**US Army Corps
of Engineers®**
Engineer Research and
Development Center

Baldcypress (*Taxodium distichum*) at the Wallisville Lake Project

A Review of Applicable Literature and Management Considerations

Nathan R. Beane

April 2020

The U.S. Army Engineer Research and Development Center (ERDC) solves the nation's toughest engineering and environmental challenges. ERDC develops innovative solutions in civil and military engineering, geospatial sciences, water resources, and environmental sciences for the Army, the Department of Defense, civilian agencies, and our nation's public good. Find out more at www.erdcl.usace.army.mil.

To search for other technical reports published by ERDC, visit the ERDC online library at <http://acwc.sdp.sirsi.net/client/default>.

Baldcypress (*Taxodium distichum*) at the Wallisville Lake Project

A Review of Applicable Literature and Management Considerations

Nathan R. Beane

*U.S. Army Engineer Research and Development Center (ERDC)
Environmental Laboratory (EL)
3909 Halls Ferry Road
Vicksburg, MS 39180-6199*

Final Technical Report (TR)

Approved for public release; distribution is unlimited.

Prepared for U.S. Army Corps of Engineers
Galveston District, Galveston, TX

Under MIPR No. W45VAK81564878, "Baldcypress at the Wallisville Lake Project."

Abstract

Changing hydropatterns within the Wallisville Lake Project, near the mouth of the Trinity River in Chambers and Liberty Counties, Texas, have the potential to alter baldcypress forest resiliency. Increasing water levels support saltwater barrier operations while maintaining navigation and recreational access. However, potential impacts of increased water levels on the baldcypress forests are of particular concern because these ecosystems provide unique ecological value and wildlife habitat. The maintenance, succession, and resiliency of baldcypress under various flooding, salinity, and inundation regimes remain poorly defined and pose challenges to resource managers. This report reviews available literature pertaining to salinity and inundation impacts to baldcypress forests. Specific emphasis is placed on the ecological effects of water quality and quantity on the health and persistence of baldcypress. The information gathered in this report is intended to supplement material in the Wallisville Lake Project Water Control Manual to improve management of baldcypress forest conditions and avoid negative ecological impacts. Additionally, this report provides management considerations designed to maintain or enhance baldcypress forests within the Wallisville Lake Project.

DISCLAIMER: The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products. All product names and trademarks cited are the property of their respective owners. The findings of this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

DESTROY THIS REPORT WHEN NO LONGER NEEDED. DO NOT RETURN IT TO THE ORIGINATOR.

Contents

Abstract	ii
Figures	iv
Preface	v
1 Introduction.....	1
1.1 Purpose	1
1.2 Introduction and project area operation	1
2 Operational Modes of Wallisville Lake Project Area Hydraulic Structures	6
2.1 Normal operation.....	6
2.2 Salinity monitoring.....	6
2.3 Salinity control operation	6
2.4 Special salinity control operations.....	7
2.5 Hurricane operations.....	8
2.6 Other special operations:	9
2.6.1 Ecology of baldcypress.....	9
2.6.2 Baldcypress regeneration and seedling research	11
2.6.3 Salinity effects on baldcypress	16
2.6.4 Impact of impoundments and inundation on long-term growth trends of baldcypress	18
3 Conclusion and Management Considerations.....	21
3.1 Conclusions.....	21
3.2 Management considerations	22
4 Summary.....	25
References	26
Unit Conversion Factors	30
Report Documentation Page.....	31

Figures

Figure		Page
1	Wallisville Lake Project area boundary	2
2	The Wallisville Dam (left) and one of four tainter gates (right) that control water levels within the Wallisville Lake Project	4
3	Navigation lock infrastructure located adjacent to the Wallisville Dam	4
4	Control Structure A from the Trinity River.....	5

Preface

This study was conducted for the U.S. Army Corps of Engineers Galveston District via Military Interdepartmental Purchase Request (MIPR) No. W45VAK81564878, “Baldcypress at the Wallisville Lake Project.” The technical monitor was Dr. Alfred Cofrancesco, Technical Director.

The work was performed by the Wetlands & Coastal Ecology Branch of the Ecosystem Evaluation & Engineering Division, U.S. Army Engineer Research and Development Center, Environmental Laboratory. At the time of publication, Ms. Patty Tolley was Chief of the Wetlands & Coastal Ecology Branch; Mr. Mark Farr was Chief of the Ecosystem Evaluation & Engineering Division. The Deputy Director of ERDC-EL was Dr. Jack Davis and the Director was Dr. Ilker Adiguzel.

