

THE INFLUENCE OF SALINITY ON THE GERMINATION AND DISTRIBUTION OF
TAXODIUM DISTICHUM (L.) RICH, BALD CYPRESS, ALONG THE NORTHEAST
CAPE FEAR RIVER

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A Thesis Submitted to the
University of North Carolina Wilmington in Partial Fulfillment
of the Requirements for the Degree of Master of Science

Department of Biology and Marine Biology
University of North Carolina Wilmington

2007

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This thesis was formatted in the style of the journal of Wetlands.

TABLE OF CONTENTS

ABSTRACT CHAPTER 1	v
ABSTRACT CHAPTER 2	vi
ACKNOWLEDGEMENTS.....	vii
LIST OF TABLES.....	viii
LIST OF FIGURES.....	x
CHAPTER 1	
INTRODUCTION	1
MATERIALS AND METHODS	3
Study Area	3
Field Survey	4
Germination Assay	4
Statistical Analysis	9
RESULTS	9
Field Survey	9
Germination Assay	12
DISCUSSION	16
LITERATURE CITED	21
CHAPTER 2	
INTRODUCTION	24
MATERIALS AND METHODS	26
Study area.....	26

Vegetation Survey	27
Data Analysis.....	27
RESULTS	31
DISCUSSION	42
LITERATURE CITED	49
SUMMARY	56
APPENDIX 1.....	A
APPENDIX 2.....	B
APPENDIX 3.....	D

ABSTRACT
CHAPTER 1

A survey of three sites along the Northeast Cape Fear River, NC indicated that natural regeneration of *Taxodium distichum* (bald cypress) only occurred at the most oligohaline site along a salinity gradient. Floodwater salinity from 2000-2006 at this site was routinely < 0.1 , while salinity at the other two downstream sites was < 2 and $2-9$, respectively. Germination and emergence of *T. distichum* seeds collected from the Northeast Cape Fear River were evaluated in a range of salinities (0, 2, 4, 6, 8, 10, and 12). Seeds germinated in all salinities, but at lower rates with increasing salinity. Salinity significantly impacted germination above 6 ($p=0.001$). Establishment, the ability to germinate, emerge and survive the duration of the study, occurred only in the lowest salinities, 0 and 2, suggesting that salinity is a major factor limiting *T. distichum* recruitment and establishment along the Northeast Cape Fear River. The results of this study indicate that as sea level rise increases, salt water intrusion will likely restrict *T. distichum* from tidal swamps along the lower Cape Fear River, where mature stands now occur.

ABSTRACT
CHAPTER 2

A vegetation survey was conducted at three sites along the Northeast Cape Fear River, a natural salinity continuum, to assess the persistence of *Taxodium distichum* and associated vegetation when exposed to rising sea level. Three permanent plots measuring 20 x 50 m were established at each of the sites and surveyed using the NCVS protocol. A total of 89 species representing 54 families were identified. Live *T. distichum* were absent from the site furthest downstream, the most saline. Both NMS and DCA ordinations show that the vegetation assembles along a continuum of average tidal duration and soil sulfate concentrations (a proxy for salinity intrusion). Swamps dominated by *T. distichum* are being replaced by salt and brackish marsh species, such as *Juncus roemerianus*, due to sea level rise. A lack of allochthonous riverine input may accelerate the process of vegetation regression. These swamps will be limited to upstream areas of higher elevation and those exposed to freshwater flooding.

ACKNOWLEDGMENTS

Many thanks to my advisor, Dr. Courtney Hackney, and to my committee members, Dr. Steven Brewer and Dr. Michael Durako. To my husband, Fleck my gratitude for your support and encouragement, not to mention your plumbing abilities. To my son Toby, you were the light at the end of the tunnel and the motivation to complete the thesis in a timely fashion, always ready with a smile when formatting or technical difficulties presented themselves. To my father and mother in law, many thanks for the babysitting services, home cooked meals, and endless support, emotional and otherwise, that you provided over the years. To all the graduate and undergraduate students for your help in the field and greenhouse; especially Mikaela Anderson, Jenn Berting, Katie Chartrand, Sara Dorman, Dave Dummond, Kristin Hardy, Carie Hett, Ana Jimenez, Amanda Kahn, Clay Morris, Melissa Pearce, and countless others. This wouldn't have been possible without you.

LIST OF TABLES

Table	Page
CHAPTER 1	
1. Site descriptions for Rat Island, Fishing Creek, and Prince George Creek located along the Northeast Cape Fear River, NC. Data reported are averaged for the years 2000-2006 from Hackney et al. (2006). Site coordinates are the location of the 1 st substation used in the Cape Fear River Monitoring project for the given transect. Tidal frequency is the average number of tides at the site out of 27 possible tides. Salinity is the average of the mid point of salinity to which the site is exposed. Maximum salinity is the maximum salinity recorded, to which the site has been exposed. Tidal Height is the average water height, in meters, above the marsh surface during recorded tides.....	6
CHAPTER 2	
2. Site descriptions for Rat Island (RI), Fishing Creek (FC), and Prince George Creek (PGC) located along the Northeast Cape Fear River, NC. Data reported are averaged for the years 2000-2006 from Hackney et al. (2006). Site coordinates are the location of the 1 st substation used in the Cape Fear River Monitoring project for the given transect. Tidal frequency is the average number of tides at the site out of 27. Salinity is the average of the mid point of salinity to which the site is exposed. Max salinity is the maximum salinity recorded, to which the site has been exposed. Tidal Height is the average water height, in meters, above the marsh surface during recorded tides.	30
3. Species identified in field survey, nomenclature follows Radford et al. (1968). Species codes are those used in ordinations. Average cover values reported for each site are the midpoints of the average NCVS cover class (Peet et al. 1998). Site abbreviation are RI=Rat Island, FC=Fishing Creek, PGC=Prince George Creek.....	32
4. Weighted correlation matrix of environmental variables from DCA analysis in relation to herbaceous species (A) and woody species (B) composition. Collinearity of variables is revealed, but to be expected as environmental variables used were close proxies for each other. TDAVE= Average Tidal Duration, FEAVE= Average number of flood events, WHAVE= Average water height above swamp surface, SAMID=Average of yearly salinity range mid points, SAMAX= Maximum salinity recorded at a site, CLAVE= average soil chloride concentration, SUAVE= average soil sulfate concentration.	36
5. Pearson correlation coefficient for abiotic variables and axis 1 in DCA analysis. Correlation >0.75 are significant and shown in bold. Environmental	

parameters used were: TDAVE= Average Tidal Duration, FEAVE= Average number of flood events, WHAVE= Average water height above swamp surface, SAMID=Average of yearly salinity range mid points, SAMAX= Maximum salinity recorded at a site, CLAVE= average soil chloride concentration, SUAVE= average soil sulfate concentration.38

6. Pearson correlation coefficient between species and axis 1 in DCA analysis. $r > 0.75$ is significant and shown in bold. Species name abbreviations follow those listed in Table 3.39

LIST OF FIGURES

Figure	Page
CHAPTER 1	
1. Map of Cape Fear River System, North Carolina depicting the three sites used for field survey of <i>T. distichum</i> distribution and recruitment. RI=Rat Island, FC=Fishing Creek, and PGC= Prince George Creek. Adopted from Hackney et al. (2006)	5
2. a. Photograph depicting the definition of 1) germination, the breaking of the seed coat, and 2) emergence, the epicotyl's clearing of the soil surface. b. Photograph of greenhouse layout.	8
3. Average size class distribution for <i>T. distichum</i> at Fishing Creek and Prince George Creek. Standard error bars are shown.	10
4. Maximum salinity exposure by site for 2000-2006. Data provided by the Cape Fear River Monitoring Project (Hackney et al. 2006).....	11
5. a. Total germination, emergence and establishment by salinity. b. Average number of seeds germinating in each salinity treatment. Standard error bars are shown. Columns with different letters are statistically different from one another.....	13
6. Number of seeds germinating by parent and salinity treatment. Columns are ranked by total number of seeds germinating per parent; parent 2 had the highest overall germination while parent 7 had the lowest.....	14
7. Cumulative seed germination for 6 salinity treatments. Salinity 12 is omitted because date of germination was not observed for either of the two seeds germinating in this treatment.	15
CHAPTER 2	
8. Map of southeastern North Carolina depicting the Northeast Cape Fear River and the three permanent monitoring stations used for field survey and vegetation analysis. RI=Rat Island, FC=Fishing Creek, and PGC= Prince George Creek. Adopted from Hackney et al. (2006)	29
9. NMS of vegetation plots along a salinity gradient, using the compliment of Jaccard's index as a measure of distance a.) for all species surveyed b.) just woody stem data used c.) just herbaceous species data used. For all ordinations black circlces= Prince George Creek, white circlces= Fishing Creek and grey circles= Rat Island.	35

10. DCA ordination of woody species and plots. Species abbreviations follow those listed in Table 3. Environmental abbreviations follow those listed in Table 4 and 5. Plots with black circles= Prince George Creek, white circles= Fishing Creek and grey circles= Rat Island.....	40
11. DCA ordination of herbaceous species and plots. Species abbreviations follow those listed in Table 3. Environmental abbreviations follow those listed in Table 4 and 5. Plots with black circles= Prince George Creek, white circles= Fishing Creek and grey circles= Rat Island.	41
12. Rank abundance by (a) number of stems and (b) total basal area for all woody species at Fishing Creek. Scale is logarithmic.	43
13. Rank abundance by (a) number of stems and (b) total basal area for all woody stems at Prince George Creek. Scale is logarithmic.....	44
14. Maximum salinity exposure by site from 2000-2006. Data provided by Hackney et al. (2006).	45

INTRODUCTION

Cypress, *Taxodium distichum* (L.) Rich., is endemic to the Southeastern United States (Mattoon 1915). As a species extremely tolerant of waterlogging, it often serves as the canopy dominant in permanently flooded vegetation associations such as bottomland hardwood swamps and floodplain forests. Cypress swamps provide wildlife habitat, function in substrate stabilization, and possess decay-resistant wood making them an economically valuable resource (Mattoon 1915, Mitsch and Gosselink 2000, Kozlowski 2002). Despite the high flood tolerance of adult *T. distichum* (Hook 1984), seedlings are only moderately flood tolerant and seeds are intolerant, being unable to germinate in permanently flooded conditions (Demaree 1932). Historically, cypress swamps were widely distributed, covering over 15 million ha. Through logging and habitat destruction they have been reduced to 2 million ha, and their continued persistence in the landscape is threatened by saltwater intrusion and habitat alteration (Sasser et al. 1986, DeLaune et al. 1987, Conner and Brody 1989, Allen 1992).

Modeling predictions indicate that *T. distichum* will potentially be lost from the landscape in the next 100 years due to the combination of relative sea-level rise and loss of germination safe sites (Conner and Brody 1989). Because of their economic and ecological importance, many studies of *T. distichum* tolerance to both increased flooding and salt intrusion have been conducted. Populations exhibit different tolerances to salinity stress which also varies with life history stage. Inherent intraspecific variation

in salinity tolerance also occurs (Allen et al. 1994a, Krauss et al. 1998, Krauss et al. 1999, Conner and Inabinette 2005). This variation makes identification of salt tolerant life history stages and salt tolerant populations of paramount importance to current restoration efforts.

Most studies have focused on seedling response to increased salinity and flooding (Demaree 1932, Shanklin and Kozlowski 1985, Pezeshki 1990, Pezeshki et al. 1990, Conner 1994, McLeod et al. 1996, Krauss et al. 1999). Only one study has examined the germination capability of *T. distichum* when exposed to saline conditions. Krauss et al. (1998) found that seeds of *T. distichum* from coastal Louisiana had decreased germination as salinity approached 6. Germination at salinities greater than this was not reported. Germination success ranged from 26.3% at 0 to 10.2% at 6.

Taxodium distichum rely on natural ridges for germination safe sites (Hunneke and Sharitz 1986, DeLaune et al. 1987, Battaglia et al. 2000). Typically, seeds are dispersed in winter high waters and transported to the river/swamp interface. A water draw down, which usually occurs in the following spring or summer, allows germination on slightly raised elevations, such as fallen logs or hummocks (Schneider and Sharitz 1988, Middleton 2000).

In coastal North Carolina, along the Cape Fear River, cypress swamps cover almost 80,000 ha. They are the dominant vegetation association of the floodplain

ecosystem in the lower reaches of the river, but signs of “reverse succession”, e.g. the conversion of bottomland hardwood swamps to herbaceous wetlands, are evident. These swamps are exposed to semi-diurnal tidal flooding, by floodwater that may be converting from freshwater to brackish or saline water as sea level rise continues to inundate the Coastal Plain (Hackney et al. 2006).

Taxodium distichum seeds from the lower Cape Fear River have demonstrated the highest germination success compared to other regional seed sources in freshwater conditions (58%), but seedlings from this region exhibited some of the lowest tolerance to salt water (Conner and Inabinette 2005). This study assessed 1) the natural regeneration of *T. distichum* along the tidally influenced portion of the river (a natural salinity continuum) and 2) determined germination and survival of *T. distichum* from the Northeast Cape Fear River under various saline conditions in a controlled greenhouse germination assay.

MATERIALS AND METHODS

Study Area

Three sites along the Northeast Cape Fear River (Figure 1), in North Carolina were chosen for study of *T. distichum* recruitment. Rat Island, Fishing Creek and Prince George Creek were located approximately 6.4, 12.8, and 25.6 km upstream from Wilmington, NC. All three sites supported mature *T. distichum* and were tidally influenced. However, they differed with respect to *T. distichum* dominance as well as

demonstrate a range of exposure to tidal duration, frequency, salinity, and floodwater height (Table 1). Detailed site descriptions can be found in Carroll et al. (2001).

Field Survey

Three permanent vegetation monitoring plots measuring 20 x 50 m were established at the three sites along the Northeast Cape Fear, for a total of nine plots. One plot at Fishing Creek measured 20 x 40 m due to topographic and environmental constraints. These plots were established at the river/swamp interface where most germination was expected (Schneider and Sharitz 1988). Within these plots, all *T. distichum* seedlings (<1.5 m tall), saplings, and trees were recorded and placed into DBH size classes.

