APPENDIX A -- RESULTS OF A LITERATURE REVIEW FOR THE LOXAHATCHEE RIVER AND ESTUARY

CONTENTS

One of the requirements for developing a minimum flow for a river is the use of “best available information” (Section 373.042(1), Florida Statutes). To assist in defining a flow/salinity relationship or recommended minimum flow for the Loxahatchee River, a literature review was conducted to review the results of studies of the river that were performed over the past three decades. The studies are summarized in this appendix. An additional section was written to summarize what is currently known about the effects of salinity on baldcypress. Topics that were covered include the response of baldcypress to acute and chronic exposure of saline waters, age sensitivity, intraspecific variation, symptoms of salinity stress, and the potential mechanisms used by baldcypress to minimize the concentration of chloride and sodium ions in plant tissue. Also included at the end of this appendix is the list of all documents that were reviewed by South Florida Water Management District (SFWMD or District) staff.

STUDIES RELATED TO THE PROBLEM OF SALTWATER INTRUSION

The studies related to the problem of saltwater intrusion are organized chronologically beginning in the early 1970s when the problem of saltwater intrusion within the Northwest Fork became a major public concern. Several portions were obtained from Law Environmental (1991).

- **Land et al. (1972)** discussed saltwater intrusion in the Loxahatchee River and area ground water. The report states that reduced flows to the Loxahatchee River have permitted seawater to advance several miles upriver where it had previously been held back near the mouth of the inlet. This reduction in flow was thought to be primarily due to the diversion of freshwater flow from the Loxahatchee Slough into the Southwest Fork and to irrigation operations. The report comments that it was necessary to discontinue pumping at several wells during the drought of 1970-71 because of increasing chloride levels in Tequesta and Juno Beach. The report also states that the old Jupiter municipal wellfield and wells near the Loxahatchee River Estuary, the Intracostal Waterway, and the ocean had to be shut down several previous years because of saltwater intrusion.

- **Rodis (1973a,b)** In 1973, the United States Geological Survey (USGS) published a report entitled: *The Loxahatchee - A River in Distress, Southeast Florida* (Rodis 1973b). The study concluded that the primary cause of environmental problems facing the river was the upstream movement of salt water. The study attributed changes in the flora and fauna in Jonathan Dickinson State Park and other portions of the river to this cause. Rodis (1973) prepared an atlas for the USGS describing these problems and outlined some possible solutions.

  Before the area was settled in the early 1900s, stream flow and the water table were high enough to hold seawater at the coast. Coastal springs seeped into the ocean from the shallow aquifer and streams carried fresh water seaward to Jupiter Inlet. The Everglades and area lakes stored most of the rain that fell. This stored water recharged the shallow aquifer and provided a nearly constant wet season flow to the sea. Early settlers began to drain the Everglades to make additional land available for farms and homes and lakes and streams were connected to the sea. As a result, the flow of fresh water into the estuary and shallow aquifer gradually diminished and salt water moved inland to compensate for the reduction of fresh water. In 1972, after the 1971 drought, wedges of saline ground water threatened municipal wellfields in Tequesta and Juno Beach and saltwater ocean tides reached the upper portion of the Loxahatchee River.

  Rodis (1973) also noted that by 2000, freshwater needs for coastal communities may increase eight to ten fold. He made numerous suggestions for meeting these demands:

  - Freshwater sources were available west of the present wellfields.

  - Use of the present wells could be prolonged by reduced pumping rates, wider well spacing, improved well design, and water reuse.

- Treated sewage effluent and storm water runoff could be reused to irrigate golf courses and maintain a freshwater head at the freshwater-saltwater interface.

- The remaining freshwater environment of the Loxahatchee River can be maintained by diverting enough fresh water from inland canals and water storage areas to the river to retard the advance of salt water.

- Preventing upstream movement of saltwater tides by constructing a salinity barrier, dam, or lock downstream would also aid in maintaining the freshwater environment.

Rodis (1973) also reviewed existing flow and salinity data for the Northwest Fork of the Loxahatchee River and concluded that a minimum continuous flow of 50 cubic feet per second (cfs) (23,000 gallons per minute) across the Lainhart Dam, was required to retard further upstream movement of salt water in the river under the drainage and development conditions that existed at the time of the study. This assumed that flows from other contributing tributaries would provide another 90 cfs such that the total Northwest Fork flow would be 130 cfs below Kitching Creek.

- **Birnhak (1974)** conducted an early study on the effect of freshwater discharges from canals in six southeastern coastal estuaries with the Loxahatchee River Estuary. The report briefly discusses the problem of saltwater intrusion into the upper reach of the Northwest Fork and the replacement of the cypress forest in the lower reaches of the river by salt tolerant species.

Freshwater flows to the lower three stations (Stations 7, 8, and 9) were reported to have a negligible effect in diluting the salinity of these areas during the period of the study. The uppermost station (Station 1), at the confluence of Kitching Creek and the River, remained essentially fresh throughout the twelve month period. A saltwater wedge intruded up river to Station 2 during the low flow period (April and May). The higher freshwater flows flushed out the saltwater wedge by August. Station 4 showed a good correlation between freshwater flow and salinity in that part of the river. Farther downstream at Station 6, the bottom salinity remained high and fairly constant throughout the study period.

Birnhak (1974) recommended that the freshwater flow to the Loxahatchee River be maintained. He suggested that 60 cfs would be sufficient to keep significant saltwater intrusion below Station 5. He suggested realigning existing canals and directing good quality stormwater runoff from the Florida Turnpike and the then yet to be constructed I-95 Highway into the Loxahatchee River. The report also listed redirecting discharge waters from the Loxahatchee Slough to the Loxahatchee River instead of to the C-18 canal. The SFWMD accomplished this redirection by installing a culvert (G-92) in the C-18 canal that diverted excess flows to the main stem of the Loxahatchee River in the mid-1970s (Dames and Moore 1989). Finally, Birnhak suggested the construction of a low head dam to act as a salinity control barrier immediately downstream of Jonathan Dickinson State Park. While this would prevent the saltwater wedge from moving up the river, it would also eliminate the flowing character of the lower river and interfere with navigation.

- **Christensen (1973)** made a preliminary investigation of the oyster bars that used to exist in the vicinity of the FEC railroad trestle prior to their removal in 1976-77. These bars occupied a significant portion of the narrowest part of the Loxahatchee River Estuary. Freshwater flow from the area (about 330 square miles) and tidal flow into the estuary must pass through this opening. Previous filling of this area further restricted this opening to about 510 feet wide. Christensen (1973) calculated that the oyster bars and bridge piling limited the area of free flow through the narrows to one-fifth of the existing width. Christensen's (1973) preliminary report recommended removing the living oysters to another location and dredging the remaining bars to a depth not greater than -6 feet mean seal level. His calculations indicated that this removal would not greatly increase the upstream encroachment of seawater to the Northwest Fork and would improve circulation in the estuary particularly along the south side of the river.