COL Teresa A. Schlosser was Commander of ERDC, and Dr. David W. Pittman was the Director.

THIS PAGE INTENTIONALLY LEFT BLANK

1 Introduction

1.1 Purpose

Changing hydropatterns within the Wallisville Lake Project, located near the mouth of the Trinity River in Chambers and Liberty Counties, Texas (and the larger Trinity River system), have the potential to alter baldcypress forest resiliency. For example, Lake Livingston (a water supply reservoir located upstream) may increase water releases in the future, which would provide an opportunity to hold more water within the project area. Such increases in water levels support saltwater barrier operations while maintaining navigation and recreational access. However, potential impacts of increased water levels on the baldcypress forests are of particular concern because these ecosystems provide unique ecological value and wildlife habitat. The maintenance, succession, and resiliency of baldcypress under various flooding, salinity, and inundation regimes remain poorly defined and pose challenges to resource managers.

This report reviews available literature pertaining to salinity and inundation impacts to baldcypress forests. Specific emphasis is placed on the ecological effects of water quality and quantity on the health and persistence of baldcypress. The information gathered in this report is intended to supplement material in the Wallisville Lake Project Water Control Manual, specifically to improve management of baldcypress forest conditions and to avoid negative ecological impacts. The following sections introduce project area operations and discuss baldcypress ecology, regeneration requirements, and response to salinity and inundation tolerance. Additionally, this report provides management considerations designed to maintain or enhance baldcypress forests within the Wallisville Lake Project.

1.2 Introduction and project area operation

The Wallisville Lake Project is located near the mouth of the Trinity River in Chambers and Liberty Counties, Texas. The Trinity River delta is an integral part of the Galveston Bay and remains one of the most productive estuaries in the United States (USFWS 1990). The project area contains an estimated 23,277 acres of bottomland delta and adjacent terrace margins,

including numerous bayous, abandoned channels, ponds and lakes interspersed with marsh, swamp, bottomland hardwood, upland pine and hardwood, and prairie habitats (Figure 1).

Figure 1. Wallisville Lake Project area boundary.

The Wallisville Lake Project was authorized in 1962, with planned construction of a 19,700-acre reservoir and a diversion dam at river mile 3.9. This included the establishment of a navigation lock, diversion structure, and diversion channel. Construction was initialized in 1966 but was halted following a lawsuit filed in the U.S. District Court in 1971. The District Court found the environmental impact statement for the project deficient and further environmental studies were conducted. Study findings led to re-evaluation and modification of the original project, resulting in a Post Authorization Change Report (PACR) in July 1981. The PACR included an alternatives analysis and the selected alternative elected to avoid impact to valuable marsh habitat west of the Trinity River by reducing the reservoir size to 5600 acres.

A pair of endangered bald eagles was found nesting in the baldcypress swamps within the project area before construction on the revised project plan in November 1989. To protect the nest site under the U.S. Endangered Species Act (ESA), the reservoir was further reduced to 3,800 acres. Construction resumed in 1991 and additional refinements were integrated into the design to reduce impacts to the baldcypress swamps. Ultimately, a controlled spillway river structure was installed to mimic pre-project river flow.

The Wallisville Lake Project prevents saltwater intrusion into the Trinity River, which supports upstream water supply and irrigation requirements. During low-flow periods, a salinity wedge moves up the river from Trinity Bay and threatens fresh water supply in the Trinity River. The project prevents saltwater intrusion via a gated spillway that controls freshwater flow, allowing operators to counteract salinization (Figures 2 and 3). Additionally, a 26-ft single span control structure (Control Structure A) is located farther upstream to prevent salt-intrusion from entering the Trinity River via the Old and Lost Rivers (Figure 4).

The hydraulic structures at the Wallisville Lake Project area are operated to prevent salinity from affecting water supply within the Trinity River system. The structures remain open during normal flow conditions and do not alter water levels. However, during low-flow conditions, the structures are closed to prevent saltwater intrusion. The following chapter includes guidelines that provide a general description of operations under six operational modes as reported by the Wallisville Project Operation Plan.*

* Operations Plan for Hydraulic Structures. August 2, 1999 (unpublished, internal report provided by USACE Galveston District).

Figure 2. The Wallisville Dam (left) and one of four tainter gates (right) that control water levels within the Wallisville Lake Project.

