaf elemental contents among treatments were found in this study (Table 7). Significant differences of K, S, and Na in *Taxodium* leaf tissue were found at various salt rates (Table 7). Leaf K at 2 ppt salt concentration were significantly lower than 7 and 12 ppt salt concentration. Of four salinity treatments, leaf S concentration in *Taxodium* at 2 ppt was significantly higher than 12 ppt. Concentrations of Na in *Taxodium* leaves were significantly different across the salt treatments. Leaf Na concentration at 2, 7, and 12 ppt was 146%, 200%, 269% of controls. There was no significant difference in leaf P, Ca, and Mg content among the salinity treatments.

Table 7. Leaf tissue elemental concentrations of *Taxodium* at four salt rates.

<table>
<thead>
<tr>
<th>Rate</th>
<th>P(%)</th>
<th>K(%)</th>
<th>Ca(%)</th>
<th>Mg(%)</th>
<th>S(%)</th>
<th>Fe (ppm)</th>
<th>Mn (ppm)</th>
<th>Zn (ppm)</th>
<th>Cu (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.26a</td>
<td>1.22ab</td>
<td>0.97a</td>
<td>0.15a</td>
<td>0.18ab</td>
<td>0.13c</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 ppt</td>
<td>0.25a</td>
<td>1.09b</td>
<td>1.04a</td>
<td>0.15a</td>
<td>0.19a</td>
<td>0.19bc</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 ppt</td>
<td>0.25a</td>
<td>1.23a</td>
<td>1.04a</td>
<td>0.15a</td>
<td>0.18ab</td>
<td>0.26ab</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 ppt</td>
<td>0.25a</td>
<td>1.25a</td>
<td>0.93a</td>
<td>0.14a</td>
<td>0.17b</td>
<td>0.35a</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Means within a column followed by the same letter are not significantly different at the 0.05 level of probability according to Tukey’s studentized range test.
From the graph, we can conclude, concentrations of Na in *Taxodium* leaves increased as sea salt concentration increased (Figure 6). For example, Na concentrations in T302 leaves increased from 0.1% in control to 0.37% at 12ppt sea salt concentration. The high salt rate created leaf Na concentrations in BC up to 5,500 ppm.

The ratio of K to Na in *Taxodium* leaves was significantly different among the salt treatments (Figure 7). The ratio decreased as salt concentration increased. The ratio decreased from 11.4 in leaf tissue of plants in control to 4.54 in leaf tissue of plants at the highest salt rate of solution.
In the present study, the salt rate did not significantly affect the growth of *Taxodium*. Pezeshki (1990) found no significant effect on height growth, net photosynthesis or stomatal conductance when BC seedings were watered with a 3 ppt saltwater solution for 60 days.

In this study, salt treatment had a significant effect on leaf Na, K, and S content and K/Na value, but no significant effect on other leaf tissue contents. Leaf Na concentration increased with increasing of salt rates as *Taxodium* became less adept at excluding Na. K/Na decreased as the salt rates increased. Other studies have shown the effect of salinity on the leaf tissue contents. For instance, Pezeshki et al. (1988) reported there was a significant increase in Na, K, Ca, and Mg concentration of leaf tissue of BC subjected to saltwater flooding.
as compared to flood-stress plants. Clough (1984) reported in salt-resistant plants such as mangrove, salinity treatments had little effect on the concentration of K, Ca, and Mg in leaves. Wang G et al. (2004 a) reported the N, Ca, Na, P, Mg, and Fe content in leaf tissue increased with the increase of soil salt content; the K/Na ratio decreased with increasing of soil salt content. Krauss et al. (2000) reported leaf Na, and Cl increased with the increase of site salinity; the mean K/Na ratio decreased as the salinity levels increased in the field site experiment.

**Propagation Study**

**Experiment One**

Hormone treatment had significant effects on rooting percentage and RDR (root density ranking) of T302 (Table 8). Hormone treatment significantly increased rooting percentage and RDR. The rooting percentage and RDR increased as the concentration of K-IBA increased. The rooting percentages of cuttings treated with 10000 and 5000 ppm K-IBA were significantly higher than control and 2500 ppm K-IBA. Treatment with 10000 ppm K-IBA caused 68% of the cuttings to root, compared with 16% rooting of the non-treated control cuttings. No significant differences were seen between 10000 and 5000 ppm K-IBA. RC treatment had no significant effect on rooting percentage and RDR (Table 8).
Table 8. Effect of hormone and RegalCrown® (RC) on the rooting percentage and root density ranking (RDR) of T302 cuttings (collected on July 6 and analyzed on October 18, 2006).