Germination Assay

Seeds of *T. distichum* were collected from the Northeast Cape Fear between November 26 and December 1, 2006 from parent trees located in the tidally-influenced, oligohaline portion of the river, between Fishing Creek and Prince George Creek. Seeds were subsequently allowed to air dry for one week and then stratified according to Schopmeyer (1974).

After stratification, five seeds from nine parents were sown in seed flats containing Sun Gro® Metro Mix 400, for a total of 45 seeds per seed flat. Seeds were laid on the soil surface without reference to seed orientation. The seed flats were placed in plastic trays, which were randomly distributed throughout the greenhouse and

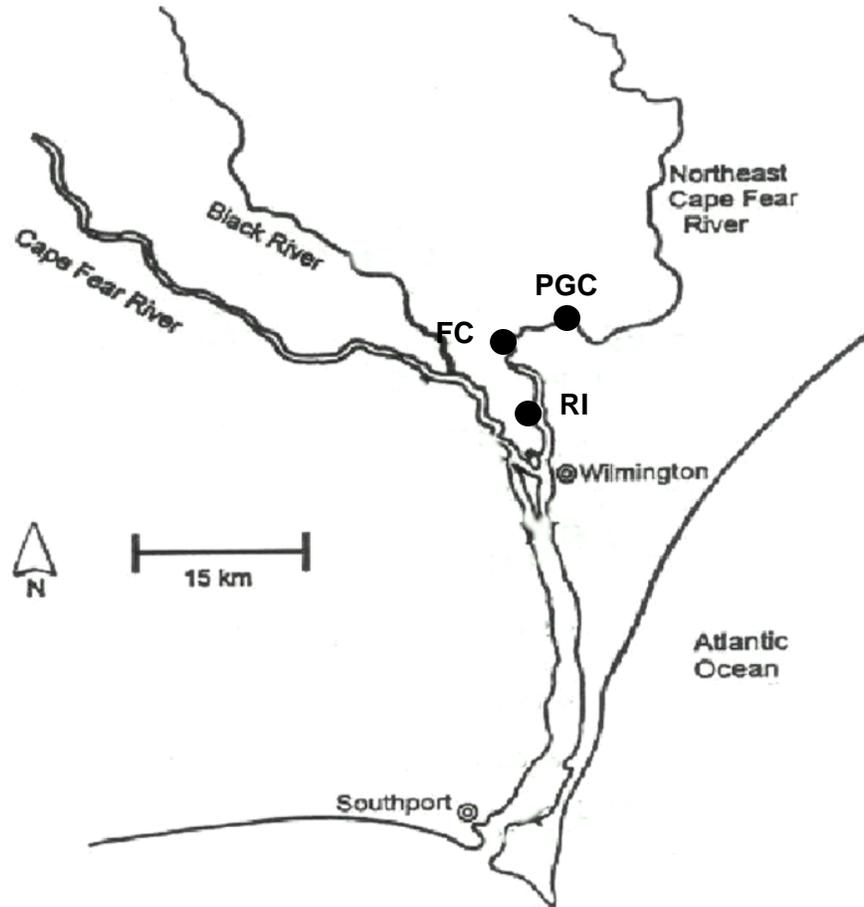


Figure 1. Map of Cape Fear River System, North Carolina depicting the three sites used for field survey of *T. distichum* distribution and recruitment. RI=Rat Island, FC=Fishing Creek, and PGC= Prince George Creek. Adopted from Hackney et al. (2006).

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Site	Distance from Wilmington, NC (km)	Elevation NAVD88 (m)	Site Coordinates	2000-2006				
				Tidal Duration (hrs)	Tidal Frequency	Salinity	Max Salinity	Tidal Height (m)
Rat Island	6.4	0.27	34.1814 N 77.5740 W	6.08	25.43	3.77	13	1.86
Fishing Creek	12.8	0.43	34.2016 N 77.5940 W	6.39	19.57	1.11	9	0.87
Prince George Creek	25.6	0.21	34.2210 N 77.5619 W	7.49	26.14	0.11	2	1.47

watered through the bottom of the pot once daily with one of 7 mixtures of saline water (0, 2, 4, 6, 8, 10, 12, Figure 2b). Four replicate trays per treatment, for a total of 180 seeds per treatment or 1260 seeds for the entire study, were tested in the greenhouse at the Center for Marine Science of the University of North Carolina Wilmington. Instant Ocean® and tap water were used to mix saltwater, which was stored in 30 gallon containers at the appropriate concentration. The major ionic components of Instant Ocean® are found in roughly the following percentages: Cl (47%), Na (26%), SO₄ (6%), Mg (3%), Ca (1%), and K (1%). Source water salinity was checked daily using a YSI-30 and corrected when necessary. Saline water was mixed weekly for the duration of the 10 week study.

Germination, emergence, and survival were monitored every 2-3 days, beginning nine days after sowing. Germination was defined as: the breaking of the seed coat, emergence: the epicotyl's clearing of the soil surface, and establishment: the ability to survive the duration of the study (Figure 2a). For 10 weeks, time of germination was observed; when two weeks had passed with no additional observed germination, all seeds were harvested. At this time, it was noted that time of germination had not been observed for some seeds due to the way they laid on the soil. In these instances, germination was recorded, but these seeds were not included in analysis of time to germination.



a.



b.

Figure 2. a. Photograph depicting the definition of 1) germination, the breaking of the seed coat, and 2) emergence, the epicotyl's clearing of the soil surface. b. Photograph of greenhouse germination assay experimental layout.

Statistical Analysis

Germination, emergence and establishment were analyzed using SAS proc Logistic and Freq. Non parametric analysis was carried out on the proportional germination to determine what salinity significantly effected germination success. Bonferroni corrected p-values for multiple hypothesis testing are reported.

RESULTS

Field Survey:

There were no live *T. distichum* in the plots established at station furthest downstream, Rat Island. Up river, at Fishing Creek, *T. distichum* was the dominant tree species with respect to basal area and number of stems (Figure 3). However, there was no active recruitment observed. Further upstream, at PGC, there were few large cypress, however, it was the only site with visible cypress recruitment (Figure 3).

Droughts in 2001 and 2002 allowed pulses of saltwater to intrude upstream into all three sites (Figure 4) and correspond to high salinity events at the sites. Both Fishing Creek and Prince George were exposed to maximum salinities of 9 and 2, respectively, in 2001. The maximum salinity exposure of 13 at Rat Island occurred in 2004. The three sites are monitored for salinity at slightly different times in the season. The peak observed at Rat Island, but not the other two sites in 2004, may be a result of this. Regardless, the peak is also attributed to drought conditions. Prince George has not been flooded by water more saline than 2, whereas Fishing Creek has been exposed

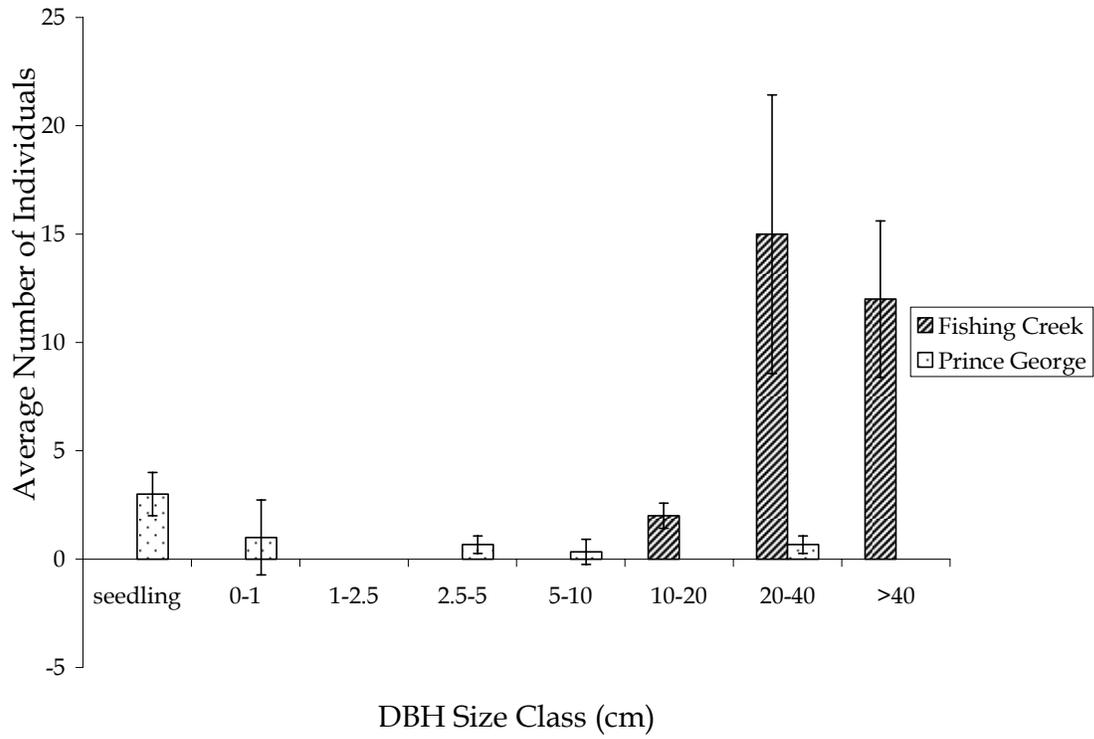


Figure 3. Average size class distribution for *T. distichum* at Fishing Creek and Prince George Creek. Standard error bars are shown.

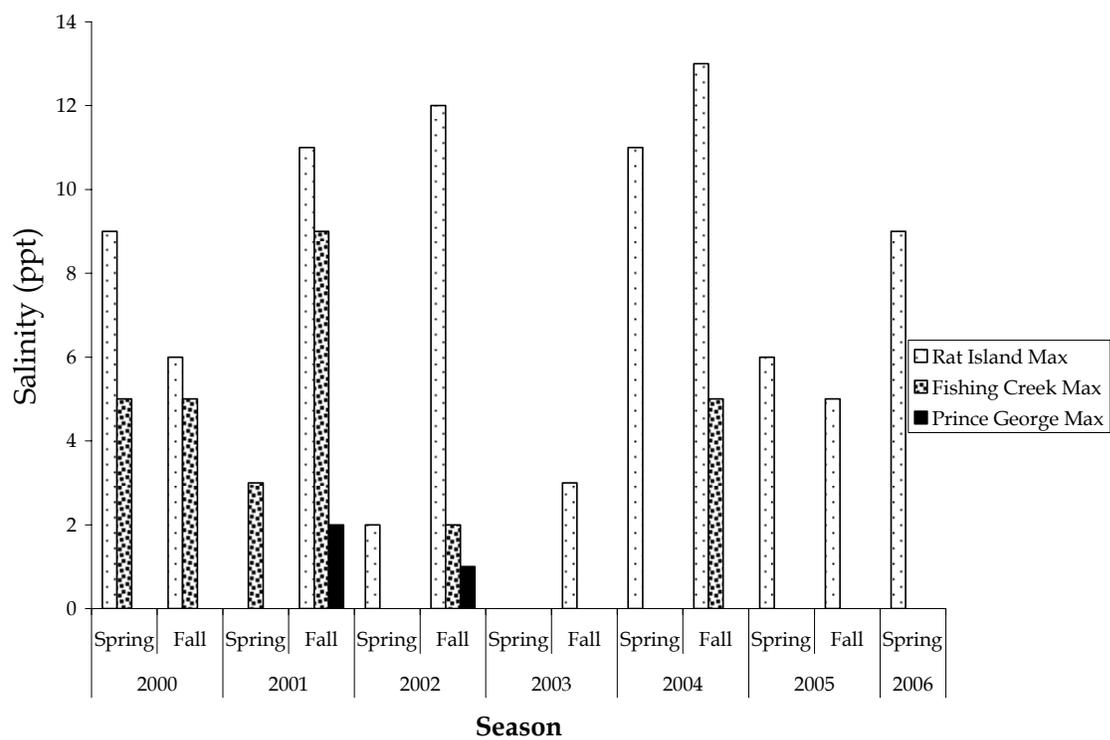


Figure 4. Maximum salinity exposure by site for spring and fall 2000-2006. Data provided by the Cape Fear River Monitoring Project (Hackney et al. 2006).

to salinity pulses of 2-9, and Rat Island routinely received saltwater pulses in the range of 2-13 (Table 1 and Hackney et al. 2006).

Germination Assay:

Seeds from the Northeast Cape Fear River germinated in all treatments. However, germination decreased significantly as salinity increased (28.9% germination at 0, 1.1% at 12, $p < 0.0001$, Figure 5). At salinities greater than 6, germination was significantly less than control ($p < 0.0001$). Emergence and establishment were similarly affected by increased salinity. Seedlings only emerged in salinities less than 6, and the only seedlings to survive the experimental period were those in the control group and those exposed to the lowest salinity, 2 (Figure 5).

Intraspecific variation among parental seed source germination was observed (Figure 6). Seeds from 5 of the 9 parents (parents 2, 3, 4, 5, and 6) accounted for 86% of observed germination. Seeds from parent 2 germinated in all salinities and at 0 salinity had 65% germination success. In contrast, parents 7 and 8 had low overall germination; only two seeds from parent 7 (one at a salinity of 6 and one at 12) and three seeds from parent 8 (one at a salinity of 2 and two at a salinity of 8), germinated (Figure 6).