Figure 3. Navigation lock infrastructure located adjacent to the Wallisville Dam.

Figure 4. Control Structure A from the Trinity River.

2 Operational Modes of Wallisville Lake Project Area Hydraulic Structures

2.1 Normal operation

Condition: The Trinity River flow to Trinity Bay is equal to or greater than 2,000 cubic feet per second (cfs).

Operation: All spillway gates, lock gates, and Control Structure A will remain fully open so that flow and navigation are unimpeded. River flows will be monitored so that the Trinity River flow to Trinity Bay can be estimated and recorded. The value will normally be estimated from upstream gage reports at Romayor, less any downstream diversions. The daily diversion rate will be obtained from the Trinity River Authority.

2.2 Salinity monitoring

Condition: The Trinity River flow to Trinity Bay is less than 2,000 cfs.

Operation: All spillway gates, lock gates, and Control Structure A will remain fully open so that flow and navigation are unimpeded. Begin monitoring salinity levels at permanent gage sites and begin gathering additional portable measurements to detect salinity moving upstream toward the project. (Permanent salinity and water level gages are located immediately upstream and downstream of the spillway.)

2.3 Salinity control operation

Condition: Salinity measurements indicate salinity intrusion is threatening water supplies.

Operation: The spillway gates and lock gates are closed to form a salinity barrier.

Limited gate openings are made as needed to pass remaining river flow. The lock is operated to pass boat traffic on a scheduled basis.

More specifically, while the project is in salinity control operation:

- Some gate openings will generally be required to pass any remaining river flow. An initial tainter gate setting of two gates at 4 ft is suggested for nominal flow conditions. Lock gate openings may be substituted for tainter gate openings. An increasing pool level will indicate the need for increased gate openings. A falling level will indicate the need for smaller openings or complete closure.
 - In the long term, the gates will be adjusted so that the pool elevation tracks within a target range. The target range is as follows:
 - * The upper limit is 0.5 ft above the average tide level.
 - * The lower limit is 0.5 ft below the average tide level.
 - The average tide level will be computed from readings taken every 6 hours for the previous 48-hour period.
- Any remaining gate openings must periodically be closed in response to rising tides to prevent backflow. A positive head of at least 0.1 ft is required to prevent salinity intrusion through tainter gate openings. A larger (0.3-ft) positive head is required for lock gate openings.

Condition: Salinity measurements indicate that intrusion is a threat at Structure A and C.

Operation: Close Structure A and leave closed until resumption of normal river flows.

Structure C is the temporary sheet pile barrier on the Old River just downstream of the confluence with The Cutoff. Structure C will be put in place on a temporary basis during drought conditions to prevent salinity intrusion at the pumping plant on the Old River. Placement will not be required until this plant is made operational, and the barrier will only be put in place when required to prevent salinity intrusion. When Structure C is in place, Structure A will be opened as required to allow flow to the pump station.

2.4 Special salinity control operations

Condition: During sustained regular salinity control operations, salinity levels are increasing in the project.

Operation: To lower the rate of intrusion and decrease pool salinity levels the following steps may be taken:

- Suspend lock operations during backflow tide conditions.
- Raise the target range for the pool by as much as 1 ft. Coordination and approval from the District's environmental staff will be required before changing the target range. Releases from Lake Livingston may be needed to fill the pool to the higher target.
- Request special releases from Lake Livingston to flush salt from the project.

Note that these steps are listed in order of preference. Conventional operations should be resumed as soon as possible.

Condition: During regular salinity control operations the tide level rises to 4 ft National Geodetic Vertical Datum (NGVD) or greater and gate overtopping is beginning to occur.

Operation: All four spillway gates and the lock gates will remain closed.

2.5 Hurricane operations

Condition: High winds and tides are imminent at the project, and an evacuation order has been issued to operation personnel by the District office.

Operation: Begin emergency operation procedures as follows:

- Before evacuation. First, the lock gates and Structure A will be opened. Next, the spillway gates will be closed to protect them from storm conditions. The project should be re-staffed as soon as conditions allow. A shutdown plan should be coordinated with Emergency Management so that it may be included in the District's overall hurricane plan.
- Returning from evacuation. If the project has been flooded by tidal water or river flows, open all spillway gates to allow floodwater to exit. The gates should not be opened until hurricane wind conditions subside and the flood level at the project is less than +7.0 NGVD (so that the initial gate opening sequence will not result in an overtopping condition). Gates will be opened in a rotational sequence starting with the innermost gates with each gate opened 4 ft in turn until all gates are fully open. All gates will remain open to allow exit of floodwater until flooding conditions subside.
- Subsequent operation. If the Trinity River flow to Trinity Bay is equal to or greater than 2,000 cfs, then resume normal operating status with all gates and lock open. If the Trinity River flow to Trinity Bay is less than 2,000 cfs, then resume monitoring followed by salinity control operations if necessary.