- **Alexander and Crook (1975)** produced a comprehensive study of the major changes in vegetation that have occurred in South Florida over the last 30 or more years. This study utilized aerial photographs and ground truthing to examine plant communities along the Northwest Fork of the Loxahatchee River and Kitching Creek. Plant species lists were compiled for Sites 13 (RMs 7-8), Site 14 (RMs 7.0-7.5), and Site 15 (RMs 6.0-6.5) on the Northwest Fork and Site 10 on Kitching Creek. Upon identifying the signature of the most abundant community types, they were able to use photointerpretation to identify major vegetative communities from a 1940 aerial photograph. Areas of dead and living cypress canopy with a mangrove understory were noted in 1970. They concluded that since 1940, prairie and swamp hardwoods had been displaced by pineland and mangrove communities due to a lowering of the groundwater table and invasion of salt water between RMs 6 and 8. They were able to identify areas of active logging in the aerial photographs, which could explain the loss of mature trees within portions of the watershed. Also, they mentioned the impact of fire, hurricanes, and heavy frost on the major plant communities. At RM 6.5, they collected freshwater peat at a depth of 24 inches below the surface. Based on this information, they further concluded that there was no evidence that cypress forest had extended much further downstream than about RM 6. Wanless (written communication, 1982) suggested that RM 6 has experienced brackish conditions for at least the last 4,500 years. Finally, Alexander and Crook (1975) predicted that the mangrove invasion would accelerate, if anthropogenic activities in the upper floodplain of the river further reduced the freshwater head.

- **FDEP 1985**. Ten years after publication of Alexander and Crook's (1975) study, the Florida Department of Natural Resources (FDNR 1985) produced a follow up report indicating that many mature cypress trees from river mile 7.0 to 9.0 were dead and the number of trees stressed near river mile 9.0 had increased substantially from 1979 to 1982 as compared to the 1975 study. By 1984, the majority of cypress trees downstream of Kitching Creek (RM 7.8) were observed to be dead (FDNR 1985).

- **Chiu (1975)** conducted a saltwater intrusion study to determine the effect of removing the oyster bars that had formed in the vicinity of the FEC railroad trestle over the mouth of the estuary. The oyster bars were considered by local government and citizens to be a major cause of the deteriorating condition of the river. This was due to their restrictive effects on tidal and freshwater flow that are vital to the self cleaning capacity of the river. The oyster bars were also considered to inhibit boating by local residents and tourists. Chiu's (1975) study was conducted to determine the effect of removing the oyster bars on the tides, tidal currents, and saltwater intrusion into the Loxahatchee River. The study consisted of field studies to determine the existing river hydraulics and salinity distribution. Salinity was measured at 43 stations, seven tide recorders were installed, and current measurements were taken at seven locations. Chiu relied on published soundings for river bathymetry. These data were used to set up and calibrate a two stage numerical model to predict the effect on the river system of removing the oyster bars.

  The study concluded that dredging the oyster bars to a depth of -6 feet MSL under and adjacent to the FECRR trestle and AlA bridges will decrease the tidal range on the east side of the bridges about three percent and the time phase will be delayed about five minutes. The tide range on the west side of the bridges will increase about three percent and the tidal time phase will advance about five minutes. The model predicted an increase peak flood tidal flow of 320 feet/second (ft') and the peak volume will increase by 4 x 106 ft. The model also predicted that the high water slack salinity profiles would move 260 feet to 600 feet further inland. This model was also used to predict the effect of removing the sandbars adjacent to the FECRR trestle and AlA Bridge along with the oyster bars. This modification resulted in a predicted further inland movement of the high slack salinity profiles by 350 feet to 900 feet.

- **Hill (1977)** conducted a salinity-monitoring project during the removal of the oyster bars in the vicinity of the FECRR trestle from August 5, 1976, to August 29, 1977. The objective was to determine the extent of saltwater intrusion in the Loxahatchee River estuary at high slack tide before, during and after the removal of the bars. Twelve permanent sampling stations were selected along the estuary from 1.44 to 9.24 river miles above Jupiter Inlet. Measurements were taken at the deepest location at each of the sites and intermediate sites were sampled to determine the exact location of the saltwater wedge for that tide. The leading edge of saltwater intrusion in this study was defined as the location where the salinity equaled 1 ppt at high slack water, one foot above the streambed. Measurements were taken at one foot above the streambed and one foot below the surface at each location. Salinity data were taken once a month for one year at the highest slack water tide each month. Hill (1977) presented no conclusions that related the tide and salinity changes to the oyster bar removal project. The report instead presents the data collection methodology and their findings on tables, maps, and graphs. The study estimates that the inflow measured at this gauge represents roughly one-third of the daily freshwater inflow to the river. The extent of the saltwater wedge appears to correlate more closely to the level of freshwater inflow than it does to the tide height data. The effect of the oyster bar removal on the salinity wedge is not apparent from these data.

- **McPherson (unpublished)** During 1980-81, McPherson studied the transitional area between the cypress forest community and the mangrove community on the Northwest Fork. In May of 1981, he observed surface salinities of 20 to 30 ppt in an area of dead and stressed cypress. In another area of intermediately stressed cypress, surface salinities ranged from 15 to 20 ppt. Shallow groundwater salinities decreased with depth below the land surface and distance from the river with the exception of areas where seepage of fresh water was observed from nearby higher pinelands. McPherson concluded that there was no evidence that cypress forest ever extended much further than his Site 7E (approximately river mile 5.5, RM) on the Northwest Fork. Site 7E was characterized as an area of dead cypress snags now populated by mangrove forest in the middle of the river. It was assumed that cypress were unable to survive due to high surface and groundwater salinities.

- **McPherson and Sabanskas (1980)** reviewed the history and environmental concerns of the Loxahatchee River basin identifying those areas that need further study. For most of the areas identified, establishment of a baseline for the estuary and basin was recommended. Specific needs included saltwater encroachment, sedimentation, and pollution in the estuary. Specific objectives of their study included defining: (a) basin characteristics (e.g., basin divides, land cover, land use, and soil type; (b) major input and output patterns of water, sediment, and selected chemical constituents to and from the estuary, and the transport of these items within the estuary; (c) baseline information on the bottom sediment, seagrass beds, and wetlands, and on areal, tidal, and seasonal patterns of water quality within the estuary; and (d) selected functions and interrelationships within the estuary in terms of water, sediment, chemical input and output, basin characteristics, circulation, water quality and biology. The balance of this report concerns itself with the first objective of the investigation; it presents the major physical features of the basin, divides the basin into sub-basins, identifies the direction of surface water flow, and locates selected USGS stations on a photomosaic map.

- **McPherson et al. (1982)** conducted a study (1980-81) to provide baseline information on the estuary. The report was presented in the form of a large one page atlas providing information on bathymetry, hydrology, and benthic sediment and biota. The base map provides information on the location of seagrass, sand bars and oyster bars in the estuary. Other maps and tables show the evolution of the sand bars over the previous forty years, the bottom sediment characteristics, and the biomass of seagrass. The report also gives a history of the estuary to aid in understanding the physical and biological characteristics of the present system. The Loxahatchee River estuary was originally formed by a gradual rise in the sea level and the level of rainfall in this area. The estuary was shaped and modified by natural processes until the early 1900s when early settlers made alterations to the upstream watershed. Due to the opening of additional inlets and changes to area water flow, the inlet closed up and remained closed most of the time except when opened by dredging until 1947. The estuary has been maintained open by dredging since that time.