Germination was not observed before the 9th day of experimentation. Seeds exposed to salinities 0-6 completed >70% of total germination by day 30 (Figure 7). Seeds exposed

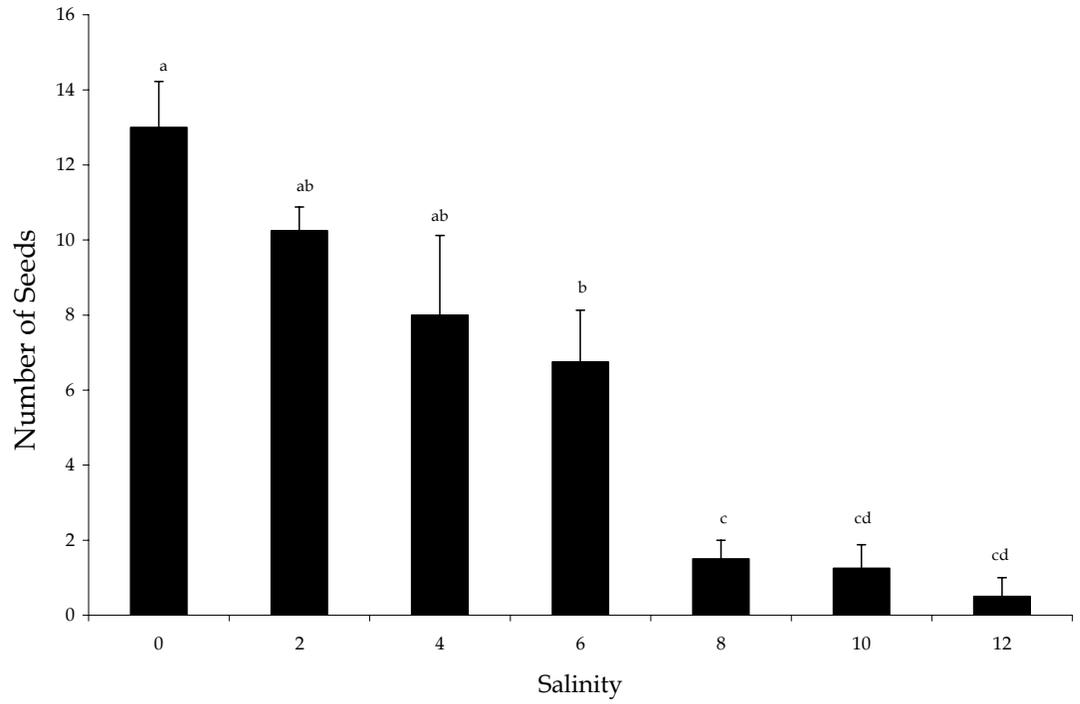
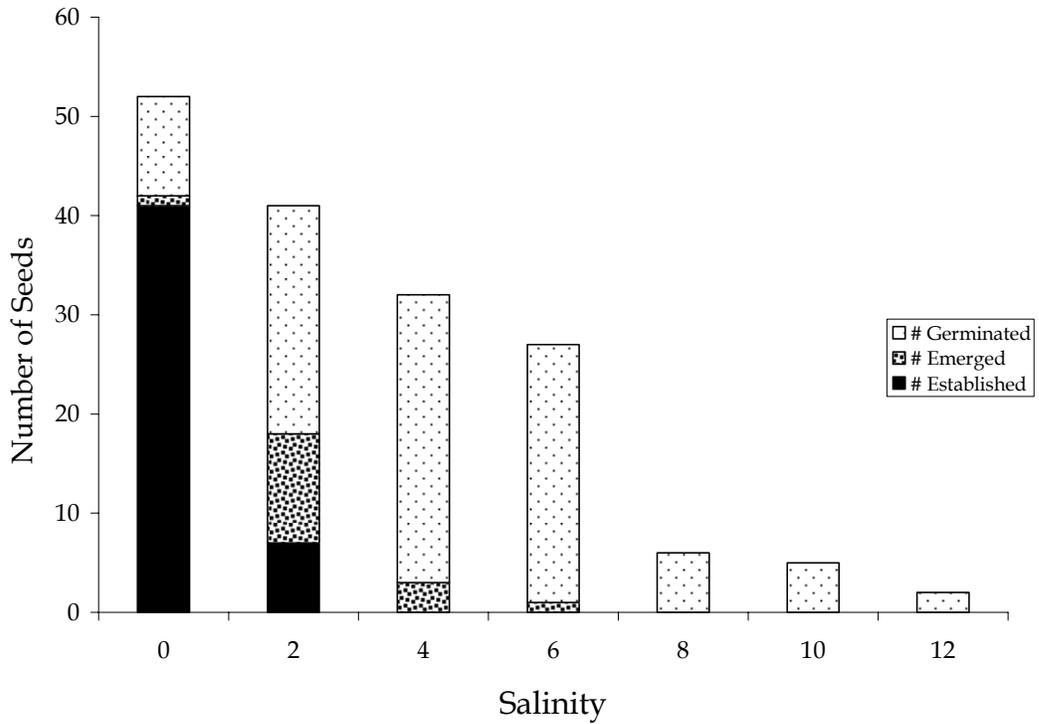


Figure 5. a. Total germination, emergence and establishment by salinity. b. Average number of seeds germinating by treatment. Standard error bars are shown. Columns with different letters are statistically different from one another.

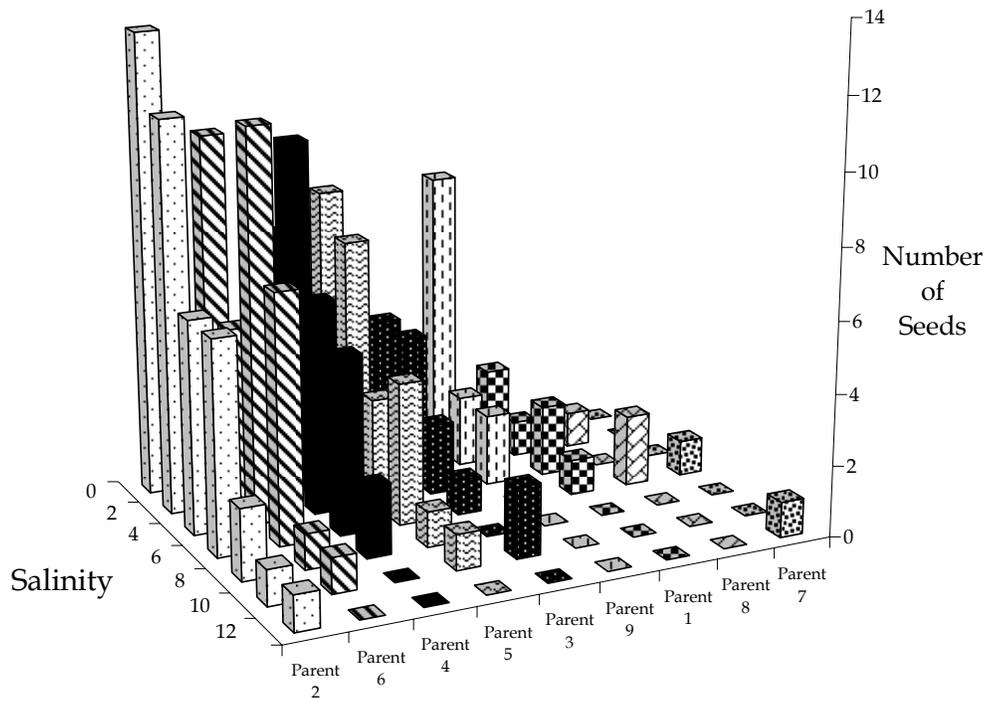


Figure 6. Number of seeds germinating by parent and salinity treatment. Columns are ranked by total number of seeds germinating per parent; parent 2 had the highest overall germination while parent 7 had the lowest.

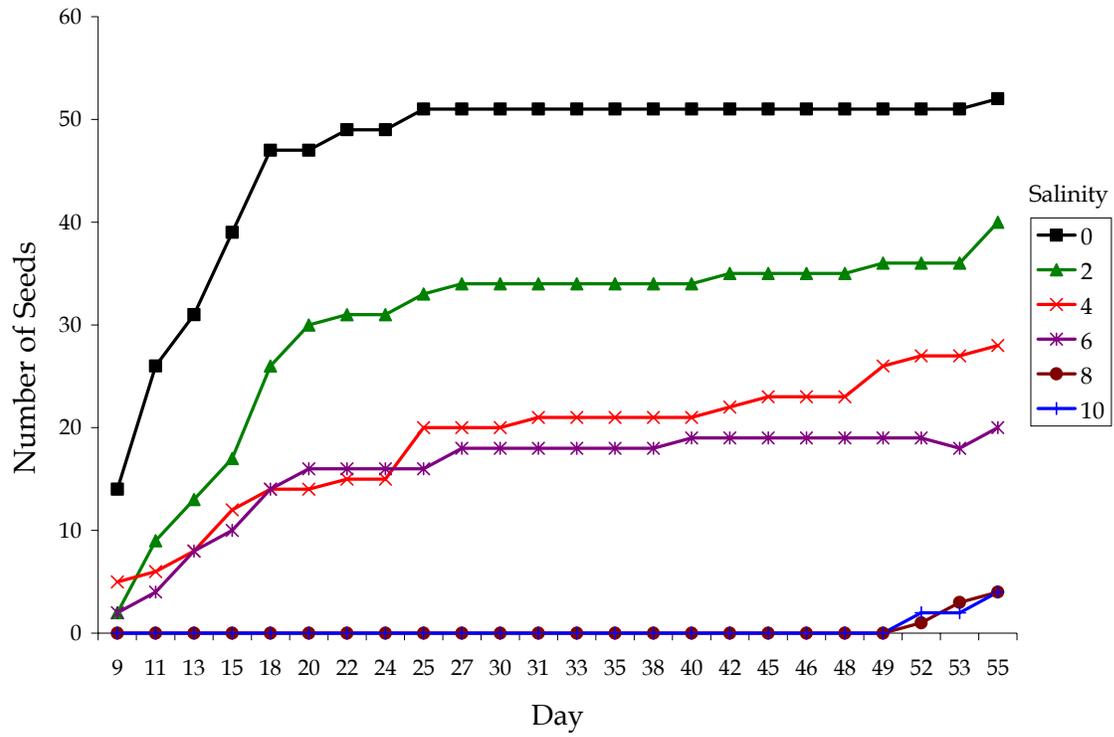


Figure 7. Cumulative seed germination for 6 salinity treatments. Salinity 12 is omitted because date of germination was not observed for either of the two seeds germinating in this treatment.

to salinities of 8 and 10 delayed germination until the end of experimentation. Date of germination was not observed for either of the two seeds that germinated in salinity 12.

DISCUSSION

Natural *T. distichum* recruitment is not commonly observed (Conner and Day 1976, Conner 1995, Visser and Sasser 1995). Seedling presence is typically limited by 1) lack of germination safe sites (Hunneke and Sharitz 1986, DeLaune et al. 1987), and/or 2) lack of viable seed source (Dunn and Sharitz 1987, Schneider and Sharitz 1988, Conner 1995, DeSteven and Sharitz 1997). In this study, recruitment was only observed at Prince George. Prince George has a heterogeneous microtopography with typical hummock-hollow terrain, which creates many potential safe sites for cypress germination. It also has a viable seed source, evidenced by the germination assay, which used seeds from this area. Of the three sites surveyed, this site is rarely inundated by saline water, and when it is, only by dilute sea water with a salinity <2.

Furthest downstream, at Rat Island, the most saline site, there were no live adult *T. distichum*, nor was there any recruitment of *T. distichum* within plots. Rat Island has a slightly higher elevation than Prince George, but may lack the heterogeneous microtopography needed to create germination safe sites. A lack of a viable seed source does not fully explain the absence of *T. distichum* at Rat Island, as seeds could be transported via hydrochory, i.e. water dispersal, from upstream parents (Schneider and Sharitz 1988). Similarly, lack of viable seeds does not explain the absence of recruitment

observed at Fishing Creek. Seeds collected from this area germinated in the greenhouse assay and the abundance of adult cypress at this site should presumably ensure active recruitment. In addition, Fishing Creek has the highest relative elevation of the three sites, which decreases flooding frequency and depth, thereby exposing germination safe sites. However, both sites are exposed to pulses of salinity >2 , which likely limits cypress establishment. Pulses of salinity occurring regularly and/or during the growing season may be enough to limit cypress recruitment. This was shown in the germination assay, where cypress seedling establishment did not occur in salinities >2 .

Taxodium distichum seeds do not germinate under water and seedlings do not survive prolonged periods of flooding, especially during the growing season (Mattoon 1917, Demaree 1932, Shanklin and Kozlowski 1985). Therefore, in most cypress swamps, periods of drought are required to ensure recruitment as water levels drop and germination sites are exposed. However, in tidally-influenced areas, drought coupled with rising sea level, allows salt water intrusion to propagate into freshwater areas, as occurred along the Cape Fear River in 2000 and 2001. In effect, drought years may be making what otherwise would be successful germination years, unproductive. Timing of the drought and subsequent salinity intrusion may be a critical factor in *T. distichum* establishment, with late fall/winter drought being less detrimental to survival than drought during the growing season.

Salinity > 2 appears to be the threshold for NC *T. distichum* establishment. A previous threshold, based on salt tolerance of seedlings from Gulf Coast states, was suggested to be between 8 and 10 (Allen et al. 1994a, Conner 1994, Conner and Inabinette 2005). While this may be an accurate salinity threshold for seedlings that are transplanted to saline sites, natural recruitment will not likely occur in these conditions. Populations of *T. distichum* along the Northeast Cape Fear River are limited in their establishment by lower levels of saltwater, < 2. Germination, i.e. breaking of the seed coat, is not the critical step of the process; at all salinities tested, seeds were able to imbibe water and break the seed coat. Some plant species are more tolerant of salinity during the germination stage than as seedlings (Poljakoff-Mayber et al. 1994). *T. distichum* appears to demonstrate this characteristic. As a gymnosperm with little stored reserve, the transition from a newly-germinated seed to an established seedling is the critical process where the developing seedling is vulnerable to the effects of saline water as it shifts to actively photosynthesizing. Allen et al. (1997) demonstrated that *T. distichum* net photosynthesis declines with increasing salinity exposure, due to the metabolic cost of maintaining stable ion ratios.