2.6 Other special operations

Condition: Special gate operations are desired for wildlife or environmental management.

Operation: The District's environmental staff may direct special operations for wildlife or environmental management.

2.6.1 Ecology of baldcypress

Baldcypress is a large, slow-growing, deciduous conifer characteristic of rivers, lake margins, swamps, coastal marshes, and river bottoms of the Southeastern and Gulf Coastal Plains (Burns and Honkala 1990, USDA-NRCS 2002, Hardin et al. 2001). Baldcypress grows on saturated and seasonally inundated soils, ranging in elevation from sea level to 1750 ft above sea level. Baldcypress frequently grows to heights of over 100 ft, reaching diameters of 3-6 ft. The leaves of baldcypress are decurrent, narrowly linear, and appear two-ranked along the stem. Twigs are pendant or horizontally spreading from the branches, with dark reddish-brown fibrous bark with shallow furrows developing (Hardin et al. 2001).

Baldcypress trees exposed to prolonged inundation are easily identified by their fluted, tapering trunks and heavy buttressing. The swelling of the bole of the tree is described as 'stem hypertrophy' and is a characteristic adaptation of many vascular plants to waterlogged conditions, best represented by baldcypress and water tupelo in southeastern forests (Mitsch and Gosselink 2015). Baldcypress trees exhibit other morphological adaptations to life in saturated soils including growth of pneumatophores (i.e., air roots) commonly referred to as "cypress knees." These root structures are formed by upward growing lateral roots and have been shown to improve gas exchange to the root system, with the heights often used as indicators of high-water levels in wetlands (Mitsch and Gosselink 2015). Pneumatophores may also aid in stabilization of the tree in wet soil substrates by counterbalancing weight distribution, providing a mechanism for the low rate of baldcypress windthrow (Pulliam 1992).

Baldcypress are monoecious with the distinct male and female strobili maturing in one growing season. Pollen is typically disseminated March-April, with female flowers producing globose cones maturing late October-December. The resinous cones are produced singly or in a small cluster of 2 to 3 cones.

Each cone contains an average of 16 seeds; however, they may vary considerably — ranging from 2 to 34 seeds per cone (Burns and Honkala 1990).

While seed production is annual, good seed crops are cyclical and occur approximately every 3 years (USDA-NRCS 2002, Burns and Honkala 1990). Mature seed cones (with diameters of $\frac{3}{4}$ in. to 1 in.) will persist on the tree through the winter months, with floodwaters being the primary means of seed dispersal. Squirrels (*Sciurus* sp.) often forage on the seeds from the tree's canopy and drop scale fragments with seeds that remain viable for dispersal (Burns and Honkala 1990).

Seed germination in baldcypress is epigeal (i.e., above ground), and in swamp conditions generally occurs in moist soil conditions. Seeds of baldcypress will not germinate under water; however, seed viability can be maintained under water for up to 30 months (Burns and Honkala 1990). Conversely, seeds also do not germinate successfully on well-drained soils. Soils that are saturated but lack inundation for a period of 1 to 3 months after seed-fall are ideal for germination. Seedling survival in flood prone environments is dictated by the ability of the seedling to maintain at least a portion of its crown above the water during the growing season. Although seedling growth is halted when completely submerged from flooding, mortality rarely occurs unless inundation is prolonged for several days (Burns and Honkala 1990).

Survival of baldcypress is maximized where overhead light is available, and growth in partial shade remains considerably slower than in full sun (Hardin et al. 2001). While baldcypress can withstand partial shading, the species exhibits 'intermediate' shade tolerance (Hardin et al. 2001). Under heavy shaded conditions, seeds will germinate but mortality is high. Additionally, baldcypress seeds display an internal dormancy period with cold stratification or submergence typically required for successful germination. Control of vegetation may be necessary for successful baldcypress establishment, particularly if planted outside of a swamp where reduced flood frequency and/or duration increases interspecies competition.