- **Duever (unpublished data)** The principal problem affecting the plant communities located along the NW Fork of the Loxahatchee River has been the gradual reduction in the number and geographic extent of healthy bald cypress in the floodplain and their replacement by mangroves. Virtually all of the cypress in the lowermost area of the wild and scenic river segment are now dead, as are the majority of cypress below Kitching Creek. Above Kitching Creek, the number of live trees increases with increasing distance up the river. An analysis conducted by the U.S. Geological Survey between 1979 and 1982 documented the extent of environmental stress in the bald cypress community along the Loxahatchee River corridor (Duever, unpublished data). The study examined core samples collected from cypress trees at 21 sites (69 trees in total) located up and down the river to identify changes in tree ring width and quality over time. The results of the study indicated that although all of the trees sampled had experienced stress at periodic intervals over their life histories, the proportion of stressed trees in the downstream section (below river mile 9.0) increased from 30 percent in 1940 to 80 percent in 1982. Stressed trees above River Mile 9.0 decreased from 11 percent to 3 percent during the same period. Further, the study found a high correlation between the incidence of growth stress and high salinity in surface water and soils**. Figures A-1 and A-2,** show the results of this study for the percent of trees with poor quality tree rings, percent of trees with small rings, and percent of trees with large rings from year 1760 to 1982.

- **Russell and McPherson (1984)** conducted an intensive study of the relationship of salinity distribution and freshwater inflow in the Loxahatchee River estuary from 1980-1982. The report presents baseline information on the areal and seasonal variations of salinity in the Loxahatchee River estuary and evaluated the effects of freshwater inflow on that salinity regime. The report contains information on areal and vertical salinity distribution, freshwater inflow, tidal fluctuations, and rainfall. The study had the benefit of both extreme high and low freshwater flow periods during their study. Characteristic low flows were measured in the dry season (November to May) and extremely high freshwater flows occurred for several days following Tropical Storm Dennis (August 18, 1981).

  Freshwater inflows to the major tributaries were measured at six continuous gauging stations including the Northwest Fork of the Loxahatchee River, Cypress Creek, Hobe Grove Ditch, and Kitching Creek. Information on freshwater inflow to the Southwest Fork was provided by the SFWMD at S-46. Key results of this study showed that in the NW Fork, a gradient of fresh water mixing with seawater occurs over a distance of 5 to 10 miles. The saltwater wedge (identified in this study as a bottom salinity > 2 ppt) moved daily over 0.5 to 1. 5 river miles as a result of change in freshwater inflow. The estimates of the total amount of fresh water [from all sources] needed to restrict brackish water (>2 ppt) from the upstream reaches of the NW Fork at mean high tide if tidal discharges are not altered are presented in **Table A-1**.

Table A-1. Estimates of the Total Amount Fresh Water Needed to Restrict Brackish Water at Mean High Tide

Total* Mean Daily Freshwater Discharge (cfs)	Upstream Extent of Saltwater Wedge in River Miles
220	7.0
130	8.0
120	8.2
75	9.0
43	10.0
26	11.0

* includes NW Fork + all upstream tributaries

For comparison, average inflow of fresh water to the NW Fork during the 1980-81 extended dry season was 57 cfs. Large volume freshwater discharges from the C-18 canal to the SW Fork can cause extreme vertical stratification of the estuary with a freshwater layer on the surface overlying denser seawater. However, most of the time, no fresh water is discharged from C-18, and tidal flows of high salinity water (>25 ppt) predominate the SW Fork. **Figure A-3, Appendix A** provides a summary of salinity profiles (at high tide) developed by Russell and McPherson (1984) for the NW Fork of the Loxahatchee River under various flow discharge rates.

Based on the flow/salinity relationships provided in this study, the total amount of fresh water (from all sources) needed to restrict the saltwater wedge from the upstream reaches of the river was determined to be 120 cfs at river mile 8.2 (located at the confluence of Kitching Creek and the NW Fork of the river). Of this total flow, 57% (or about 68 cfs) is derived from the NW Fork, 32% (38 cfs) from Cypress Creek, 7% (8 cfs) from Hobe Grove Ditch, and 4% (5 cfs) from Kitching Creek (Russell and McPherson, 1984)

- **Russell and Goodwin (1987)** describe the development of a two-dimensional estuarine simulation model (SIMSYS 2D) to simulate tidal flows and circulation patterns in the Loxahatchee River Estuary system (Jupiter Inlet, the North and South Intracoastal Waterways, the central embayment, and three tributary streams). The model was calibrated using new and existing tidal stage data, tidal velocity data, and new information relating to the distribution of tidal flow volumes. The model was used to predict water levels, water-velocities, and water-transport and could simulate tidal flow and circulation in the estuary. The report acknowledges that the 250 foot grid size of the model, the narrow channel widths of connecting waterways, and the central embayment channel to the inlet makes detection of circulation features within them difficult.

- **Dames and Moore (1989)** submitted a preliminary plan to the SFWMD for conceptual approval that would supply additional fresh water for the NW Fork of the Loxahatchee River and groundwater recharge to areas east of the Loxahatchee Slough. The plan called for restoration of the Loxahatchee Slough to predevelopment conditions and the construction of above ground reservoirs to retain wet season rainfall until the dry season when it could be used to supply the Loxahatchee River and groundwater recharge.

Specific objectives of the plan were:

- To restore the predevelopment conditions in the Slough by raising and maintaining water levels to closely reflect those present prior to development.

- To provide an additional base flow of fresh water to the headwaters of the Loxahatchee River in order to prevent further saltwater intrusion and impacts to wildlife habitat.

- To restore and maintain groundwater and surface water levels in areas east of the Loxahatchee Slough which are currently experiencing depressed groundwater levels due to withdrawals from municipal well fields and other large users.

- The planned reservoirs encompassed approximately 4,800 acres with a total storage capacity of 26,000 acre-feet. The plan also used the existing canal network so that the further excavation of canals will be kept to a minimum. A probabilistic computer modeling analysis was conducted on the proposed design (Dames and Moore 1989). The results of the probabilistic model predicted that the following objectives could be achieved:

- An increase in the duration of Loxahatchee Slough water levels at or above elevation 17.5 feet MSL

- An increase in the duration of 50 cfs or higher flows to the Loxahatchee River from 75 percent of the time to 97 percent, and;

- The plan provided an average flow of 20 cfs for ground water recharge to areas east of the Slough every year.

The plan also called for a canal connection to the Loxahatchee River via Cypress Creek to provide direct discharge from a reservoir located to the west of the creek in Martin County. The plan would create an additional 650 acres of shallow wetland habitat, and 3,965 acres of deepwater aquatic habitat, restore and enhance 4,200 acres of freshwater wetland habitat, provide flood control benefits for the South Indian River Water Control District, reduce the amount of excess water in the canal systems during the wet season, reduce amounts of flood waters discharged into the southern part of the estuary through the Southwest Fork, and maintain residential lake levels east of the Slough and additional areas available for recreation to local citizens.