Taxodium distichum from the Cape Fear River population were previously reported to have germination rates of 58% (Conner and Inabinette 2005). While in the present study, overall germination did not exceed 30%, some parent trees (parents 2 and 6) exhibited >50% germination in the control treatment. Differences in reported germination capabilities could indicate inter-annual variation, differences in planting

protocol, or be an artifact of seed source. Low seedling survival under chronic salinity exposure agrees with previous studies (Conner and Inabinette 2005) and indicates that North Carolina *T. distichum* seedlings have low salinity tolerance. However, there were some observed differences in germination based on parent. Seeds from parent 2 had highest overall germination and were able to germinate in all salinities. Furthermore, other studies have identified adult *T. distichum* along the Cape Fear River that persist in areas routinely exposed to saline pulses >15 (Harmon 1993, Yanosky et al. 1995). Seeds from these trees were not used in the present study and it would be of interest to determine if their seeds and seedlings were more salt tolerance. Allen et al. (1994a) found that seedlings from brackish water sources along the coast of the Gulf of Mexico had higher salinity tolerance than their freshwater counterparts. Further study of the salt tolerance of seeds and seedlings from Parent 2 and those from brackish water sources are needed, but these parents may provide a naturally occurring salt tolerant seed source along the river

Regional variations in salt tolerance may impact the future distribution of *T. distichum*. The use of genetic screening, germination assays, and supplemental plantings are all methods that may be used to assess *T. distichum* tolerance. The greenhouse germination assay corroborates the field-study observations, i.e., no seedlings were observed where salinity exposure ranged above 2. This may indicate that although there is a viable seed source along the Northeast Cape Fear River,

germinating seedlings are not able to establish, in the presence of even infrequent exposure to dilute seawater.

The future persistence of *T. distichum* along the lower reaches of the Cape Fear River is unlikely. *T. distichum* already established possesses the ability to withstand low levels of salt intrusion in the short term. However, they will eventually be unable to persist in this increasingly saline environment. As sea level continues to rise, germination safe sites will be lost and natural recruitment, which is already occurring at a low rate, will not be able to replace lost trees. Periods of drought, historically ensuring seedling establishment in non-tidal swamps, may now cause their demise as tides drive saline water further upstream. *T. distichum* will only be able to establish in areas of higher elevation with less salinity intrusion, limiting them to upstream parts of the river and along the upland edge of the swamp.

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CHAPTER TWO INTRODUCTION

Bald cypress, *Taxodium distichum* (L.) Rich., dominated swamps are highly valued for their wildlife habitat, unique plant associations, and economic importance (Yeager 1938, Belden et al. 1988, Maehr 1990, Weaver and Pelton 1992, Buhlmann 1995, Rodgers et al. 1996, Heckscher 2000). They also provide hydrological services, such as improved water quality, flood control, and ground water recharge (Ewel 1990, Mitsch and Gosselink 2000). Logging practices in the early part of the 20th century and habitat alteration have led to a decline in cypress swamps (Sasser et al. 1986, Conner and Inabinette 2003, Middleton and McKee 2004). Because of their occurrence in the Outer Coastal Plain of the Southeast United States, their persistence is also threatened by saltwater intrusion via tides, hurricanes, and sea level rise (DeLaune et al. 1987, Conner 1995, McLeod et al. 1996, Michener et al. 1997, Williams et al. 1999, Conner and Inabinette 2003).

The most extensively studied cypress swamps are those that are exposed to seasonal flooding (*e.g.* cypress domes) and/or exist as riparian floodplain forests (Conner and Day 1976, Conner and Flynn 1989, Jones et al. 1989, Megonigal et al. 1997, Rheinhardt et al. 1998, Battaglia et al. 2000). These swamps are commonly referred to as bottomland hardwood swamps, where *T. distichum* is found in association with up to 70 other hardwood species. Bottomland hardwood swamps were once common on the Coastal Plain. Little is known about the effect of tidal flooding on bottomland

hardwood forests that have become subjected to tidal flooding. The Cape Fear watershed has over 80,000 hectares of cypress swamp and is tidally influenced 40 km inland. It offers an opportunity to better understand these cypress associations and factors affecting their long term persistence in the landscape (Hackney et al. 2007). Some evidence shows that *T. distichum* and its associated forest species have varying degrees of salt and flooding tolerance (Hook 1984, Pezeshki 1990, Allen et al. 1994a, McLeod et al. 1996, Allen et al. 1997, Kozlowski 1997, Conner et al. 1998, Krauss et al. 1998, McCarron et al. 1998, Krauss et al. 1999, Kozlowski 2002).

Signs of “reverse succession”, e.g. the conversion of bottomland hardwood swamps to herbaceous wetlands, are evident in coastal southeastern United States (Salinas et al. 1986, Michener et al. 1997, Williams et al. 1999). Channelization and sea level rise increase saltwater intrusion through the widening and deepening of the given channel, thereby permitting saltwater to penetrate further upstream and increase the associated tidal amplitude (Odum 1988, Hackney and Yelverton 1990). Channelization also results in longer periods of flooding further upstream. Plant species face the difficulties of persisting under increasing salt and decreasing oxygen availability (Flowers et al. 1977, Greenway and Munns 1980, Allen et al. 1994b, Allen et al. 1996, Pezeshki 1996, Kozlowski 1997). Swamps in the Lower Cape Fear River are exposed to semi-diurnal tidal flooding. The salinity gradient along the Cape Fear River provided a natural space-for-time experiment on salinity impacts to *T. distichum* plant communities (Figure 8). The objective of this study was to determine the vegetation composition and

diversity, as well as physical structure of cypress swamps along a salinity gradient. Comparisons allow an interpretation of the effect of future salinity and sea level rise impacts on swamps along rivers of the Southeastern U.S.

METHODS

Study Area

Three sites along the Northeast Cape Fear River, NECFR (Figure 8), in North Carolina were chosen for study of the vegetation assemblage and *T. distichum* recruitment. Rat Island (RI), Fishing Creek (FC), and Prince George Creek (PGC) were located approximately 6.4, 12.8, and 25.6 km upstream from Wilmington, NC. All three sites supported cypress and were tidally influenced. However, they differed with respect to cypress dominance and in their exposure to tidal duration, frequency, salinity, and floodwater depth (Table 2). Detailed site descriptions can be found in Carroll et al. (2001).

Permanent transects from the river edge to nearest uplands were previously established at these three sites (Carroll et al. 2001). The three study sites vary with respect to tidal duration, frequency, salinity and floodwater depth (Hackney et al. 2006) (Table 2).

Vegetation Survey

Three permanent 20 x 50 m plots were established at each of the three sites along the Northeast Cape Fear River, following the North Carolina Vegetation Survey (NCVS) protocol (Peet et al. 1998). One plot at Fishing Creek measured 20 m x 40 m due to topographic and environmental constraints. All plants were identified to species when possible, using Radford et al. (1968). Some plants were identified to genus and morphospecies, as some taxa could not be found in fertile condition (*e.g.*, many of the *Carex* spp.) Percent cover by cover class was visually estimated for all species. All woody stems were measured and those greater than 7 cm DBH were permanently marked with a uniquely numbered aluminum tag for future monitoring.

Data Analysis

Ordination techniques and Mantel tests were used to relate vegetation distribution to environmental variation along the Northeast Cape Fear River using both the complement to Jaccard's index, a measure of distance based on species presence and absence (Jaccard 1902), and chord-euclidean distance, a measure of distance based on proportional abundance of species (Pielou 1984). Both indices yielded similar results. Therefore, only ordinations using Jaccard's index are shown. Indirect gradient analysis was performed using non-metric multidimensional scaling (NMS) (Shepard 1962, Kruskal 1964) and Detrended Correspondence Analysis (DCA) (Hill 1979, Hill and Gauch Jr. 1980) performed with PCORD version 4.25 (McCune and Medford 1999) and CANOCO v. 4.5 (ter Braak and Šmilauer 2002). The NMS ordination procedure places

samples in relative positions in ordination space, rather than fitting axes based on sample eigenvalues or other methods for partitioning sample variance. NMS performs well in data sets with high beta diversity and noisy environmental information and has relatively few assumptions about the nature of data analyzed (Prentice 1977). NMS examines the relationships of *T. distichum* communities to salinity and flooding without making *a priori* assumptions about either variables or relationships (Okland 1996).

Detrending by segments without down-weighting of rare species was performed in the DCA. The interpretation of DCA results was restricted to the first ordination axis because of the known distortions of the higher order axes in DCA (Hill and Gauch Jr. 1980, Gauch Jr. 1982) and because of an apparent arch effect in the second axis of the DCA ordination of plots. Pearson correlations of abiotic predictor variables with ordination axes were used to interpret relationships of these variables to cypress community composition and species relationships to the flooding and salinity variables. With an $N = 9$, variables with a Pearson $r \geq 0.75$ were significant at $p = 0.05$. Bonferroni corrections were not performed due to low statistical power (Perneger 1998, Moran 2003, Nakagawa 2004).

Mantel tests (Mantel 1967, Sokal 1979) were performed to compare dissimilarity values for species composition among plots with differences among plots in Abiotic variables. Mantel tests were also performed as a means of comparing composition differences among plots with respect to herbaceous and woody vegetation. This

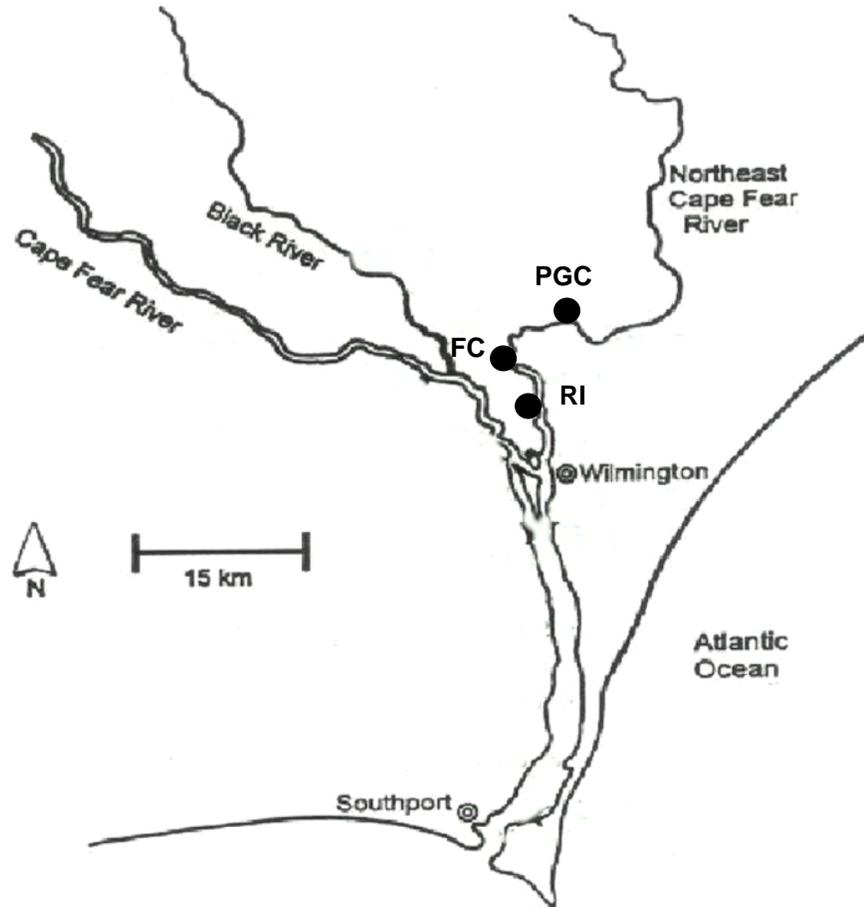


Figure 8. Map of southeastern North Carolina depicting the Northeast Cape Fear River and the three permanent monitoring stations used for field survey and vegetation analysis. RI=Rat Island, FC=Fishing Creek, and PGC= Prince George Creek. Adopted from Hackney et al. (2006).

Table 2. Site descriptions for Rat Island (RI), Fishing Creek (FC), and Prince George Creek (PGC) located along the Northeast Cape Fear River, NC. Data reported are averaged for the years 2000-2006 from Hackney et al. (2006). Site coordinates are the location of the 1st substation used in the Cape Fear River Monitoring project for the given transect. Tidal frequency is the average number of tides at the site out of 27. Salinity is the average of the mid point of salinity to which the site is exposed. Max salinity is the maximum salinity recorded, to which the site has been exposed. Tidal Height is the average water height, in meters, above the marsh surface during recorded tides.

Site	Distance from Wilmington, NC (km)	Elevation NAVD88 (m)	Site Coordinates	2000-2006				
				Tidal Duration (hrs)	Tidal Frequency	Salinity	Max Salinity	Tidal Height (m)
Rat Island	6.4	0.27	34.1814 N 77.5740 W	6.08	25.43	3.77	13	1.86
Fishing Creek	12.8	0.43	34.2016 N 77.5940 W	6.39	19.57	1.11	9	0.87
Prince George Creek	25.6	0.21	34.2210 N 77.5619 W	7.49	26.14	0.11	2	1.47

procedure computes a correlation between two n by n distance matrices and is free from the assumption of independence of values within a matrix.

RESULTS

Eighty-nine plant species representing 54 families were identified at the three sites (Table 3). Distinct plant associations corresponding to the three sites, and therefore salinity level, were evident in the ordinations, using the compliment of Jaccard's index as a measure of distance (Figure 9). Similar groupings of plots according to site result from ordinations regardless of whether herb or woody stem data were used (Figures 9b, 9c). A Mantel test, using the asymptotic approximation approach indicated that differences among plots in species composition between the herb and canopy layers were highly positively correlated ($r=0.82$, $p<0.0001$). In addition, differences among plots in species composition were highly positively correlated with differences in environmental variables ($r=0.69$, $p<0.0001$).