Baldcypress growth is maximized on moderately drained, deep, fine, sandy loams with high moisture in surface layers. However, baldcypress is rarely found in these areas due to competition from hardwood species that limits baldcypress abundance. As a result, baldcypress dominance typically occurs in frequently flooded or inundated areas where pure stands develop

in response to reduced competition. The most common co-dominant species in the Gulf Coast region associated with baldcypress is water tupelo (*Nyssa aquatica* L.). Other bottomland hardwood species occurring in conjunction with baldcypress (although often in slightly higher landscape positions) include swamp tupelo (*Nyssa biflora* Walt.), sweetgum (*Liquidambar styraciflua* L.), green ash (*Fraxinus pennsylvanica* Marshall), red maple (*Acer rubrum* L.), elm (*Ulmus* sp. L.), and oak (*Quercus* sp. L.).

2.6.2 Baldcypress regeneration and seedling research

Vegetative species distribution within floodplain forests reflects environmental gradients driven by topographic position and hydrologic feature characteristics (Wharton et al. 1982). Within the Gulf Coastal Plain, baldcypress and water tupelo often occur as co-dominant canopy trees in areas experiencing frequent to semi-permanent inundation and/or flooding (Sharitz and Lee 1985, Wakeley et al. 2010). The transition from permanently saturated conditions into areas exposed to more water table fluctuation coincides with a shift from baldcypress and tupelo to other bottomland species (described above). Notably, non-native, invasive Chinese tallow (*Triadica sebifera* (L.) Small), which is lacking in areas with prolonged inundation, represents an increasing management concern as flood frequency decreases. Chinese tallow is a major competitor to woody vegetation in bottomland sites throughout much of the southeast (Hardin et al. 2001). As a result, management activities that change hydrologic regime or edaphic conditions can alter the complex mosaic pattern of species and wetland-community distribution (Hook 1984, Sharitz and Lee 1985). Therefore, careful consideration of flooding regime and inundation periods are important when identifying suitable habitats for the development of bottomland hardwood species and in particular the management of baldcypress forests.

Loss of bottomland forested wetlands has occurred in the southeastern United States with respect to both area and species composition (Sharitz and Mitsch 1993). For example, bottomland hardwood wetland extent within the Lower Mississippi Valley displayed a 74% decrease from historic values, with only 2.8 of an original 10 million ha remaining intact by the 1980s (The Nature Conservancy 1992, King et al. 2006). While agriculture, timber harvesting, and urban expansion have contributed to the losses of these lowland habitats, management of these wetlands for timber, recreation, or navigation within the watershed have often limited their viability and/or persistence. This is particularly evident for baldcypress-dominated

forested wetlands where historic connections of depressional areas and floodplains adjacent to rivers and streams have been largely disconnected.

This loss of connectivity has major implications regarding the success of baldcypress wetland habitats, as floodwaters provide pulses of fresh water and nutrients essential for health and maintenance of these ecosystems. This is particularly evident with respect to recruitment of baldcypress seedlings, with flooding playing a key role in their successional strategy (Burns and Honkala 1990). Floodwaters and inundation create moist soils for germination while reducing competition from faster-growing bottom-land tree species and herbaceous vegetation; therefore, alteration of hydrologic regimes can reduce site suitability. In areas where wetland hydroperiod is decreased, seedling establishment success and increased competition limit baldcypress establishment. Conversely, increasing hydroperiods by maintaining artificially high-water tables or other means also limits baldcypress establishment and decreases growth rates.

The presence of nutria (*Myocastor coypus*) also limits baldcypress establishment throughout much of the southeastern United States. This introduced, invasive species was imported into Louisiana in the 1930s in an attempt to develop a fur trade. Following release, nutria spread throughout the region where they pose significant challenges to baldcypress regeneration. Nutria primarily feed in shallow water or along the water's edge. As a result, nutria grazing has negative impacts on baldcypress seedling survival. Specifically, nutria feed on the aboveground portion of baldcypress seedling and their roots, resulting in seedling mortality (Burns and Honkala 1990). Two other mammals also cause significant damage to baldcypress seedlings, white-tailed deer (*Odocoileus virginianus*) and swamp rabbits (*Sylvilagus aquaticus*). However, deer and rabbits are less destructive to baldcypress as they do not uproot the plant, which is then capable of resprouting. The ability to resprout is an uncommon characteristic among conifers but is typical of tree species adapted to high severity disturbance regimes such as frequent flooding or fire (Clarke et al. 2013).