- **Law Environmental (1991)** developed the *West Loxahatchee River Management Plan* for the Jupiter Inlet District. A portion of the report discussed the analysis of unpublished flow, salinity and rainfall data collected from the NW Fork by the SFWMD (Dewey Worth, personnel communication, 1991). The data set (January 1985-January 1988) included *in situ* water column measurements of salinity collected on a monthly basis at high tide from 18 sites located within the three forks of the river and estuary. This period of record encompassed years of above and below normal rainfall, including extreme high flow and prolonged periods of zero from both G-92 and S-46. Flows from G-92 were used as a surrogate parameter for estimating freshwater discharges to the NW Fork.

Average and median flows discharged to the NW Fork of the river through G-92 were recorded as 50 and 56 cfs, respectively over the three year study. Average bottom salinity recorded at river miles 9.2, 8.0, 6.9, and 5.7 were 0.4, 2, 8, and 17 ppt, respectively. Vertical stratification of the water column was most prominent at river miles 2.6 and 8.0. A shallow sill in the river bend at RM 4.0 acted to restrict the saltwater wedge from penetrating upstream. Under extreme low flow conditions (G-92 flows < 8 ppt) the salinity profile of the NW Fork was transported upstream by slightly more than one river mile. Under these low conditions average bottom salinity values recorded at river miles 9.2, 8.0, 6.9, and 5.7 were 3, 13, 17, and 25 ppt. Surface and botton salinity at river mile 8, located within the area of cypress die-off, was less than 0.2 ppt and 0.4 ppt for 50% of the 1985-1988 data set.

The study suggested that releases from S-46 could be used to form a freshwater "plug" in the central embayment which can be transported upstream within the NW Fork on a rising high tide. In this sense these releases would act as a salinity barrier to prevent saltwater intrusion of the NW Fork. In addition, discharges from S-46 were reported to have substantial effects upon salinity regimes many miles upstream of the NW Fork. Possible management options for the river may include maintaining discharges from S-46 and G-92 in order to maximize the effectiveness of limited volumes of fresh water.

Although the flows from S-46 and G-92 were shown to be independent from each other, the lower portion of the estuary demonstrated a significant relationship with flows from S-46. Flows from S-46 were also strongly associated with the bottom salinity at river mile 5. In order to maximize the amount of fresh water available to the Loxahatchee River, management options could include maintaining designated discharges from both G-92 and S-46 that are linked to the daily tidal cycle.

Based on the SFWMD 1985-1988 data set, the report divided the tidal Loxahatchee into five zones. Zone I extends down river to a point below Kitching Creek and is tidal fresh water **(Table A-2).** From Hobe Grove Ditch to Kitching Creek it overlaps Zone II, which extends downstream to river mile five. Zone III begins near river mile seven and includes much of Zone II, but also includes the upper embayment area down to river mile four. Zone IV covers the river between miles five and three, and Zone V runs from river mile four to the inlet.

Table A-2 Proposed Salinity Zones for the Loxahatchee River and Estuary*

Zones	Minimum Salinity (ppt)	Maximum Salinity (ppt)
I	Fresh	4.0
II	2	15
III	11	19
IV	15	28
V	23	Marine

* As proposed by Law Environmental (1991) using the estuarine classification system of Bulger et al. (1990) which is based on species salinity ranges

The report concluded that salinity control within the river would be better served if implemented as a program of freshwater discharge management. Salinity control by a regulated freshwater discharge at average flow conditions of 40 to 50 cfs could benefit the region by establishing a stable salinity wedge location for the estuary system.

- **Ward and Roberts (unpublished)** Between October 1993 and January 1994, Ward and Roberts examined six vegetative transects on the Northwest Fork of the Loxahatchee River between Indiantown Road (State Road #706) and the mouth of Kitching Creek (RM 8.0). Generally the density (tree density stems/hectare) of bald cypress (*Taxodium distichum*) increased from downstream (Transect #6, RM 8.5) near Kitching Creek to upstream (Transect #1, upstream of RM 10 just north of State Road #706). A noticeable drop in cypress occurred at Transect #3 (upstream of RM 10 and just north of Interstate 95), which was heavily populated with pop ash (*Fraxinus caroliniana*), red maple (*Acer rubrum*) and cabbage palms (*Sabal palmetto*). They did not examine the density of mangrove during their study.

- **McPherson and Halley (1996)** in their publication, *The South Florida Environment: A Region Under Stress*, documented the encroachment of mangroves, along with the overall reductions in freshwater flows, maintenance of lower groundwater levels, short duration high volume freshwater flows for flood protection, and changes in the quality of runoff.

- **Hohner (1994)** used aerial photography and satellite imagery to examine vegetative changes in the Loxahatchee Slough between 1940 and 1989. The Loxahatchee Slough is part of the headwaters of the Loxahatchee River. In a comparison of the vegetative classes forest land (hammock), nonforested wetland (wet prairie), forested wetland (cypress), and nonforested wetland (marsh), she concluded that with GIS analysis there was a general trend toward dryer hydroperiod vegetation land cover. A portion of the study area, in which water levels were raised to pre-channelization levels in 1979, exhibited a recovery to longer hydroperiod vegetation.

- **Dent (1997).** Water quality studies were performed by the Loxahatchee Environmental Control District to assess the effects of constructing two rock and earthen dams to close off channels that had been providing a "short cut" for water flow up and down the NW Fork of the River (Dent 1997). The construction of these two dams helped to restore more natural river flow to the historic meandering oxbow sections of the river. This added approximately 0.7 river miles distance that salt water must now travel upstream to impact the freshwater cypress swamp communities of the NW Fork. Salinity studies were conducted for two, nine month periods prior to, and after construction of the project. Maximum daily bottom salinity from two water quality stations located above and below the construction sites were used for comparison. Results of the study showed that closure of these short cuts resulted in lower salinity concentrations after construction, and longer response times for the upstream station to experience an increase in salinity as compared to pre-construction values.

- **Dent and Ridler (1997).** The Loxahatchee River District completed a 12-month salinity monitoring study of the NW Fork (March 1996-February 1997), to establish a flow/salinity relationship using three water quality monitoring stations 63, 64 and 65 (see **Figure 15** of this report). Water quality station #63 is located near the Jonathan Dickinson boat ramp; water quality station #64 is located downstream of Kitching Creek; water quality station #65 is located upstream of Kitching Creek. Although the monitoring period was slightly wetter than normal, the following observations were made.

    - Flow rates, decreasing from 150 cfs to below 60 cfs over five days, resulted in the almost immediate movement of salt water into the monitoring area. As flow increased to near previous levels, the saline water was rapidly pushed downstream out of the monitoring area.

    - During the study period, salinity was recorded on 294 days. On the average, 50 cfs was met on 33% of the 294 monitoring days. When flow was equal to or less than 50 cfs, the salinity was greater than 2 ppt at the station 65 95% of the time and the salinity was greater than 2 ppt at station 64 100% of the time. Therefore, 50 cfs was insufficient to maintain freshwater conditions at either of the two sampling stations. It was determined that if flows of 100 cfs or higher were achieved, for 41% of the sampling days, salinity at Station 65 would not be greater than 2 ppt and the salinity at Station 64 would be greater than 2 ppt only 9% of the time.