DCA results indicate collinearity among variables used in analysis (Table 4). This is to be expected as the environmental parameters used can serve as proxies for one another. Tidal duration (TDAVE), maximum salinity (SAMAX), average soil chloride concentration (CLAVE), and average soil sulfate concentration (SUAVE) were correlated with midpoint of the salinity range (SAMID). Similarly, average flood frequency (FEAVE) and average water height (WHAVE) were correlated. Pearson's correlation coefficient indicated a significant correlation, for both herb and woody cover

Table 3. Species identified in 9 NCVS plots, nomenclature follows Radford et al. (1968). Species codes given are those used in ordination of species. Average cover values reported for each site are the midpoints of the average NCVS cover class (Peet et al. 1998). Site abbreviations are RI=Rat Island, FC=Fishing Creek, PGC=Prince George Creek.

Family	Scientific Name	Species Code	Average Cover		
			RI	FC	PGC
Aceraceae	<i>Acer rubrum</i> L.	Acerub	0.17	0.83	20.83
Alismataceae	<i>Sagittaria lancifolia</i> L.	Saglan	0.50	1.50	
Amaranthaceae	<i>Amaranthus cannabinus</i> (L.) J. D. Sauer	Amacan		0.83	0.03
Amaryllidaceae	<i>Hymenocallis</i> sp. Salisbury <i>Toxicodendron radicans</i> (L.) Kuntze	Hymeno Toxrad	0.03		
Anacardiaceae			0.37	0.50	1.17
Apiaceae	<i>Cicuta maculata</i> L. <i>Eryngium yuccifolium</i> L. <i>Hydrocotyle verticillata</i> Thunberg <i>Sium suave</i> Walter	Cicmac Eryyuc Hydver Siusua		0.50 0.20	0.03
Aquifoliaceae	<i>Ilex opaca</i> Aiton <i>Peltandra virginica</i> (L.) Kunth	Ileopa Pelvir	0.17	0.53	1.50
Araceae	<i>Serenoa repens</i> (Bartman) Small	Serrep	0.17	1.83	4.17
Arecaceae			0.03		
Aspidaceae	<i>Onoclea sensibilis</i> L.	Onosen			0.03
Asteraceae	<i>Baccharis halimifolia</i> L. <i>Bidens laevis</i> (L.) BSP <i>Bidens polylepis</i> Blake <i>Boltonia asteroides</i> (L.) L'Her <i>Mikania scandens</i> (L.) Willd. <i>Murdania keisak</i> <i>Senecio glabellus</i> Poiret	Bachal Bidlae Bidpol Bolast Miksca Murkei Sengla	0.83	0.20 0.20 0.37 0.20 0.33	0.50 2.70 0.83
Balsaminaceae	<i>Impatiens capensis</i> Meerb. <i>Alnus serrulata</i> (Aiton) Willd.	Impcap Alnser		0.17	0.50
Betulaceae				0.17	24.17
Bignoniaceae	<i>Campsis radicans</i> (L.) Seemann	Camrad		0.03	0.37
Blechnaceae	<i>Woodwardia areolata</i> (L.) Moore	Wooare		1.17	0.50
Caprifoliaceae	<i>Viburnum dentatum</i> L.	Vibden		0.03	
Clethraceae	<i>Clethra alnifolia</i> L.	Clealn			0.03

Table 3 cont.

Commelinaceae	<i>Commelina virginica</i> L.	Comvir			0.07
Convolvulaceae	<i>Cuscuta campestris</i> Yuncker	Cuscam		1.50	0.50
Cornaceae	<i>Cornus stricta</i> Lam.	Corstr		2.50	9.50
Cyperaceae	<i>Carex</i> spp.	Carex1		0.20	3.83
	<i>Carex comosa</i>	Carcom	0.50	0.17	
	<i>Carex</i> spp.	Carex3		0.17	0.37
	<i>Carex hylanolepsis</i>	Carhyl	11.83	2.50	0.03
	<i>Scirpus americanus</i> Persoon	Sciame	28.83		
	<i>Scirpus robustus</i> Pursh	Scirob	1.75		
Cyrtaceae	<i>Cyrtilla racemiflora</i> L.	Cyrrac			0.03
Ericaceae	<i>Leucothoe racemosa</i> (L.) Gray	Leurac		0.33	4.83
	<i>Lyonia lucida</i> (Lam.) K. Koch	Lyoluc			1.23
	<i>Oxydendrum arboreum</i> (L.) DC.	Oxyarb			1.17
Fabaceae	<i>Amorpha fruticosa</i> L.	Amofru		0.07	
	<i>Apios americana</i> Medicus	Apiame		0.83	0.33
Fagaceae	<i>Quercus lyrata</i> Walter	Quelyr		0.17	
	<i>Quercus nigra</i> L.	Quenig	0.17		
	<i>Sabatia calycina</i> (Lam.) Heller	Sabcal		0.07	0.10
Hamamelidaceae	<i>Liquidambar styraciflua</i> L.	Liqsty			0.03
Juncaceae	<i>Juncus roemerianus</i> Scheele	Junroe	0.37	0.03	
Lauraceae	<i>Persea palustris</i>	Perpal	0.33	0.23	1.83
Liliaceae	<i>Smilax laurifolia</i> L.	Smilau		0.20	0.50
	<i>Smilax bona-nox</i> L.	Smibon	0.03	0.50	0.50
	<i>Phoradendron serotinum</i> (Raf.) M. C. Johnston	Phoser			0.03
Lythraceae	<i>Decodon verticillatus</i> (L.) Ell.	Decver		0.67	0.33
Magnoliaceae	<i>Magnolia virginiana</i> L.	Magvir		0.17	0.20
Myricaceae	<i>Myrica cerifera</i> L.	Myrcer	0.50	2.50	17.50
Nyssaceae	<i>Nyssa sylvatica</i> Marshall	Nyssyl	0.17	5.50	8.17
Oleaceae	<i>Fraxinus caroliniana</i> Miller	Fracar	0.17	4.17	8.17
	<i>Fraxinus pennsylvanica</i> Marshall	Frapen		2.50	8.33
	<i>Fraxinus profunda</i> Bush-S	Frapro		4.83	24.17
	<i>Ludwigia bonariensis</i> (Micheli) Hara	Ludbon		0.37	0.20
Orchidaceae	<i>Habenaria repens</i> Nuttall	Habrep			0.03
Osmundaceae	<i>Osmunda cinnamomea</i> L.	Osmcin			0.17

Table 3 cont.

	<i>Osmunda regalis</i> (Willd.) Gray	Osmreg	0.53	1.83	
Pinaceae	<i>Pinus serotina</i> Michaux	Pinser			0.20
Poaceae	<i>Arundinaria gigantea</i> (Walter) Muhl.	Arugig		0.17	
	<i>Cinna arundinacea</i> L.	Cinaru		1.50	0.33
	<i>Elymus virginicus</i> L.	Elyvir		0.17	0.37
	<i>Panicum</i> spp.	Panic	1.83		
	<i>Spartina cynosuroides</i> (L.) Roth	Spacyn		15.17	
	<i>Zizania aquatica</i> L.	Zizaqu		1.33	
	<i>Zizaniopsis miliacea</i> (Michaux) Doell & Ascherson	Zizmil			1.50 0.17
Polygonaceae	<i>Polygonum arifolium</i> L.	Polari		0.67	4.83
	<i>Polygonum hydropiper</i> L.	Polhyd		2.83	2.17
	<i>Rumex verticillatus</i> L.	Rumver	0.20	2.83	
Pontederiaceae	<i>Pontederia cordata</i> L.	Poncor		0.50	1.37
Ranunculaceae	<i>Clematis crispa</i> L.	Clecri			0.03
Rosaceae	<i>Rosa palustris</i> Marshall	Rospal	0.10	0.83	1.50
	<i>Rubus</i> spp. L.	Rubus	0.20		0.03
Rubiaceae	<i>Cephalanthus occidentalis</i> L.	Cepocc		0.67	
	<i>Galium obtusum</i> Bigelow	Galobt			0.03
Saururaceae	<i>Saururus cernuus</i> L.	Saucer		1.50	4.83
Saxifragaceae	<i>Decumaria barbara</i> L.	Decbar			0.67
Taxodiaceae	<i>Juniperus virginiana</i> L.	Junvir	0.03		
	<i>Taxodium distichum</i> (L.) Richard	Taxdis		0.17	29.50 3.50
Typhaceae	<i>Typha angustifolia</i> L.	Typang	0.07		
	<i>Typha latifolia</i> L.	Typlat	0.50	0.37	
Ulmaceae	<i>Ulmus americana</i> L.	Ulmame			0.07
	<i>Boehmeria cylindrical</i> (L.) Swartz	Boecyl		0.33	1.83
Urticaceae	<i>Viola pedata</i> L.	Vioped			0.20
Vitaceae	<i>Parthenocissus quinquefolia</i> (L.) Planchon	Parqui	0.17	0.20	0.50
	<i>Vitis rotundifolia</i> Michaux	Vitrot			0.23

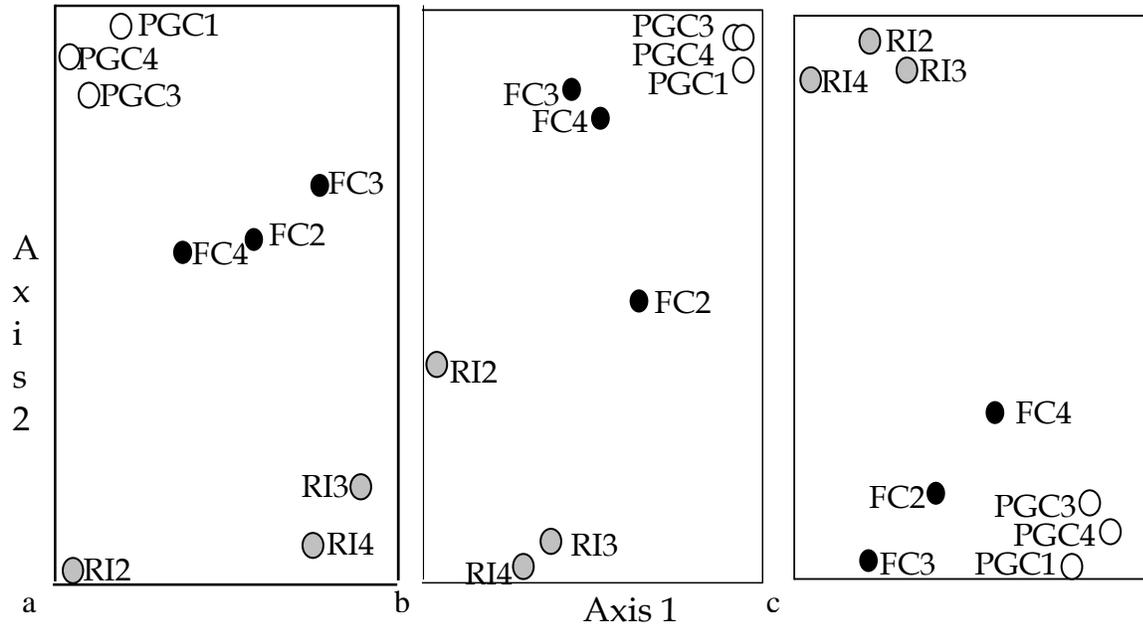


Figure 9. NMS of vegetation plots along a salinity gradient, using the compliment of Jaccard's index as a measure of distance a.) for all species surveyed b.) woody stems only c.) herbaceous species only. For all ordinations black circles= Prince George Creek, white circles= Fishing Creek and grey circles= Rat Island.

Table 4. Weighted correlation matrix of environmental variables from DCA analysis in relation to herbaceous species (A) and woody species (B) composition. Collinearity of variables is revealed but to be expected as environmental variables used were close proxies for each other. TDAVE= Average Tidal Duration, FEAVE= Average number of flood events, WHAVE= Average water height above swamp surface, SAMID=Average of yearly salinity range mid points, SAMAX= Maximum salinity recorded at a site, CLAVE= average soil chloride concentration, SUAVE= average soil sulfate concentration.

A.	TDAVE	FEAVE	WHAVE	SAMID	SAMAX	CLAVE	SUAVE
TDAVE	1						
FEAVE	0.2819	1					
WHAVE	-0.2562	0.8552	1				
SAMID	-0.8786	0.2104	0.6867	1			
SAMAX	-0.9895	-0.1406	0.3929	0.9383	1		
CLAVE	-0.9643	-0.0177	0.5031	0.9737	0.9924	1	
SUAVE	-0.9987	-0.233	0.3048	0.9017	0.9956	0.9764	1
B.	TDAVE	FEAVE	WHAVE	SAMID	SAMAX	CLAVE	SUAVE
TDAVE	1						
FEAVE	0.9517	1					
WHAVE	0.8722	0.9892	1				
SAMID	-0.8878	-0.7037	-0.5493	1			
SAMAX	-0.9974	-0.927	-0.8344	0.9188	1		
CLAVE	-0.9871	-0.8904	-0.7827	0.95	0.9961	1	
SUAVE	-0.9997	-0.9445	-0.8609	0.898	0.9988	0.9905	1

data, between axis one and both TDAVE and SUAVE; therefore Axis 1 serves as a proxy for the range of these variables (Table 5) with the strongest correlations being between Axis 1 and TDAVE ($r = -0.785$) and SUAVE ($r = 0.8$) for woody species. Pearson's correlation coefficient also indicated a significant positive correlation between Axis one and herbaceous species: *Carex comosa* and *Typha latifolia*, which are therefore positively correlated with soil sulfate and tidal duration. A significant negative correlation was found between Axis one and the following species: *Alnus serrulata*, *Hymenocallis* spp., *Impatiens capensis*, *Mikania scandens*, *Polygonum hydropiper*, *Saururus cernuus*, and *Smilax bona-nox*, which are therefore negatively correlated with soil sulfate and tidal duration (Table 6). DCA and NMS show similar patterns of plot and species ordinations (Figures 9-11). DCA ordinations show that Rat Island plots and representative species (*Juncus roemerianus* and *Typha latifolia*) are most closely related to higher salinity and soil sulfate (Figure 11). Prince George plots and representative species (*Alnus serrulata* and *Saururus cernuus*) are more closely related to lower salinity (Figures 10 & 11).