While baldcypress trees grow within permanently inundated swamps and sloughs, germination of seedlings requires contact with the saturated soil surface, preferably on exposed mineral substrates. The utility of microsite features (e.g., downed logs, stumps, debris piles) as well as microtopography are often essential in continuously inundated or frequently flooded areas for germination and survival (Sharitz and Mitsch 1993). Pietrzykowski

et al. (2015) examined tree growth within a created forested wetland in Virginia 10 years following establishment. Their findings indicated that both height and diameter growth for young baldcypress was significantly affected by microsite features (i.e., level, pit, and mound).

While the threshold growth characteristics and regeneration requirements for baldcypress are well documented (e.g., Burns and Honkala 1990, Coladonato 1992), few studies have examined the ecological effects of submergence patterns and shading conditions on the establishment and growth of baldcypress under various management scenarios (e.g., Neufeld 1983, Sharitz and Lee 1985, Souther and Shaffer 2000, Wang et al. 2016). Moreover, much of the published literature was performed before 1970, and few studies report *in-situ* seedling survival. Relevant studies published after 1970, including those addressing both nursery and field-based approaches are described below.

Sharitz and Lee (1985) examined the limits on baldcypress regeneration processes, included seed production, microsite availability and hydrologic regime, in southeastern riverine wetlands. Within their study area (i.e., Savannah River floodplain—South Carolina), microsite characteristics and water level changes were identified as limiting factors for regeneration success. Seed production was not considered a limiting factor and the article identified management of water levels as a strategy to promote regeneration and maintain floodplain wetland-community structure. They identified four major factors with the capacity to limit baldcypress and tupelo regeneration:

1. Low seed production, viability, and dispersal
2. Lack of suitable microsites for germination and seedling establishment
3. Physiological and growth restrictions of seedlings under environment stress
4. Catastrophic environmental events, e.g., major fluctuations in water levels.

Annual seed production of baldcypress was evaluated using floating seed traps. Peak seedfall occurred in November (spanned September-February) at an average of four seeds/square-meter/day. Flooding substantially increased (i.e., several orders of magnitude) potential seed dispersal, with as many as 100 to 200 seeds moving across an area during periods of high water. Given an adequate viable seed source, the availability of suitable substrates for germination and seedling establishment represents a major factor limiting baldcypress regeneration success (Sharitz and Lee 1985).

Sharitz and Lee (1985) also identified catastrophic environmental stresses as a potential controlling factor on regeneration of baldcypress in floodplain forests, particularly when associated with regulated streams. They noted that

maintenance of high river levels during the growing season and continuous inundation of the floodplain may limit tree [cypress] regeneration success by reducing the availability of exposed substrates suitable for seed germination and seedling establishment.

Moreover, flood events that inundate seedlings during the growing season were found to cause high mortality. The authors reported 89% survival of a cohort of 1200 baldcypress and water tupelo seedlings during the typical winter floods. However, two desynchronized high-volume discharges from an upstream reservoir (during May and early August) increased seedling mortality to >99%. As a result, Sharitz and Lee (1985) suggest that alteration of stream discharges without considering the requirements of high value ecosystems represents a management oversight. While most river discharges and water level maintenance plans prioritize recreation and/or navigation, it is imperative to maintain floodplain wetlands in support of watershed management objectives since wetlands improve floodwater storage and other functions.

Neufeld (1983) examined the effects of light on growth, morphology, and photosynthesis in both baldcypress and pondcypress (*Taxodium ascendens* Brongn.) seedlings. With respect to baldcypress, cones were collected near Gainesville, Florida, in mid-November and stratified in flats of wet sand at 5 °C in the dark for 6 weeks. Flats were placed in a greenhouse and seed germination was monitored. After approximately 2 months, seedlings were transferred to 16-cm diameter pots with standard greenhouse soils. Seedlings were watered weekly with a 1/2 strength nutrient solution. Twenty seedlings were randomly allocated to each of the five light regimes (100%=full sun, 75%, 50%, 25%, and 5%) used for the study. Height and diameter were measured weekly and were grown for 117 days, with 10 individuals from each treatment randomly harvested. Leaf, stem, branch, and root biomasses were evaluated from oven-dried samples of collected materials.

With decreasing light intensity, overall growth decreased. Biomass accumulation and height growth was minimized under 5% light, while the treatments exposed to >5% light conditions showed improved outcomes.

Branch production was small and variable across treatments, with no branches developed in 5% light. Root biomass was observably more sensitive to light and steadily declined in the three lower light treatments. Approximately 40% of total biomass was allocated to stem tissue, with no significant differences among treatments.