<table>
<thead>
<tr>
<th>Hormone</th>
<th>Without RC</th>
<th></th>
<th>With RC</th>
<th></th>
<th>Mean</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>rooting %</td>
<td>RDR</td>
<td>rooting %</td>
<td>RDR</td>
<td>rooting %</td>
<td>RDR</td>
</tr>
<tr>
<td>0</td>
<td>11.1b z</td>
<td>0.3b z</td>
<td>22.2b z</td>
<td>0.8b z</td>
<td>16.6c z</td>
<td>0.6c z</td>
</tr>
<tr>
<td>2500ppm K-IBA</td>
<td>22.2ab</td>
<td>0.7ab</td>
<td>22.2b</td>
<td>0.5b</td>
<td>22.2c</td>
<td>0.7c</td>
</tr>
<tr>
<td>5% CYT-1</td>
<td>38.8ab</td>
<td>1.1ab</td>
<td>34.7b</td>
<td>1.0b</td>
<td>36.8bc</td>
<td>1.1bc</td>
</tr>
<tr>
<td>5000ppm K-IBA</td>
<td>40.2ab</td>
<td>1.1ab</td>
<td>75.0a</td>
<td>2.2a</td>
<td>57.6ab</td>
<td>1.6ab</td>
</tr>
<tr>
<td>10000ppm K-IBA</td>
<td>59.7a</td>
<td>1.9a</td>
<td>76.4a</td>
<td>2.4a</td>
<td>68.1a</td>
<td>2.2a</td>
</tr>
<tr>
<td>Mean</td>
<td>46.1a y</td>
<td>1.0a y</td>
<td>34.4a y</td>
<td>1.4a y</td>
<td>1.4a y</td>
<td></td>
</tr>
</tbody>
</table>

Means within a column followed by the same letter are not significantly different at the 0.05 level of probability according to Tukey’s studentized range test.

Experiment Two

The RC treatment did not significantly affect the T302 rooting rates and RDR in this experiment (Table 9). Mean value of rooting percentages was 76.4% for control cuttings, while those treated with RC spray was 75.0%. Mean value of RDR was 2.8 for control cuttings, while those treated with RC spray was 2.9. The means of rooting percentages and RDR did not differ statistically. The rooting percentages and RDR of wounded cuttings was higher than that of non-wounded cuttings, but not significantly.
Table 9. Effect of wounding treatment and RC on the rooting percentage and RDR of T302 cuttings (collected on August 3 and analyzed on November 9, 2006).

<table>
<thead>
<tr>
<th>Wounding treatment</th>
<th>Without RC</th>
<th>With RC</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>rooting %</td>
<td>RDR</td>
<td>rooting %</td>
</tr>
<tr>
<td>No wound</td>
<td>69.4a\textsuperscript{z}</td>
<td>2.6a\textsuperscript{z}</td>
<td>63.9a\textsuperscript{z}</td>
</tr>
<tr>
<td>Wound</td>
<td>83.3a</td>
<td>3.2a</td>
<td>86.1a</td>
</tr>
<tr>
<td>Mean</td>
<td>76.4a\textsuperscript{y}</td>
<td>2.8a\textsuperscript{y}</td>
<td>75.0a\textsuperscript{y}</td>
</tr>
</tbody>
</table>

\textsuperscript{z}Means within a column followed by the same letter are not significantly different at the 0.05 level of probability according to Tukey's studentized range test.

\textsuperscript{y}Means within a row followed by the same letter are not significantly different at the 0.05 level of probability according to Tukey's studentized range test.

**Experiment Three**

In this experiment, the rooting percentage and RDR were not significantly different with RC treatment or hormone treatment (Table 10). The treatments did not result in the significant increase of rooting percentage and RDR. But the percentage of rooted cuttings and the RDR were very high. The average root percentage ranged from 77.8% to 94.5% and the average RDR ranged from 2.5 to 3.4. The highest percentage of rooting (94.5%) was obtained for control cuttings. The highest RDR (3.4) was obtained when the cuttings were treated with 5000 K-IBA at the RC rate of 1.9 gram/liter.

The rooting capacity of cuttings may result from the time of year cuttings are taken from the stock plants, the age of the stock plants, and the physiological condition of the stock plants. The cuttings used in this experiment were collected in the fall and that may be a good time for rooting T302, particularly if cuttings come from young, vigorous plants.
Table 10. Effect of hormone and RC on the rooting percentage and RDR of T302 cuttings (collected on October 12, 2006 and analyzed on January 8, 2007).