Furthest downstream, Rat Island contained no live cypress where plots were established, nor any woody stems >3 cm DBH. It was dominated by brackish marsh species such as *Scirpus americanus*, *Carex* spp., *Spartina cynosuroides*, and *Scirpus robustus* (Table 3). The next site up river, Fishing Creek, exhibited the highest dominance of cypress both in basal area and number of stems (Figure 12). The canopy was dominated by *T. distichum*, *Nyssa sylvatica*, and *Fraxinus* spp. The understory was characterized by *Myrica cerifera* and *Cornus stricta*, while herbaceous vegetation was characterized by

Table 5. Pearson correlation coefficient for abiotic variables and axis 1 in DCA analysis. Correlation >0.75 are significant and shown in bold. Environmental parameters used were: TDAVE= Average Tidal Duration, FEAVE= Average number of flood events, WHAVE= Average water height above swamp surface, SAMID=Average of yearly salinity range mid points, SAMAX= Maximum salinity recorded at a site, CLAVE= average soil chloride concentration, SUAVE= average soil sulfate concentration.

	Woody Stems	Herbaceous Stems
TDAVE	-0.8	-0.838
FEAVE	-0.562	0.138
WHAVE	-0.194	0.587
SAMID	0.532	0.985
SAMAX	0.749	0.909
CLAVE	0.687	0.953
SUAVE	0.785	0.865

Table 6. Pearson correlation coefficients between species and axis 1 in DCA analysis. Statistically significant (at $\alpha = 0.05$) values correspond to an $r > 0.75$. See Table 3 for species codes.

Woody Species	r	Herbaceous Stems	r	Herbaceous Stems Cont.	r
Acerub	-0.689	Amacan	-0.227	Parqui	-0.443
Alnsr	-0.754	Amofru	-0.244	Pelvir	-0.645
Amofru	0.34	Apiame	-0.481	Pholeu	-0.358
Bachal	0.57	Arugig	-0.129	Polari	-0.733
Cephal	0.675	Bidenl	-0.221	Polhyd	-0.765
Clealn	-0.472	Bidenp	-0.151	Poncor	-0.544
Corstr	-0.683	Boecyl	-0.644	Rumver	-0.204
Cyrrac	-0.356	Bolast	-0.169	Sabcal	-0.88
Fracar	-0.242	Camrad	-0.645	Saglan	0.045
Frapen	-0.56	Carex1	-0.581	Saucer	-0.78
Frapro	-0.78	Carex2	0.775	Sciame	0.691
Ileopa	-0.394	Carex3	-0.623	Scirob	0.644
Leurac	-0.714	Carex4	0.656	Sengla	-0.618
Liqsty	-0.472	Cicmac	-0.223	Serrep	0.565
Lyoluc	-0.454	Cinaru	-0.268	Siusua	-0.398
Magvir	-0.523	Clecri	-0.358	Smilau	-0.742
Myrcer	-0.533	Comvir	-0.537	Smibon	-0.948
Nyssyl	-0.235	Cuscam	-0.395	Spacyn	0.508
Perpal	-0.632	Decver	-0.431	Toxrad	-0.612
Pinser	-0.444	Decbar	-0.418	Typang	0.735
Quelyr	0.586	Elyvir	-0.651	Typlat	0.808
Quenig	0.264	Eryyuc	-0.169	Vioped	-0.469
Rospal	-0.209	Galobt	-0.305	Vitrot	-0.507
Rubus	0.255	Habrep	-0.305	Wooare	-0.194
Taxdis	0.608	Hydro	-0.537	Zizaqu	-0.214
Ulmame	-0.626	Hymen	-0.786	Zizmil	-0.219
Vibden	-0.137	Impcam	-0.757		
		Junroe	0.739		
		Junvir	0.565		
		Ludbon	-0.432		
		Miksca	-0.775		
		Murkei	-0.437		
		Onosen	-0.405		
		Osmcin	-0.405		
		Osmreg	-0.605		
		Oxyarb	-0.358		
		Panic	0.664		

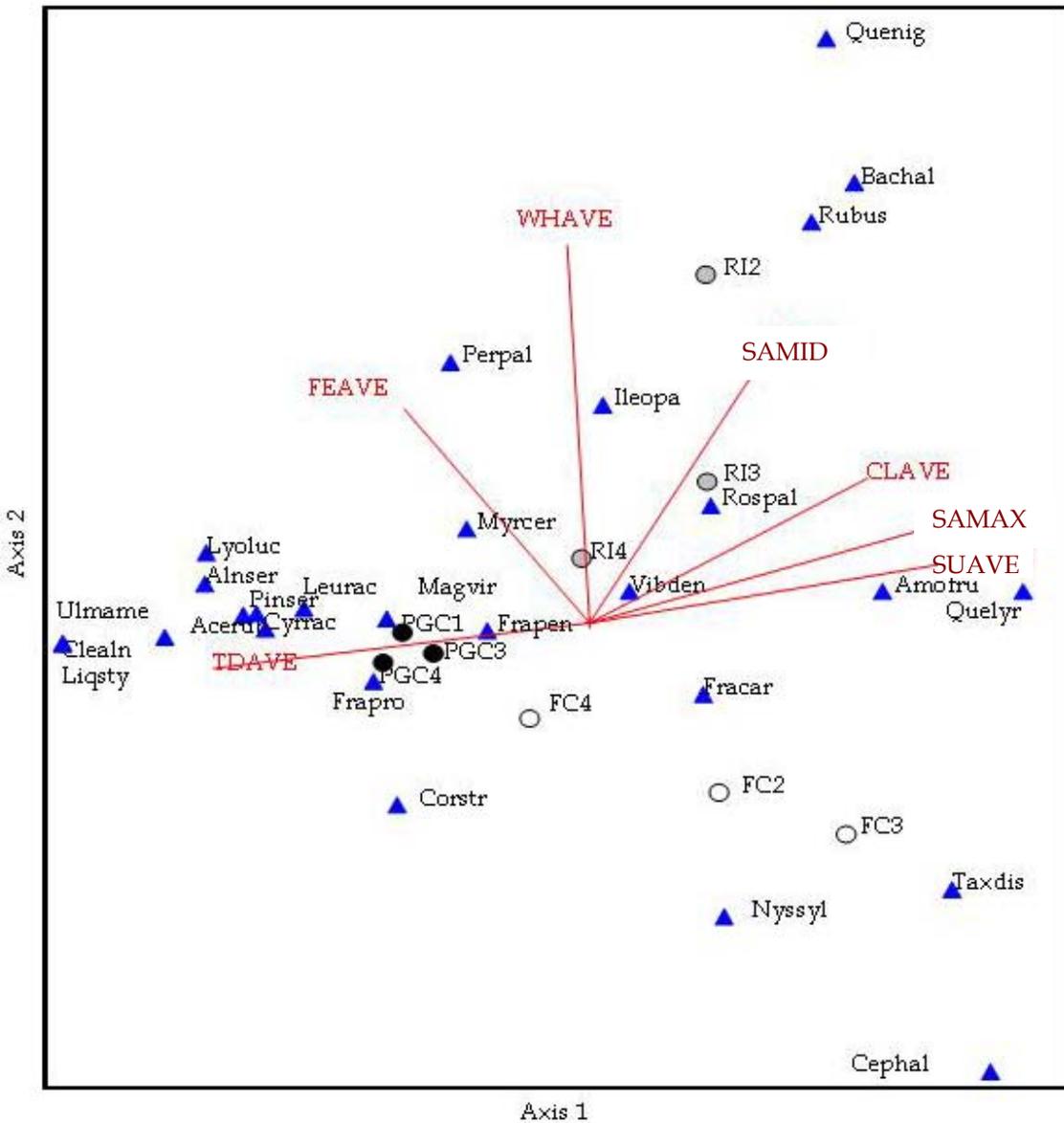


Figure 10. DCA ordination of plots and woody species. Species codes follow those listed in Table 3. Lower Axis 1 scores correlate with proxy variables for flooding, while higher scores correlate with proxy variables for salinity. Environmental abbreviations follow those listed in Table 4 and 5. Plots with black circles= Prince George Creek, white circles= Fishing Creek and grey circles= Rat Island.

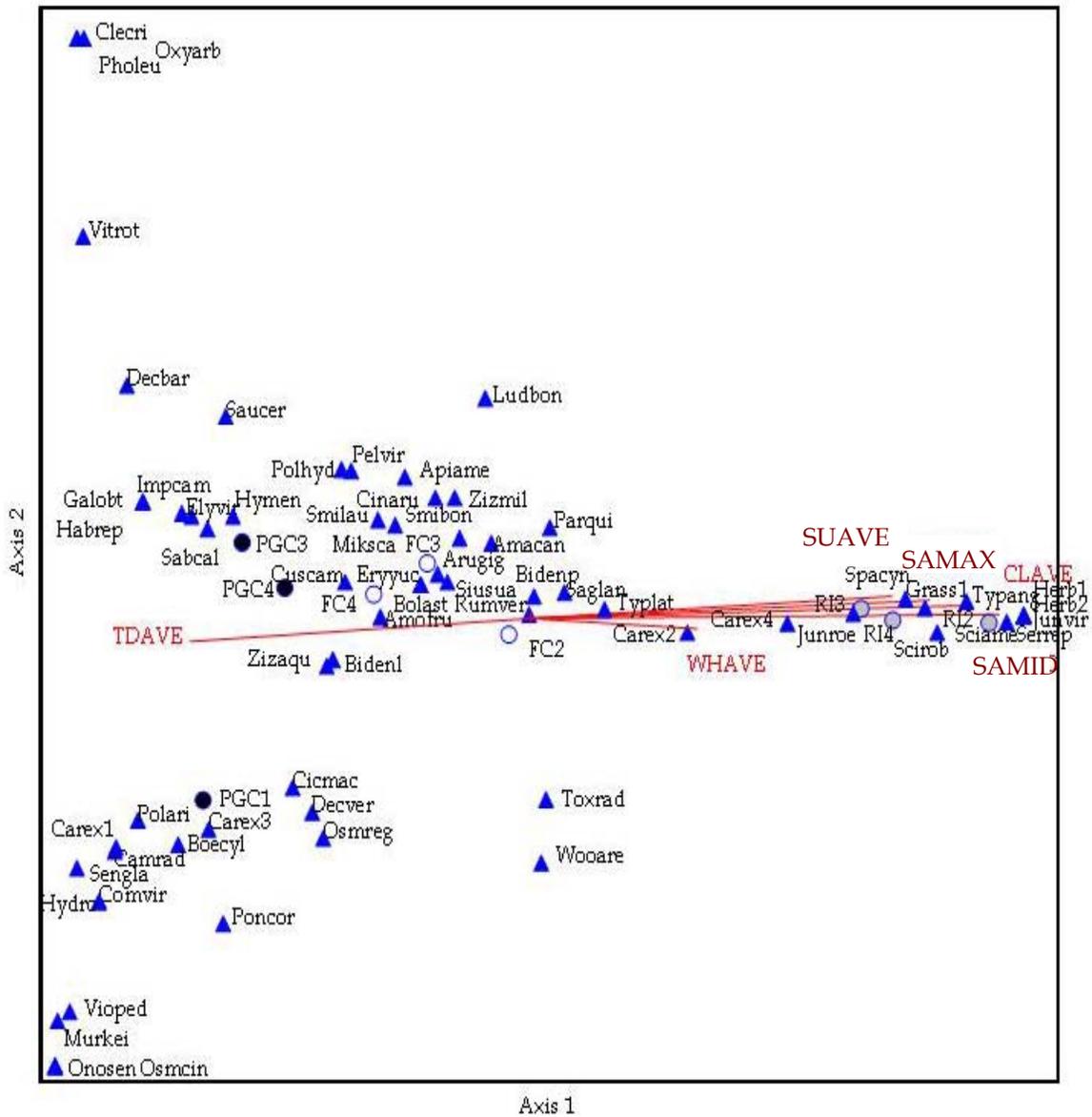


Figure 11. DCA ordination of herbaceous species and plots. Species codes follow those listed in Table 3. Lower Axis 1 scores correlate with proxy variables for flooding, while higher scores correlate with proxy variables for salinity. Environmental abbreviations follow those listed in Table 4 and 5. Plots with black circles= Prince George Creek, white circles= Fishing Creek and grey circles= Rat Island.

Rumex verticillatus, *Sium suave*, and *Polygonum hydropiper* (Table 3). Furthest upstream, Prince George Creek had few large cypress, however, it was the only site with visible cypress recruitment (Figure 13). The canopy was dominated by *Fraxinus* spp., *T. distichum*, and *N. sylvatica* with an understory of *Acer rubrum*, *Alnus serrulata*, *Cornus stricta*, and *Leucothoe racemosa*. Herbaceous vegetation was characterized by *Polygonum hydropiper*, *P. arifolium*, *Peltandra virginica*, and *Saururus cernuus* (Table 3).

Rat Island is routinely exposed to saline pulses (Table 2, Figure 14, and Hackney et al. 2006). It was exposed to a peak in salinity of 13 during the fall of 2004, when a severe drought allowed saline water to penetrate further up river. Fishing Creek has been exposed to a high saline pulse of 9, while Prince George Creek has been exposed to a high of 2, both in the fall of 2001.