Browder et al. (1974) also grew baldcypress seedlings under five light levels and reported findings similar to those of Neufeld (1983). Blanck (1980) evaluated baldcypress seedlings under several light regimes; however, growth rate was comparable to the 25% light level as reported by Neufeld (1983). In the study by Neufeld (1983), baldcypress accumulated approximately the same amount of dry weight biomass in light levels ranging from 25% to 100%. These findings demonstrate that baldcypress growth improves with increased light, and that the species tolerates a wide range of light conditions. Neufeld (1983) suggested that seedling establishment in natural conditions may be restricted to canopy openings where increased light levels occur.

Wang et al. (2016) studied the effects of *in-situ* growth responses and photosynthesis of baldcypress saplings to long-term periodic submergence in the hydro-fluctuation zone of the Three Gorges Dam Reservoir in China. Two-year-old saplings were planted within the reservoir pool and monitored over three annual inundation cycles (November through January), followed by a gradual drawdown period before reflooding. Three submergence depths (0 m = shallow, 5 m = moderate, and 10 m = deep) were used, with the 0 m depth treatment exposed to shallow submergence. Submergence duration was approximately 183, 122, and 5 days for the deep, moderate, and shallow submergence treatments, respectively. Wang et al. (2016) found that both diameter and tree height of baldcypress decreased with submergence depth. No mortality was observed following repeated submergence. The lack of mortality was attributed to the use of sapling-size trees, which display increased resiliency to inundation compared with seedlings.

Wang et al. (2016) also identified a significant correlation between net photosynthetic rate and several growth indices, indicating that lower diameter and tree height in baldcypress were mainly caused by lower photosynthetic rate. However, while saplings exposed to deep and moderate submergence regimes had comparable net photosynthetic rates, deeper inundation decreased diameter growth rate. The authors propose that baldcypress under deep submergence reallocate and consume more energy to survive, thus decreasing growth compared to the moderate submergence treatment.

Souther and Shaffer (2000) examined the effects of complete submergence and variable light regime on newly germinated and 1-year-old baldcypress seedlings. Newly germinated seedlings showed clear signs of stress after 30 days, with substantial mortality occurring after 45 days. In contrast, the 1-year-old seedlings experienced survival percentages as high as 75% for approximately 150 days.

Examination of light regime by Souther and Shaffer (2000) identified that at 100% light exposure, newly germinated seedlings experienced 100% mortality after 35 days. However, the 1-year-old seedlings were largely unaffected by prolonged flooding or light regime. These findings correspond with the conclusions of Wang et al. (2016), who observed increased resiliency in older saplings under extended inundation periods.

2.6.3 Salinity effects on baldcypress

Conner (1994) examined the effects of inundation and salinity on the growth and survival of baldcypress and Chinese tallow seedlings. Seedlings were exposed to varying water levels (watered to saturation vs. flooded to 5 cm above soil line) and salinity levels (0, 2, and 10 parts per thousand [ppt]; plus a simulated storm surge with 32 ppt). Seedlings of both species survived to the conclusion of the experiment except for those flooded with 10 ppt water. While the simulated storm surge flooded treatment resulted in no mortality, tip dieback was observed in all seedlings at time of harvest. In the 10 ppt treatment, baldcypress survived for 2 weeks whereas Chinese tallow survived for 6 weeks, suggesting a potential advantage of Chinese tallow survival in coastal areas experiencing salinity increases (Conner 1994, Conner et al. 1997).

Diameter growth was greater in the inundated treatments than in the saturated soil treatment experiments conducted by Conner (1994). Conversely, Chinese tallow exhibited diameter growth in the saturated soil treatment. Baldcypress root and shoot biomasses were not significantly different among treatments; however, Chinese tallow biomasses were 2 to 5 times lower in flooded treatments. The increased tolerance of baldcypress to flooding and decreased tolerance to salinity is an important factor to consider for creating conditions favorable for baldcypress while precluding invasive Chinese tallow establishment.