<table>
<thead>
<tr>
<th>RC rates (gram/liter)</th>
<th>0</th>
<th>5000 ppm K-IBA</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>rooting %</td>
<td>RDR</td>
<td>rooting %</td>
</tr>
<tr>
<td>0</td>
<td>94.5a^z</td>
<td>3.1a^z</td>
<td>86.1a^z</td>
</tr>
<tr>
<td>1.9</td>
<td>80.6a</td>
<td>3.1a</td>
<td>88.9a</td>
</tr>
<tr>
<td>3.7</td>
<td>77.8a</td>
<td>2.5a</td>
<td>94.4a</td>
</tr>
<tr>
<td>7.5</td>
<td>88.9a</td>
<td>3.0a</td>
<td>80.6a</td>
</tr>
<tr>
<td>15.0</td>
<td>94.4a</td>
<td>3.3a</td>
<td>83.3a</td>
</tr>
<tr>
<td>Mean</td>
<td>87.2a^y</td>
<td>3.0a^y</td>
<td>86.7a^y</td>
</tr>
</tbody>
</table>

^zMeans within a column followed by the same letter are not significantly different at the 0.05 level of probability according to Tukey's studentized range test.

^yMeans within a row followed by the same letter are not significantly different at the 0.05 level of probability according to Tukey's studentized range test.

**Experiment Four**

There were no significant differences in T302 rooting percentages or the RDR at five rates of RC solution (Table 10). Wounding significantly affected rooting percentage and RDR of T302 in this experiment. The rooting percentages and RDR of wounded cuttings were significantly higher than non-wounded cuttings. Wounding increased the average percentage of rooted cuttings of T302 from 26.7% to 43.9% and the RDR from 0.7 to 1.3.
Table 11. Effect of wounding treatment and RC on the rooting percentage and RDR of T302 cuttings (collected on November 12, 2006 and analyzed on February 6, 2007).

<table>
<thead>
<tr>
<th>RC rates (gram/liter)</th>
<th>no wound</th>
<th>wound</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>rooting %</td>
<td>RDR</td>
<td>rooting %</td>
</tr>
<tr>
<td>0</td>
<td>25.0a</td>
<td>0.6a</td>
<td>27.8a</td>
</tr>
<tr>
<td>1.9</td>
<td>38.9a</td>
<td>1.2a</td>
<td>61.1a</td>
</tr>
<tr>
<td>3.7</td>
<td>19.4a</td>
<td>0.4a</td>
<td>44.5a</td>
</tr>
<tr>
<td>7.5</td>
<td>25.0a</td>
<td>0.8a</td>
<td>61.1a</td>
</tr>
<tr>
<td>15.0</td>
<td>25.0a</td>
<td>0.6a</td>
<td>25.0a</td>
</tr>
<tr>
<td>Mean</td>
<td>26.7b</td>
<td>0.7b</td>
<td>43.9a</td>
</tr>
</tbody>
</table>

*Means in a column followed by the same letter are not significantly different at 0.05 level according to Tukey’s studentized range test.

These findings suggest that the rooting capacity of T302 is related to hormone treatment and the wounding treatment.

In the present work, high concentration of K-IBA increased the rooting percentage and RDR of the cuttings.

Seasonal variation in rooting capacity is very common in woody plants (Hartmann et al. 1990; Swamy et al. 2002). In the present work, the cuttings collected in fall indicated a greater rooting capacity than those collected in summer.

Wounding the cuttings strongly increased the rooting capacity of T302 (Table 11). The rooting percentage of wounded cuttings was 1.6 times greater than that of non-wounded cuttings. The RDR of wounded cuttings was 1.8 times greater than that of non-wounded cuttings. Wounding may stimulate rooting by promoting cell division and increasing the surface area for water and hormone.
absorption. Wounding may also remove tough tissue that prevents outward root growth from the cutting.

Genotype Growth and Performance

Significant differences of height change among *Taxodium* genotypes were found in this study (Table 12). Of seventeen *Taxodium* genotypes, the height increase of T302 in this first year was the greatest. The height increase of 108 from Florida is the least. The height increase of the hybrid T302 is significantly higher than 339 and 108. A more complete description of the *Taxodium* genotypes evaluated in this project is included in Appendix C.

Table 12. Height growth (± standard deviation) of *Taxodium* genotypes.