    - Daily tidal fluctuations through the Jupiter Inlet influence the salinity of the NW Fork in a short-term cyclical process and salinity at a specific location may increase by 5-10 parts per thousand (ppt) in the few hours between low and high tides. Tides in the Loxahatchee River typically range from 2-3 feet in height and move at approximately 5-10 mph and influence the river over a distance of 10 river miles. Winds also have a significant effect on the height of the tide; for example, strong northeast winds that occur during autumn and winter months tend to push additional amounts of saline water upstream into the River, resulting in higher than average tides. (Russell and McPherson 1984).

- Based on their analysis of data they concluded that during dry periods a minimum flow of 50 cfs was insufficient to maintain the saltwater wedge downstream of water quality stations #64 and #65. The study suggested both a minimum and a maximum flow range for the NW Fork of the Loxahatchee River. Their proposed minimum flow rate for the delivery of water to the NW Fork was 75 cfs (as measured at the SR 706 bridge) for the end of the dry season (May), and 130 cfs for the wet season (July-November). They also recommended a maximum flow target, i.e., discharges to the river should not exceed 150 cfs during the dry season (months of February-May), (dry season), and no greater than 300 cfs during the wet season (June-November).

- **SFWMD (1999)** As late as 1998, the original USGS flow target of 50 cfs established by Rodis (1973) was still identified as the recommended minimum flow target for the NW Fork. The origin of this target was based on water flowing over the Lainhart Dam; a broad crested weir located 0.1 mile north of SR 706. The dam consists of a combination of steel sheet pile and cypress logs constructed at elevation 10.5 ft. NGVD. Previous flow rating curves developed for the dam in 1984 tended to under estimate flow over the dam. The dam was reconstructed in 1998 and flow-rating curves developed for the dam tended to significantly over estimate discharge. For this reason District staff conducted a recalibration of the rating curve for the Lainhart dam in 1998 which provided a more realistic estimate of river flow over the dam. These data were compared to earlier U.S.G.S. data generated for the river ten and twenty years earlier and suggested that the 50 cfs minimum flow requirement for the river should be modified based on the newer information.

  This new calibration information was then used generate a more accurate picture of the relationship between discharges over the dam and maintaining bottom salinity values at key points along the river. Results of the analyses indicated that a minimum flow target of 64 cfs was needed to maintain the saltwater wedge (as 2 ppt bottom salinity) just downstream of the point at which Kitching Creek flows into the NW Fork of the river (SFWMD memorandum dated August 20, 1999).

A LITERATURE REVIEW OF THE EFFECTS OF SALINITY ON BALDCYPRESS

The previous section provided a comprehensive summary of the various studies that have been conducted on the Northwest Fork of the Loxahatchee River within the past thirty years and documented the changes that have occurred. Historically the Loxahatchee River supported a freshwater cypress community, which extended downstream to approximately river mile 5.5 (McPherson unpublished data). Due to hydrological alterations in the region caused by the building of canals and levees, the permanent stabilization of the Jupiter Inlet, and removal of oyster beds at FECRR Bridge the historic freshwater communities within and along the Loxahatchee River were exposed to higher salinity regimes. The saltwater intrusion and higher salinity levels allowed for salt-tolerant red mangroves (*Rhizophora mangle*) to extend upstream into areas historically dominated by baldcypress (*Taxodium distichum*). Increased levels of salinity are believed to adversely affect vegetation by three primary mechanisms: 1) direct effects such as specific toxicity and disruption of metabolic pathways 2) indirect effects such as declines in the levels of water and nutrient uptake in plants unable to adjust their internal osmotic potentials to compensate for reduced soil osmotic potentials and 3) alterations of the plant's energy relations (Greenway and Munns 1980, Allen 1994). The objectives of this section are to summarize what is currently known about the effects of salinity on baldcypress. Topics that will be discussed include the response of baldcypress to acute and chronic exposure of saline waters, age sensitivity, intraspecific variation among baldcypress individuals, symptoms of salinity stress, and potential mechanisms used by bald cypress to minimize the concentration of chloride and sodium ions in plant tissue.

According to Conner and Askew (1992) very little research has been conducted on salt tolerance in baldcypress. The studies that have been conducted to date focus primarily on areas in southeastern Louisiana, Georgia, South Carolina, and North Carolina. It is extremely important to note that although these studies can aid District staff in understanding the effects of salinity on baldcypress, the salinity thresholds cannot automatically be applied to populations in Southeast Florida. Florida's rivers and baldcypress communities have not been historically subjected to saltwater intrusion as other populations in the southeastern United States. The natural selective pressure of saltwater intrusion in other southeast populations favored the survival of more salt-tolerant individuals and the establishment of their offspring in brackish environments over a time span of many generations (Allen et al. 1997, Yanosky et al. 1995). The selective pressures in these areas began long before the early twentieth century, the timeframe that Florida's populations have been under selective pressure. Therefore, it is hypothesized that baldcypress populations in brackish environments in Louisiana, Georgia, South Carolina and North Carolina can tolerate higher salinity levels than individuals living in brackish environments in southeast Florida.

Acute and Chronic Effects of Saltwater Intrusion

A study was conducted in Georgetown, South Carolina to determine the impact that short-term saltwater flooding would have on six-month and eighteen-month baldcypress seedlings (Conner and Askew, 1992). The water had an initial salinity of 30 ppt and the water level was maintained at approximately five centimeters above soil surface. The seedlings exposure to saline waters ranged from zero to five days, and upon removal from the pool they were flushed with freshwater, and allowed to grow for an additional nine weeks. Only 30% of the six-month seedlings exposed to saline waters for one day survived to the end of the study and 0% survived flooding for two or more days. In contrast, 90% of the eighteen-month seedlings survived two days of flooding and 30% survived up to four days of flooding. The results of the experiment suggest that younger seedlings are much more sensitive and susceptible to saltwater flooding than older ones. Krauss, Chambers, and Allen (1998) found an indirect relationship between soil salinity levels and germination capacity of baldcypress seeds. The seeds used in the study were collected from eight open-pollinated half-sib families in Louisiana and Alabama and were exposed to varying levels of salinity (0 ppt, 2 ppt, 4 ppt, and 6 ppt). The mean germination under the four salinity regimes was 26.3, 22.9, 15.4, and 10.2%, respectively.

A study conducted by Krauss et. al (2000) compared survival of baldcypress seedlings planted on three sites in Louisiana characterized by coastal swamp forest degradation. The most saline site had an average salinity level of 2 ppt throughout the 1996 growing season, but the levels did rise to 4.2 ppt in August 1996 and as high as 15 ppt in October 1997. The average salinity values for the other two sites were 1.2 ppt and 0.5 ppt in 1996, with only slight modifications in 1997. Survival at the end of the 1996 growing season was 86.4%, 93.0%, and 99.5%, respectively, and 17.7%, 92.7%, and 98.3% at the completion of the 1997 growing season.