DISCUSSION

Flooding frequency and duration, and the related biogeochemical and physiological stresses with which they are associated are major forces structuring floodplain communities (Keeland et al. 1997, Kozlowski 2002). Herbivory, competition, and nutrient availability are also important (Myers et al. 1995). The impacts of tidal flooding, and resultant salinity intrusion, on riparian vegetation are poorly known, due to few opportunities for comparing natural riparian vegetation along salinity gradients. This study indicated that variation in tidal duration and sulfate delivery, and therefore differences in salinity intrusion, were significantly associated with variation in plant

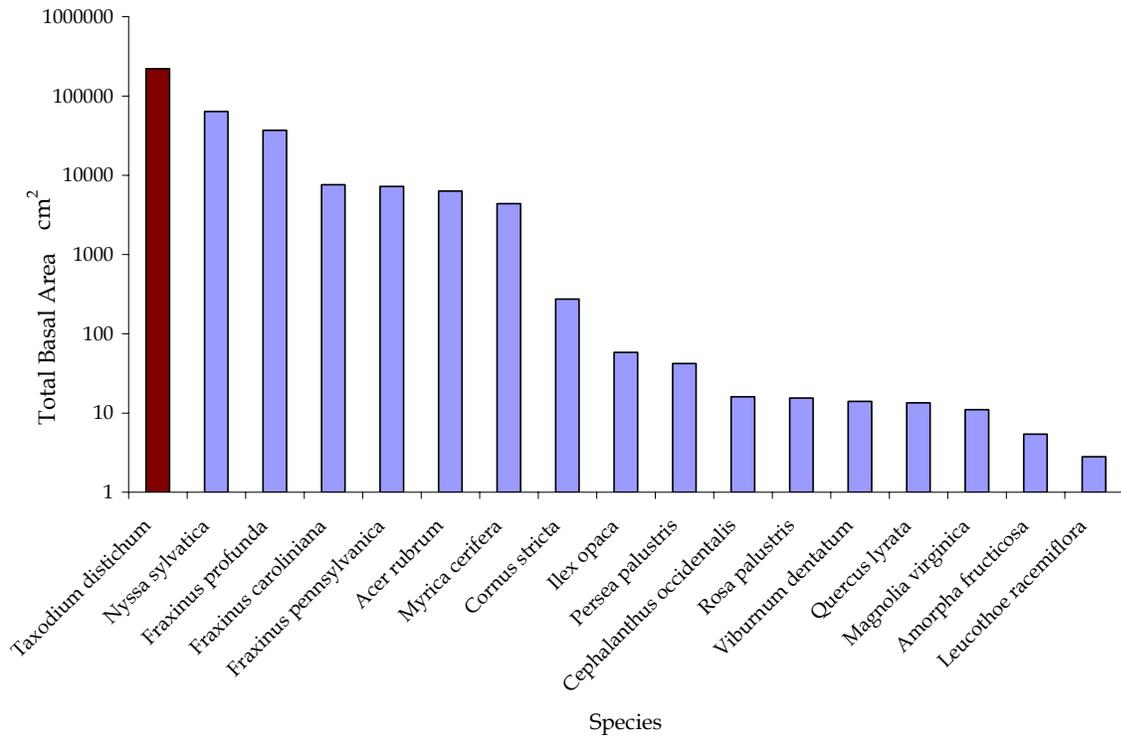
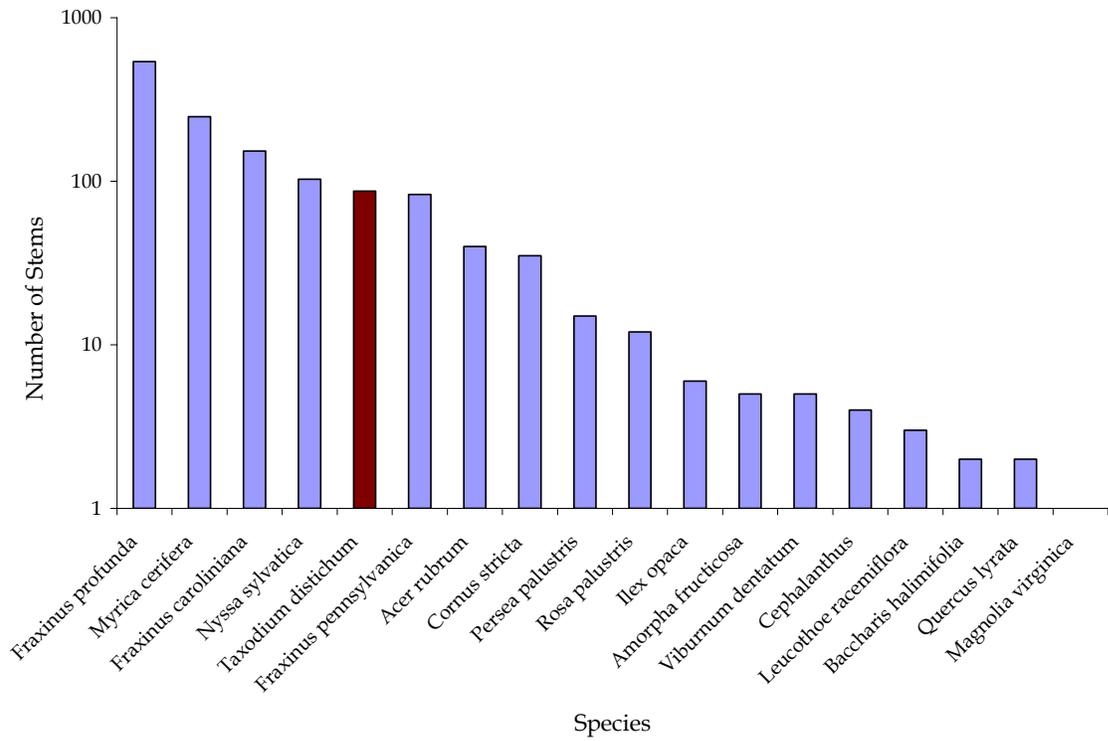


Figure 12. Rank abundance by (a) number of stems and (b) total basal area for all woody species at Fishing Creek. Scale is logarithmic.

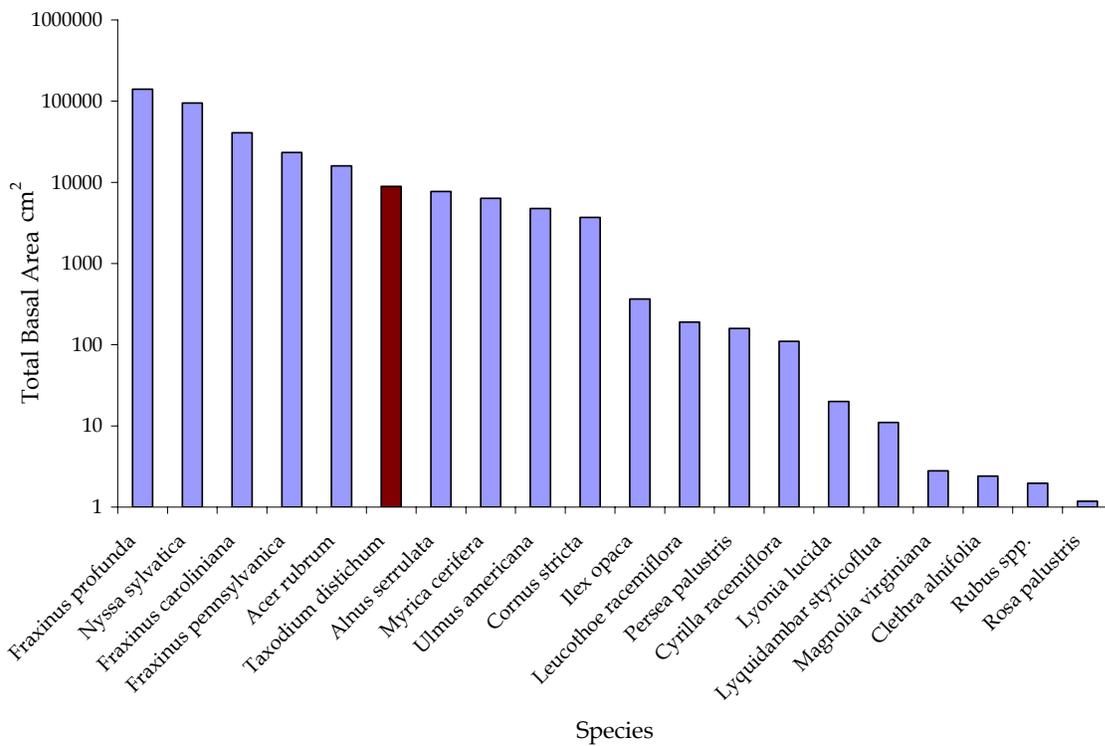
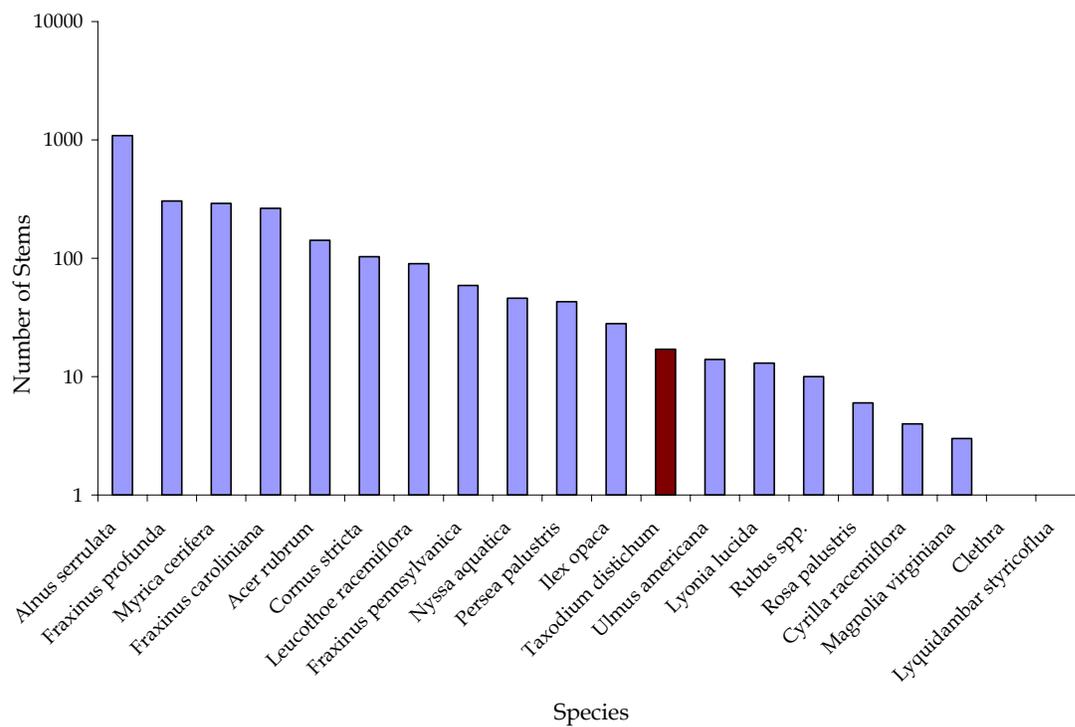


Figure 13. Rank abundance by (a) number of stems and (b) total basal area for all woody stems at Prince George Creek. Scale is logarithmic.

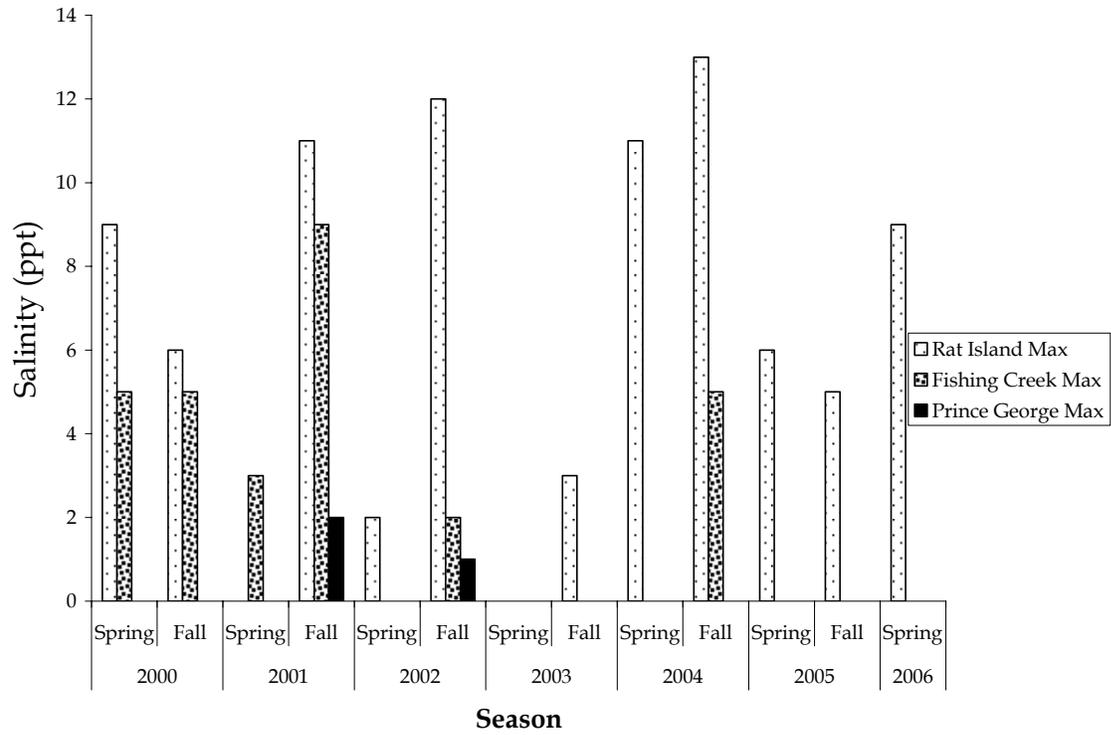


Figure 14. Maximum salinity exposure by site from 2000-2006. Modified from Hackney et al. (2006).

composition and distribution (Figures 9-11). Presumably, anoxic conditions caused by waterlogging, coupled with increased sulfate delivery from sea water create unfavorable to intolerable conditions for some plant taxa by limiting oxygen availability at the roots and creating metabolic byproducts of bacteria, especial highly toxic hydrogen sulfide (Kozlowski 1984, 1997).

Differential species response to salinity and flooding determines its abundance and persistence in the landscape, therefore, impacting species composition. *Taxodium distichum* tolerate freshwater flooding better than many other associated wetland species (Mattoon 1917, Mitsch and Ewel 1979, Shanklin and Kozlowski 1985, Keeland et al. 1997, Anderson and Pezeshki 2001, Middleton and McKee 2004). One of the adaptations that may permit it to tolerate flooded soils is the ability to increase root porosity by 163- 193%, thereby increasing oxygen exchange under anaerobic soil conditions (Anderson and Pezeshki 2001). Dickson et al. (1972) have shown that *T. distichum* is better able to assimilate nutrients from anoxic, flooded soils than *N. aquatica*, giving it a competitive advantage in permanently flooded habitats. Similarly, Donovan et al. (1988) found that *T. distichum* was better able to survive flooded conditions than three other common bottomland hardwood species, except when exposed to high water levels and high temperatures.