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Height Growth (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T302</td>
<td>92.02 ± 17.6</td>
</tr>
<tr>
<td>PC</td>
<td>85.34 ± 16.2</td>
</tr>
<tr>
<td>342</td>
<td>82.12 ± 9.3</td>
</tr>
<tr>
<td>BC</td>
<td>78.64 ± 15.1</td>
</tr>
<tr>
<td>GA</td>
<td>76.86 ± 18.3</td>
</tr>
<tr>
<td>263</td>
<td>74.04 ± 17.5</td>
</tr>
<tr>
<td>LA</td>
<td>73.66 ± 8.3</td>
</tr>
<tr>
<td>61</td>
<td>73.23 ± 14.7</td>
</tr>
<tr>
<td>172</td>
<td>72.82 ± 8.1</td>
</tr>
<tr>
<td>SC</td>
<td>70.82 ± 9.1</td>
</tr>
<tr>
<td>190</td>
<td>69.55 ± 14.4</td>
</tr>
<tr>
<td>154</td>
<td>65.94 ± 20.6</td>
</tr>
<tr>
<td>132</td>
<td>65.56 ± 22.2</td>
</tr>
<tr>
<td>AK</td>
<td>65.35 ± 16.1</td>
</tr>
<tr>
<td>327</td>
<td>61.06 ± 23.6</td>
</tr>
<tr>
<td>339</td>
<td>59.74 ± 19.6</td>
</tr>
<tr>
<td>108</td>
<td>59.06 ± 8.0</td>
</tr>
</tbody>
</table>

Means in the same column followed by the same letter are not significantly different at 0.05 level according to Tukey's studentized range test.
CONCLUSION

In the acute application salt tolerance study, we conclude that *Taxodium* was remarkably salt tolerant. All the plants survived the salinity treatments for the duration of the study. The high salt rate failed to damage plants or inhibit plant growth in this 25-week study. A partial explanation is that salt solutions were leached rapidly with the first irrigation after salt exposure. Exposure of the root system to the salt solutions occurred for only about 15% of this experimental time period, so significant differences of *Taxodium* growth were not found among salt treatments. The concentration of Na in the leaf tissue increased as the sea salt concentration increased. This suggested that salinity caused excess accumulation of Na in leaf tissue. T302 and MC were able to prevent the accumulation of Na in the foliage. BC was not able to. T302 and MC had a faster growth rate than BC. T302 and MC yielded higher wet weights than BC. These suggested T302 and MC had more salt tolerance than BC. MC is less likely to survive extended periods of flooding. Also, T302 exhibited the fastest growth rate of the seventeen genotypes in the first year in the genotype study.

Thus, T302 seems the best option for coastal wetland among the evaluated genotypes. Further evaluation of T302 should be conducted in the future.
T302 can be successfully propagated from cuttings. Based on the findings in the propagation study, it is recommended that cuttings be collected from healthy, vigorous plants, wounded at the base, treated with 10000 ppm K-IBA.
APPENDIX A

**Taxodium** Germplasm collection at Stephen F. Austin State University, Nacogdoches, Texas.

Currently in the SFA Mast Arboretum or Pineywoods Native Plant Center

*Taxodium distichum* (Missouri – Botany' Shop, Michael Shade) 11/08/2004
*Taxodium distichum* (Atchafayala Basin, Loos) 01/09/2003
*Taxodium distichum* (Daniel's Ranch FM 787@Trinity, Loos) 01/09/2003
*Taxodium distichum* (SWTS, Loos) 01/09/2003
*Taxodium distichum* ‘Cajun Snowfall’, Stanley and Son 09/23/2003
*Taxodium distichum* ‘Cave Hill’, Stanley and Sons 09/23/2003
*Taxodium distichum* ‘Fastigiata’, Stanley and Sons 09/23/2003
*Taxodium distichum* ‘Peve Minaret’, Stanley and Sons 09/23/2003
*Taxodium distichum* ‘Cajun Snowfall’, Stanley and Sons 12/06/2002
*Taxodium distichum* ‘Cascade Falls’, Stanley and Sons 11/14/2001
*Taxodium distichum* ‘Fastigata’, Stanley and Sons 11/14/2001
*Taxodium distichum* ‘Pendens’, Stanley and Sons 11/14/2001
*Taxodium distichum* ‘Secrest’, Stanley and Sons 11/14/2001
*Taxodium distichum* ‘Prairie Sentinel’, Arbor Village 11/14/2001
*Taxodium distichum* ‘Pendulum’, Stanley and Sons 11/16/2001
*Taxodium distichum* ‘Secrest’, Bill Caldwell 11/12/2001
*Taxodium distichum* ‘Autumn Gold’, PDSI 11/16/2001
*Taxodium distichum* ‘weeping’, Yadkinville Nursery, NC 11/16/2001
*Taxodium distichum* ‘Nutans’, Arbor Village 12/16/2001
*Taxodium distichum* ‘Prairie Sentinel’, Arbor Village 11/16/2001
*Taxodium distichum* ‘Pendulum’, Stanley and Sons 2005
*Taxodium distichum* (D13-04 – Yuccado collection Mexico)
*Taxodium distichum* ‘Sentido’, Paul Cox 03/28/2001
*Taxodium distichum* ‘Sentido’, Treesearch 03/22/2002
*Taxodium distichum* ‘Nanjing Beauty’ – Nanjing Botanical Garden, numerous plants
APPENDIX B