Researchers at Clemson University flooded baldcypress seedlings with water having salinities of 0 ppt, 2 ppt, and 10 ppt. Those exposed to zero ppt and 2 ppt survived until the end of the three-month experiment while those exposed to 10 ppt died within two weeks (USGS 1997). In contrast, Conner (1994) had a 100% survival rate for seedlings regularly watered for three months with a saline solution of 10 ppt. The difference between these experiments is most likely due to the fact that the former baldcypress were constantly inundated with saline water whereas the latter were only watered with it. Other studies suggest that baldcypress is more sensitive to the combined stress of flooding and salinity than either factor alone (Allen *et. al* 1996, Javanshir and Ewel 1993, Conner 1994).

Based on the results of these studies it can be concluded that the acute effects of saltwater intrusion on baldcypress seedlings are dependent on the salinity levels of the water, the age of the individuals, intraspecific variation among individuals, and the amount of time the seedlings remain flooded. At this time, very little is known about the response of mature bald cypress to acute doses of salinity and the chronic effects of long-term, low saline exposure on seedlings, saplings, and adult baldcypress. Adult intraspecific variation to salt-tolerance was discussed in a paper prepared by Yanosky and Hupp in 1995. Their study identified three mature individuals of baldcypress in Cape Fear River estuary, North Carolina that were living in highly saline areas (soil sodium concentrations ranging from 44.9 to 77.8 mg/g) where all of the other individuals had died and attributed their presence to higher salt-tolerance. The estimates of baldcypress salinity tolerance reported in the literature range from 0.1 ppt (Beal 1977) to 8.9 ppt (Penfound and Hathaway 1938). According to (1994) the most accurate estimates on the mean level of salt tolerance in Louisiana were derived from Chabreck (1972) and Wicker et al. (1981). Chabreck analyzed the average soil pore water salinity level for five baldcypress transect's located in close proximity to the swamp-marsh boundary, and estimated the average salinity tolerance to be 1.9 ppt with a standard deviation of 1.4 ppt. Wicker et al. graphed the relative rate of decline in baldcypress trees per acre versus salinity levels, and found that the rate of decline began to substantially increase between salinity levels of 1.8 and 2.1

ppt. From these findings Wicker concluded that baldcypress swamps would be confined to regions where the salinity level does not rise above 2 ppt for more than fifty percent of the time the baldcypress are exposed to flooding or soil saturation.

Symptoms of Salinity Stress in Baldcypress

There are many symptoms of salinity stress in baldcypress. These include reductions in diameter and height growth, leaf damage and biomass reductions, declines in stomatal conductance and net photosynthesis, and increases in chlorine and sodium ionic concentrations in leaf, stem, and root tissues. An indirect relationship between diameter growth and the number of days seedlings were flooded with saline water was noted in the study conducted by Conner and Askew in 1992. The six-month and eighteen-month seedlings experienced steady declines in diameter growth with the latter exhibiting shrinkage after the third day of flooding. Krauss et al. (1999) found the diameter growth of baldcypress seedlings flooded with water containing 6 ppt of sodium chloride significantly less than the control seedlings flooded with freshwater. A study was conducted by the U.S. Geological Survey from 1979 to 1982 to document the extent of salinity stress in baldcypress located along the Loxahatchee River (Duever – unpublished data). Core samples were collected from sixty-nine trees, all located along different portions of the river, to assess if the width of tree rings and their overall quality had changed overtime. It was found that although each tree sampled had endured stress at intermittent intervals throughout their life span, the percentage of individuals experiencing stress down-gradient of river mile nine increased substantially. In 1940, the percentage of stressed trees downstream of river mile nine was 30% whereas in 1982 it was 80%. The pattern of reduced radial growth discussed above has also been observed in populations subjected to permanent freshwater flooding (Young *et al*. 1993).

Conner and Askew also discovered that the height growth of the six and eighteen month cohorts was negative due to die-back of the main stem and resprouting of seedlings. A direct relationship was identified between the amount of die-back and the number of days of saltwater flooding for the older seedlings. Baldcypress seedlings exposed to 6 ppt and 8 ppt saline waters showed large declines in height growth in comparison to seedlings exposed to zero and 2 ppt (Allen, 1994). Similar results were noted in Krauss et. al (1999) in which the height increments for the 4 ppt and 6 ppt salinty treatments were fifty and twenty percent, respectively, of the control treatments. Baldcypress seedlings planted at sites with mean salinity levels of 2 ppt, 1.2 ppt, and 0.5 ppt in the 1996 growing season had average seedling heights of 121.6 cm, 165.9 cm, and 196.4 cm, respectively, at the end of the 1997 growing season (Krauss et al. 2000). Pezeshki (1990) did not find significant effects on height growth in seedlings watered with 3 ppt saltwater for sixty days, but did find the results significant when the seedlings were flooded. As in the case of ring diameter, many studies have also reported reductions in overall height of baldcypress exposed to permanent freshwater inundation (Conner and Day 1976, Duever and McCollom 1987, Keeland 1994, Mitsch *et. al* 1979 and Stahle *et. al* 1992).

Leaf injury and death both serve as good indicators of baldcypress experiencing salinity stress. A study conducted by Allen, Chambers, and Pezeshki in 1997, which exposed first-year seedlings to varying salinity conditions (0 ppt, 2 ppt, 4 ppt, 6 ppt, and 8ppt), determined that overall increases in salinity cause the highest reductions in leaf biomass followed by root biomass and then stem biomass. A significant decline in mean leaf area was noted between seedlings exposed to water containing 0 ppt and 2 ppt of sodium chloride although the individual responses varied. The more tolerant individuals did not experience die-back at the top of the plant and gradually lost their older basal leaves while maintaining and/or producing healthy, younger leaves. The less tolerant individuals experienced partial stem die-back and limited refoliation along the lower section of the stem. As salinity levels rose from 0 ppt to 4 ppt, a larger percentage of total seedling biomass was partitioned to the roots. It was suggested that this increase might be an adaptation to increase the overall surface area thereby increasing the probability that roots may encounter zones of lower salinity. The biomass partitioning to the roots was observed to decline at salinity levels above 4 ppt. The authors attributed this to the large increases in Na/K and Na/Ca ratios, which can cause significant disruption of root metabolic functions. Similar reductions in leaf, shoot, and root biomass were noted in the six-month and eighteen-month seedlings exposed to saltwater. The six-month seedlings biomass declined following one day of exposure while the eighteen month seedlings exhibited declines following two days, but showed signs of stabilization after four days (Conner and Askew, 1992). Krauss et al. (1999) evaluated the differences in root elongation among five half-sib families of baldcypress exposed to varying salinity conditions (0 ppt, 4 ppt, and 6 ppt). Root elongation was significantly greater for the control treatment than the other two treatments, which had values only 60% and 24% of the control, respectively.

Stomatal conductance[1] and net photosynthesis were reduced when salinity levels exceeded 3 ppt (Pezeshki et. al 1987, Pezeshki 1990, and Pezeshki 1992). The mean values of photosynthesis and stomatal conductance at 8 ppt were less than 30% of the mean values recorded at 0 ppt (Allen *et. al* 1997). A study conducted at the University of Georgia in which baldcypress seedlings were flooded with 32 ppt of saline water for forty-eight hours also found decreased levels of photosynthesis (University of Georgia Savannah River Ecology Laboratory News Release, 1996). A negative relationship between leaf ionic content and photosynthesis was noted in studies conducted by Pezeshki *et. al* (1988, 1990) and Allen (1994). Pezeshki's 1988 study found that internal leaf carbon dioxide concentrations remained constant as leaf ionic concentrations rose suggesting that the increased ion levels may interfere with normal photosynthetic processes by inhibiting RUBISCO or other enzyme activity.