Despite their ability to persist in freshwater flooded conditions, flooding by saline water has been shown to cause die offs of mature *T. distichum* stands (Allen 1992,

Conner 1995, Conner and Inabinette 2003) and may be the major factor limiting their recruitment in coastal swamps (Chapter 1 of this thesis). The inability to germinate in saline flooded conditions, for *T. distichum* and other freshwater wetland species, results in the reversion of swamps to marsh vegetation. For example, the most downstream site, Rat Island, is most affected by salinity pulses as reflected in the vegetation composed of dead cypress trees and high cover of halophytic vegetation (Table 3) (Wells 1928, Schafale and Weakley 1990). Williams et al. (1999) observed a similar pattern of reverse succession in coastal Florida where relict stands of *Sabal palmetto* existed. These stands were not regenerating due to sea level rise and herbaceous vegetation was converting to brackish and salt marsh. The change in understory vegetation followed the introduction of tidal flooding. It was not until environmental conditions became unfavorable for the original forest understory that salt marsh species were able to establish.

Reverse succession in cypress swamps has been observed in a variety of coastal areas (DeLaune et al. 1987, Allen 1992), but this is the first study to quantify cypress community structure and composition along a salinity continuum. Establishing baseline studies for future monitoring of vegetation in the face of changing salinity is critical to validating models of biotic changes in ecosystems due to sea-level rise. Using a space-for-time substitution, it appears that brackish marsh is colonizing upstream habitats, moving from Rat Island to Fishing Creek. This process may continue upstream to Prince George Creek as sea level rises.

At Fishing Creek, the herbaceous vegetation was still mostly characteristic of a freshwater swamp forest, but halophytic taxa (e.g. *Juncus roemerianus*) that are more characteristic of brackish marshes have increased significantly in abundance. *Juncus roemerianus* was not observed at the site in 1999, when monitoring began (Hackney et al. 2006). *Juncus roemerianus* is better able to compete in saline conditions and is predicted to move landward as sea level rises (Adams 1963).

In many areas facing the impacts of sea level rise, a common proposed management practice is to increase freshwater flow to the swamps thereby allowing 1) flushing of sodium and related ions from the soil and 2) increasing allochthonous inputs to the floodplain community, which allows for the accretion of soils. The Northeast Cape Fear River is a blackwater system confined to the coastal plain and is low in suspended solids. Sediment supplies in other coastal rivers are interrupted by dams and not able to accrete. Thus, the pattern of conversion and species/community replacement is likely to continue with sea level rise. Modifications of the river channels that allow increased tidal flushing or increased salinity will accelerate the loss of *T. distichum* swamps. They will be forced inland until dispersal is impeded by roads, railroads, and other human developments. *Taxodium distichum* swamps will be relegated to less flooded, fresher portions of the river.

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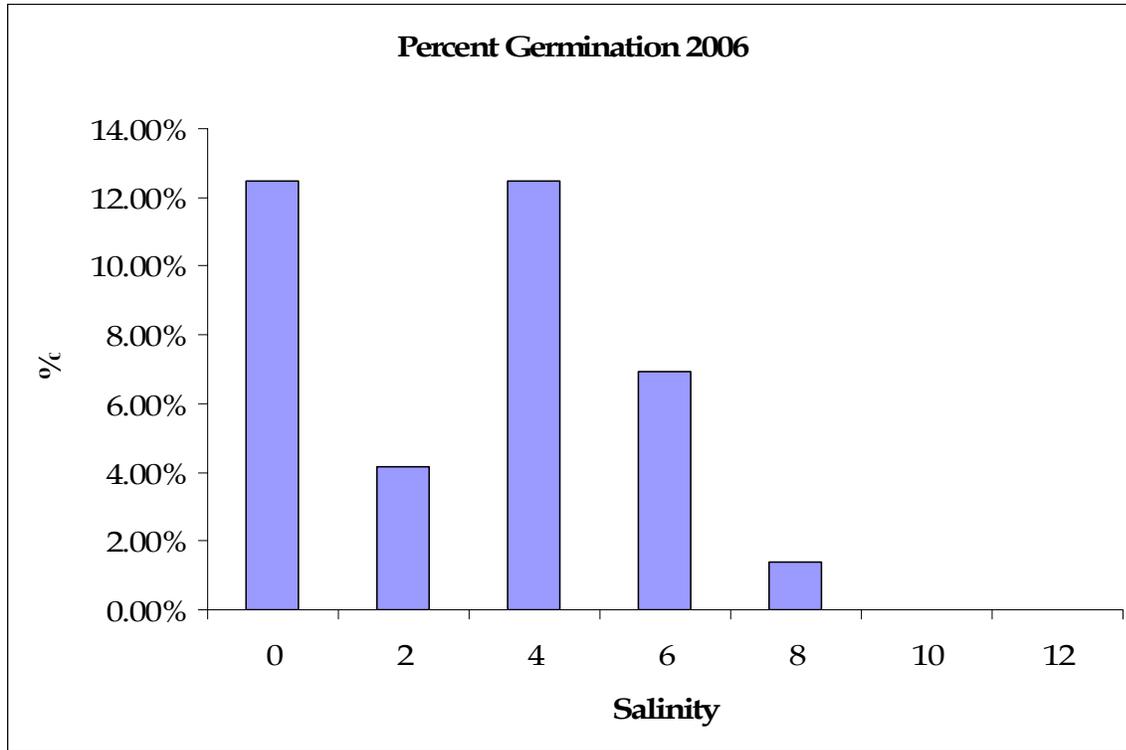
SUMMARY

As sea level continues to rise, bringing with it a landward encroaching tidal signature, floodplain habitats, such as cypress swamps, are being altered. Within the watershed of the Cape Fear River, NC bald cypress compromise ~80,000 hectares of the floodplain. Much of this habitat falls within tidal influence and its persistence is currently under threat. Anthropogenic alterations of the watershed, including deforestation for development and changes to the bathymetric features of the river, via dredging, modify the hydrologic regime to which these communities are exposed. Coupled with rising sea level, historically freshwater areas are exposed to saline water intrusion.

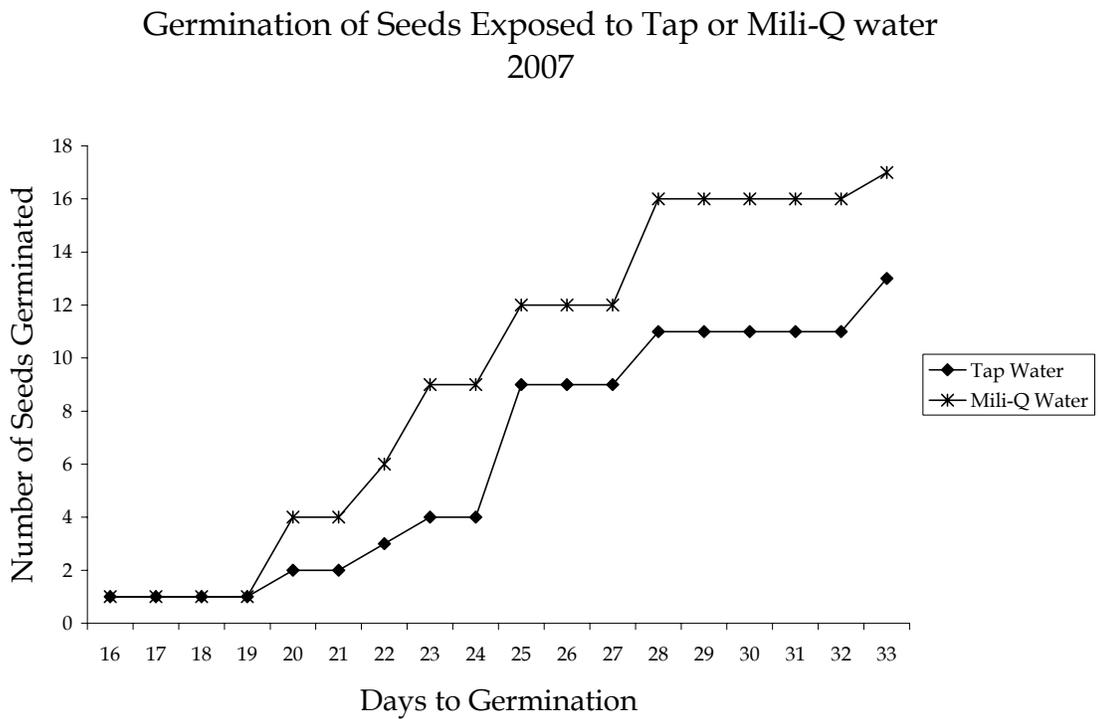
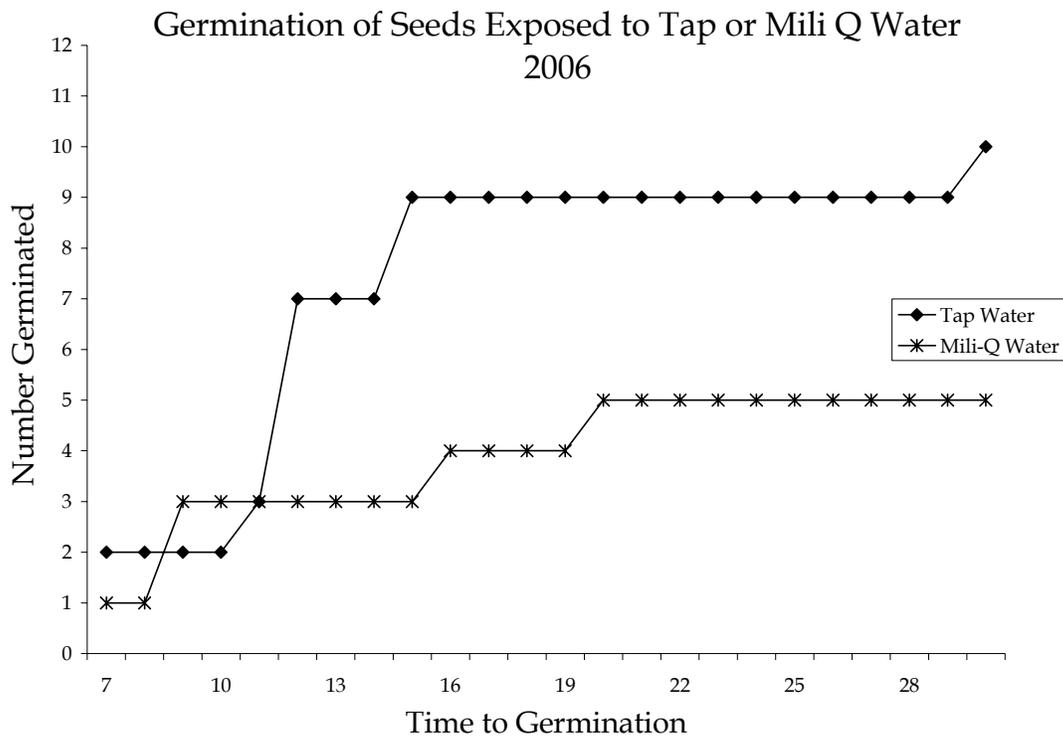
Despite their wide spread distribution throughout the Southeast and the many studies on adult and seedling response to salinity and flooding, there is a paucity of information regarding the germination capability of bald cypress when exposed to different salinity regimes and how this in turn affects community structure. This study examined these issues. The primary goals of the study undertaken were to 1) assess natural recruitment of cypress along the Northeast Cape Fear River at three points along a salinity continuum, 2) create a cursory description of the community composition and structure of cypress habitat at these three points, 3) assess germination capability of bald cypress from the Northeast Cape Fear River population under controlled greenhouse conditions.

This thesis is formatted, such that, two chapters are written with the intent that they will be submitted for publication. Chapter One of this thesis focuses primarily on the natural recruitment observed along the Northeast Cape Fear River and germination capability of bald cypress under controlled greenhouse conditions. Chapter Two, in turn, focuses on the plant community structure of cypress habitats along the river. Appendices include detailed information not incorporated in the Chapters.

Appendix 1. Data from a pilot study conducted in 2006 on the germination capabilities of cypress under varying salinity regimes. The experimental design was not robust enough to capture the underlying trend. Planting methods were also amended to maximize germination after this study. Initially seeds were buried beneath 1.5 cm of soil. Seeds were laid on the soil surface in the second study (Chapter 1 of this thesis).



Appendix 2. Data from 2006 and 2007 on the germination of cypress watered with either tap water or Mili-Q water. In 2006, 120 seeds from the population were sown on filter paper and placed in Petri dishes, 10 replicates of 6 seeds per Petri dish per watering treatment were used. Everyday one droperful of either tap or Mili-Q water was applied to the filter paper and germination was recorded. The same experiment was conducted in 2007 but with 9 seeds per Petri dish per watering treatment for a total of 180 seeds. This was to determine whether or not it was permissible to use tap water in place of Mili-Q water for mixing the different salinity waters. In 2006, it appeared that tap water increased germination and so it was deemed appropriate to use tap in place of Mili-Q water. In 2007, tap water use did not result in increased germination, but did not seem to drastically affect germination success. No statistical analysis has been conducted to determine if there was an effect of water source on germination.



Appendix 3. In an attempt to increase replication in the greenhouse study, four more tubs of 45 seeds per watering treatment were planted one week after the initial study began in 2007. Appendix 3 shows the differences between week of planting and % germination. Seeds that were planted one week later had significantly lower germination success than their counterparts in the same salinity treatment; germination at 0 salinity was 28.9% for seeds planted in week one and decreased to 20.7% for seeds planted in week two. Therefore, the seeds planted in week two were not used in analysis of germination success reported in Chapter 1 of this thesis.