Texas A and M University inventory.

Michael A. Arnold, Professor, Department of Horticultural Sciences, Texas A&M University, College Station, TX 77843-2133. Phone: 979-845-1499; Fax: 979-845-0627. E-mail: ma-arnold@tamu.edu

BC  Austin, Texas, USA
    Blanco, Texas, USA
    Waring, Texas, USA
    Hunt, Texas, USA
    *Vanderpool, Texas, USA
    Leakey, Texas, USA
    Sabinal, Texas, USA
    Poteet, Texas, USA
    New Braunfels, Texas, USA
    San Marcos, Texas, USA
    Tiawichi Creek, Texas, USA
    Lake Cherokee, Texas, USA
    Orange, Texas, USA
    Franklin, Louisiana, USA
    Lake Verret, Louisiana, USA
    Vidalia, Louisiana, USA
    Mobile Bay, Alabama, USA
    Dauphine, Alabama, USA
    *Fairhope, Alabama, USA
    *Biloxi, Mississippi, USA
    Columbia, Mississippi, USA

PC  *Weeks, Louisiana, USA
    Paradise Beach, Florida, USA
    Mobile Bay, Alabama, USA
    *Mobile Bay, Alabama, USA
    Fowl River, Alabama, USA
    Biloxi, Mississippi, USA
    Kiln, Mississippi, USA

MC  Rio Nazas, Durango, Mexico
MC  San Juan Teotihuacan, Estado de Mexico, Mexico
MC  Bolleros, Estado de Mexico, Mexico
MC  Sabinas, Coahuila, Mexico
MC  Salineno, Texas, USA
MC  Progresso, Texas, USA
MC  Southmost, Texas, USA

* denotes probable hybrid
APPENDIX C

Map of *Taxodium* genotype planting along LaNana creek at Stephen F. Austin State University.

1 – block 1

2 – block 2

3 – block 3
Block 1

1. 61
2. 108
3. 132
4. 154
5. 172
6. 190
7. 263
8. 327
9. 339
10. 342
11. AK
12. BC
13. GA
14. LA
15. PC
16. SC
17. T302
Block 2

1. 61
2. 108
3. 132
4. 154
5. 172
6. 190
7. 263
8. 327
9. 339
10. 342
11. AK
12. BC
13. GA
14. LA
15. PC
16. SC
17. T302
**Block 3**

1. 61
2. 108
3. 132
4. 154
5. 172
6. 190
7. 263
8. 327
9. 339
10. 342
11. AK
12. BC
13. GA
14. LA
15. PC
16. SC
17. T302


Dickson, R.E., J.F. Honser, and N.W. Hosley. 1965. The effects of four water regimes upon the growth of four bottomland tree species. For. Sci. 11:299-305


Li H. 2006. Study on genetic analysis on Taxodium Rich. using RAPD. MS thesis, Nanjing Agriculture University, Nanjing 210095, P.R. China. p. 44.


Lijing Zhou was raised in Harbin, China. After graduating in July 1992 from high school, she attended Harbin Normal College with the major of biology education and graduated in 1995. Then she entered Harbin Normal University in 1996 and earned the degree of English Education in 1999. She worked in Harbin No. 21 Middle School as an English teacher for 9 years in China. In September 2005, she entered the Stephen F. Austin State University graduate program, studying Agriculture with a focus on Horticulture under the direction of Dr. David Creech. She received the Master of Science degree from Stephen F. Austin State University in May, 2007.

Permanent address: No. 228 Dongzhi Lu, Daowai District Harbin, China.

American Society for Horticultural Science Style Manual was the designated style guide.

This thesis was typed by Lijing Zhou.