[1] A numerical measurement which indicates either the rate of water vapor or carbon dioxide passage through the stomates or stomatal diameter.

The study conducted by Allen *et. al* in 1997 found that as overall salinity levels rose, greater amounts of chloride and sodium were detected in leaf, stem, and root tissue. The highest chloride concentrations were found in the leaves while sodium concentrations were virtually equal in leaf and root tissue. Failure to exclude sodium and chloride from leaf tissue may result in increased water stress, ion imbalances or toxicity, and hormonal imbalances (Flowers *et. al* 1977, Greenway and Munns 1980, Poljakoff-Mayber 1988). In Allen's experiment, the three seedlings exhibiting the highest levels of salt-tolerance had sodium concentrations 34% lower than the mean value. In addition, the most tolerant individuals to 6 ppt had 20% and 25% lower chloride values in their leaves and roots, respectively, in comparison to the mean levels. The study found a significant negative linear correlation between sodium and chloride concentrations in the leaves and the Potential Survival Index suggesting that elevated ion concentrations can be associated to low salinity tolerance (Allen 1994). Varying abilities of baldcypress individuals to expel sodium and chloride are often the reasoning used to account for intraspecific variation (Thomson 1988 and Ashraf and Fatima 1995).

Allen's findings were strengthened by the Krauss et al. (2000) study, which found a linear relationship between the free soil water salinity at the time of collection and foliar concentrations of sodium and chloride. The seedlings planted at sites with mean salinity levels of 2 ppt, 1.2 ppt, and 0.5 ppt had foliar sodium concentrations of 0.54, 0.26, and 0.11%, respectively, while foliar chloride concentrations at the most saline location were approximately 1.8 times greater than the other locations. In addition, significant site-level differences in Na/K and Na/Ca tissue ratios were documented. Wyn Jones et al. (1979) proposed that Na/K ratios must be maintained at levels less than one to maintain normal cellular functions. Flowers and Lauchli (1983) hypothesize that the cells are damaged when the Na/K ratio increases because sodium can only partially substitute for potassium in the cell. The Na/K ratio on the most saline plot in Krauss' study exceeded 1.0, which may account for the higher levels of stress observed. Allen et al. (1997) and Pezeshki et al. (1988) also reported Na/K foliar ratios that exceeded one when baldcypress seedlings were exposed to salinity levels above 2 ppt and 8 ppt, respectively.

Potential Mechanisms Used by Baldcypress to Minimize Salinity Impacts

Research has been conducted to explore the possible mechanisms of ion exclusion in baldcypress. Noble and Rogers (1992) outlined the following physiological responses as potential routes of ion removal: (1) control of uptake at the root plasmalemma and tonoplasts of the cortex (2) accumulation and release of ions from stele to xylem, (3) reabsorption of ions by xylem parenchyma cells (4) phloem translocation, and (5) compartmentation in older leaves. Another tactic that baldcypress may use when overburdened by large amounts of chloride in the soil is translocation of the ions from living, outer sapwood rings to non-living, inner heartwood rings. An experiment conducted by Yanosky and Hupp in 1995, used proton induced X-ray emission spectroscopy to assess chloride concentrations in increment corings gathered from baldcypress in North Carolina. The study found that four of the five trees, which had the highest chlorine concentrations in the outer sapwood, exhibited the similar pattern of an abrupt increase in chloride within the outermost heartwood ring in comparison to the innermost sapwood ring. The authors believe that the shunting of chloride ions from younger to older rings may be a mechanism to sustain physiologically tolerable levels of ions within the living ray parenchyma, especially the parenchyma adjacent to the cambium.

Conclusions

The information gathered in this literature search can be used to help understand potentially dangerous salinity levels in regard to successful cypress recruitment and survival, the extent of intraspecific variation, the various symptoms of salinity stress, and the mechanisms used by baldcypress to minimize salinity exposure. The specific salinity levels tested in the various experiments on baldcypress seedlings, which are summarized in **Table A-3** and **Figure A-4** can only serve as initial guides to the salinity values necessary to retard further baldcypress mortality in upper reaches of the Loxahatchee River. As exemplified in the literature search, the majority of the research conducted to date has concentrated on the seedlings response to acute dosages of salinity. Although salinity tolerance appears to increase with age, it is extremely important to note that salinity levels must be maintained at levels which protect baldcypress seedlings because levels that protect only mature adults will not ensure a sustainable population. As shown on **Figure A-4,** at 2 ppt there are major declines in the seedlings net photosynthesis, stomatal conductance, and mean height, and by 4 ppt significant declines in leaf biomass and germination capacity. Although these studies demonstrate that some individuals can withstand higher levels of exposure, one may argue from established ecological principles that sodium chloride concentrations of 2 ppt and higher could have greater adverse effects on the Loxahatchee's baldcypress population than coastal Louisiana populations, as the former has had less opportunity to select more tolerant strains. It is essential that site specific studies be conducted to verify salinity levels that negatively impact survival and recruitment for freshwater baldcypress in the Loxahatchee River because they have not evolved under the same saltwater selective pressures characteristic of other populations in the southeastern United States.

Table A-3 Summary of the Physiological Responses of *Taxodium distichum* to Varying Levels of Salinity

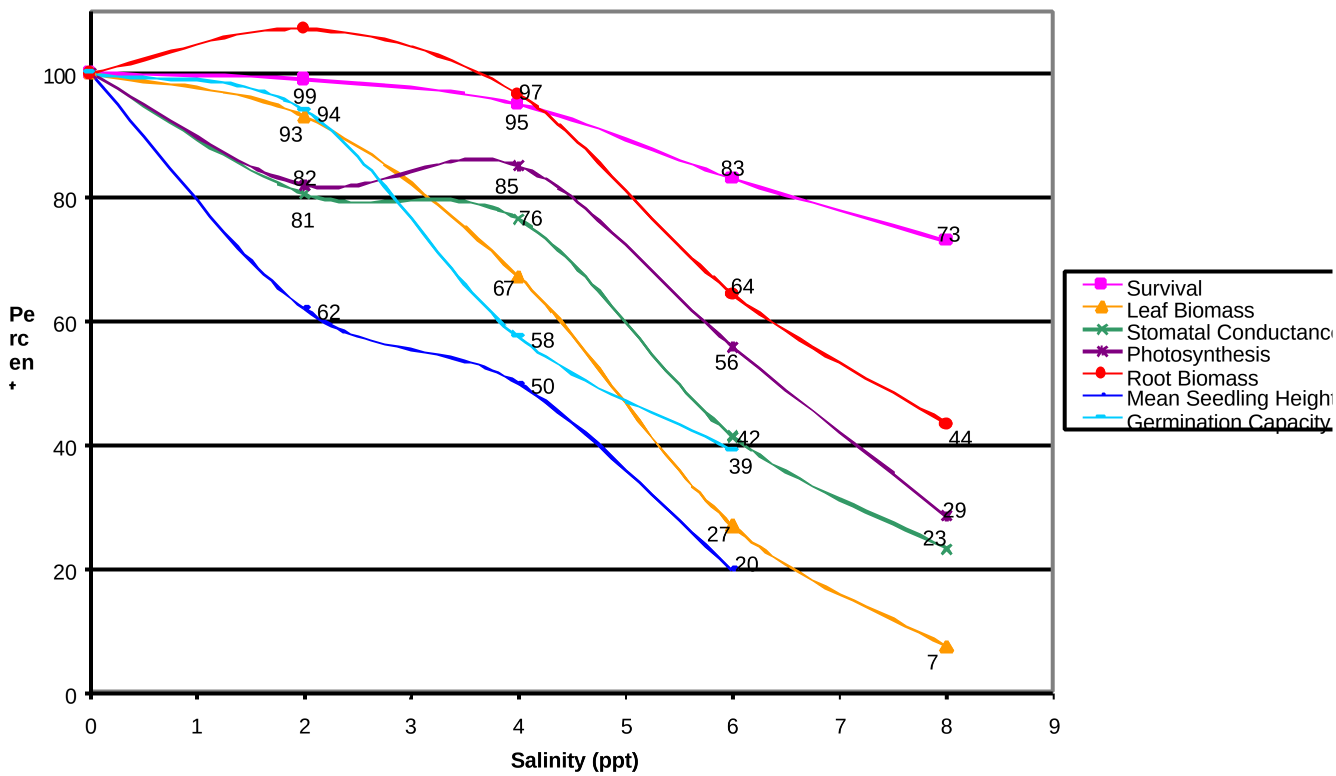
Salinity Levels	Germination Capacity	Survival	Height & Diameter	Root & Shoot Biomass (g dry wt) Leaf size (cm^2)	Stomatal Conductance (g_w) Photosynthesis(A)	Foliar ionic concentrations
0 ppt	26.3% [a]	100% @ end of 3 months when flooded [b]		Mean leaf biomass 2.14**(1[1])** [j] Mean leaf area 415 [d] Mean root biomass 2.39**(2)** [j]	g_w = 91.8 mmol m^2/s **(1)** [j] A=3.88 µmol(CO_2) m^2/s **(1)** [j]	Na^+ 0.05%* [j] Cl^- 0.38% * [j]
0.5 ppt		99.5% (1996) [c] 98.3% (1997) [c]	Average seedling ht. in 1997 was 196.4 cm [c]	Mean leaf biomass 15.4 [c]		Na^+ 0.11% [c] Cl^- 0.64% [c]
1.2 ppt		93.0% (1996) [c] 92.7% (1997) [c]	Average seedling ht. in 1997 was 165.9 cm [c]	Mean leaf biomass 7.1 [c]		Na^+ 0.26% [c] Cl^- 0.66% [c]
2 ppt	22.9% [a] (94% of control)	86.4% (1996) [c] 17.7% (1997) [c] 100% @ end of 3 months when flooded [b] 99% [j]	Average seedling ht. in 1997 was 121.6 cm [c]	Mean leaf biomass 1.99**(1)** [j] Mean leaf biomass 4.6 [c] Mean leaf area 366 [d] Mean root biomass 2.56**(1)** [j]	g_w = 74.0 mmol m^2/s **(2)** [j] A=3.18 µmol(CO_2) m^2/s **(2)** [j]	Na^+ 0.54% [c] Cl^- 0.77% [c] Na^+ 0.4% * [j] Cl^- 1.6 % * [j]
3 ppt			Significant reduction in height growth when flooded (~50%) vs. control, but not significant when only watered. [g]		Both g_w and A were reduced [g]	
4 ppt	15.4% [a] (57.5% of control)	95% [j]	-Height increment 50% of control [h]	Mean leaf biomass 1.44**(2)** [j] Mean leaf area 253 [d] Mean root biomass 2.31**(3)** [j]	g_w = 70.2 mmol m^2/s **(2)** [j] A=3.30 µmol(CO_2) m^2/s **(1,2)** [j]	Na^+ 0.6% * [j] Cl^- 1.9% * [j]

[a] Krauss et al. (1998) [b] Clemson University [c] Krauss et al. (2000) [d] Allen, Chambers, and McKinney (1994) [e] Conner (1994) [f] Conner and Askew (1992)
[g] Pezeshki (1987) [h] Krauss et al. (1999) [i] Allen, Chambers, and Pezeshki (1997) [j] James Allen L.S.U. Ph.D. Dissertation (1994)
[1] Mean values within a column followed by the same number are not significantly different ($P > 0.05$) Allen, 1994 * Values estimated from graphs in Allen 1994.

Salinity Levels	Germination Capacity	Survival	Height & Diameter	Root & Shoot Biomass (g dry wt) Leaf size (cm^2)	Stomatal Conductance (g_w) Photosynthesis(A)	Foliar ionic concentrations
				Root elongation 60% of control [h]		
6 ppt	10.2% [a] (39.2% of control)	83% [j]	-Height increment 20% of control [h] -Diameter growth significantly less then control [c]	Mean leaf biomass 0.58**(3)** [j] Mean leaf area 69 [d] Mean root biomass 1.54**(4)** [j] Root elongation 24% of control [h]	g_w = 38.1 mmol m^2/s **(3)** [j] A=2.17 µmol(CO_2) m^2/s **(3)** [j]	Na^+ 0.62% * [j] Cl^- 2.33% * [j]
8 ppt		Survival of seedlings from 15 open-pollinated families ranged from 42% to 97% [d] 73% [j]	Large declines in height growth [d]	Mean leaf biomass 0.16**(4)** [j] Mean leaf area 24 cm^2 [d] Mean root biomass 1.04**(5)** [j]	g_w = 21.4 mmol m^2/s **(4)** [j] A=1.11 µmol(CO_2) m^2/s **(4)** [j] Mean g_w and A <30% of control [i]	Na^+1.2% * [j] Cl^- 2.63% * [j]
10 ppt		100% mortality within 2 weeks when flooded [b] 100% survival @ end of 3 months when watered [e]				
30 ppt		Six month seedlings [f] -30% 1d. of flooding - 0 % 2-5d. of flooding Eighteen month seedlings [f] -90% 2d. of flooding -30% up to 4d. of flooding	Six & 18 mo. seedlings experienced steady declines in diameter growth and negative height growth [f]	6 mo. seedlings biomass declined following 1 d. of exposure. 18 mo. seedlings biomass declined after 2 d. [f]		

[a] Krauss et al. (1998) [b] Clemson University [c] Krauss et al. (2000) [d] Allen, Chambers, and McKinney (1994) [e] Conner (1994) [f] Conner and Askew (1992)
[g] Pezeshki (1987) [h] Krauss et al. (1999) [i] Allen, Chambers, and Pezeshki (1997) [j] James Allen L.S.U. Ph.D. Dissertation (1994)
[1] Mean values within a column followed by the same number are not significantly different (P > 0.05) Allen, 1994
*Values estimated from graphs in Allen 1994.

Table A-4 The Response of Baldcypress Seedlings to Increasing Salinity Levels (Measured as a Percentage of the Freshwater Control)



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