Allen et al. (1996) reviewed studies designed to predict and ameliorate the impacts of increased flooding and salinity stress on baldcypress. The study

examined species-level responses to flooding and salinity, alone and in combination. While considered highly tolerant of flooding and soil water-logging, baldcypress trees become stressed when subjected to increased depth and permanent inundation (DeLaune et al. 1987, Conner and Brody 1989, Allen et al. 1996). The added stress of salinity further exacerbates the risk to baldcypress. Where increased flood depth and duration occurs, natural regeneration is unlikely, or even impossible, under conditions of permanent flooding (Conner and Day 1976, Allen et al. 1996). Growth of baldcypress is substantially reduced in deep (>1 m), permanently flooded swamps compared to areas that experience intermittent flooding (Conner and Day 1976). Furthermore, in some cases, permanent and deep flooding has been documented to accelerate the decline and death of established baldcypress trees (Demaree 1932, Eggler and Moore 1961, Harms et al. 1980, Brown and Montz 1986, Allen et al. 1996).

Allen et al. (1996) stated that “[s]eedlings generally recover from the stress imposed by continuous shallow flooding and may grow as rapidly as seedlings subjected to well-watered conditions or periodic flooding.” A 3-year study using large experimental enclosures was conducted by Megonigal and Day (1992). They found that, after 1 year, continuously flooded baldcypress seedlings exhibited approximately one-third the biomass of periodically flooded seedlings. After 2 years, the growth of permanently flooded seedlings had improved substantially. Following 3 years of growth, no significant differences in biomass were observed.

Baldcypress are considered moderately salt tolerant (Allen et al. 1996). Pezeshki (1990) found no significant effects to height growth, net photosynthetic or stomatal conductance for baldcypress seedlings watered with 3 ppt saltwater solution for 60 days. Furthermore, Conner (1994) reported 100% survival of baldcypress seedlings regularly watered with a 10 ppt saltwater solution for 3 months, with a significantly lower height (i.e., 25% reduction) when compared to control treatments.

When flooding and salinity occur in combination, there is considerably more stress to baldcypress seedlings and increasing salinity exacerbates detrimental effects and mortality rates (Javanshir and Ewel 1993, Conner 1994, Allen et al. 1996, McLeod et al. 1996). Conner (1994) reported that seedlings watered with 10 ppt salinity water survived without growth impacts, whereas seedlings continuously flooded at the same salinity level resulted in 100% mortality within 2 weeks. However, Allen et al. (1994) and

Pezeshki et al. (1995) observed that baldcypress seedlings exhibit intraspecific variation in tolerance to a combination of flooding and salinity stress. In general, individuals from brackish sources are more tolerant of combined salinity and flooding stresses than individuals from freshwater sources, suggesting a moderate degree of heritability and phenotype.

Conner and Inabinette (2005) identified salt-tolerant baldcypress for planting in coastal areas. In their study, seeds were collected from eight estuarine areas: Virginia, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, and Louisiana. Seeds were stratified and grown for 2 years before planting in abandoned rice fields in Georgia in 1999. Salinity levels at the site reached 18.5 ppt during drought conditions and by 2002, the only seedlings surviving were from Louisiana, Alabama, and Florida. Following 5 years, the seedlings from Louisiana performed best, with a mortality rate of only 27%. These findings identified the need for further research on biologic and genetic characteristics of trees growing in Louisiana, as they represent a source of baldcypress seed possessing increased tolerance to saline conditions (Allen et al. 1996, Krauss et al. 2000). Baldcypress trees from Texas were not evaluated in the study.

2.6.4 Impact of impoundments and inundation on long-term growth trends of baldcypress

Only a few studies have examined the effects of impoundments and permanent inundation on baldcypress under field conditions. The most relevant to the Wallisville Lake Project was performed at Caddo Lake, Louisiana-Texas (Klimas 1987, Keeland and Young 1997). In this study (Klimas 1987), baldcypress stands were evaluated as part of a proposed project to increase storage capacity of the lake to provide additional water supplies for Shreveport, Louisiana. An initial report identified concerns about the health of the baldcypress ecosystem in response to increased water levels as extensive baldcypress forests occurred along the shore and on submerged islands in the lake.

Klimas (1987) reviewed the history of Caddo Lake and identified an event similar to the proposed project to increase storage capacity when the construction of a dam was implemented in 1914. Klimas (1987) evaluated the existing baldcypress stands that were subjected to increased water levels following construction of the original dam.

An initial reconnaissance of Caddo Lake revealed a strong relationship between water depth and the form, size, and age of baldcypress trees. baldcypress trees found along the shoreline and in large brakes that formed on shallow submerged islands were uniform in their appearance and possessed abrupt borders to the adjacent mixed hardwood forest communities found on slightly higher ground. The baldcypress trees occurring lakeward were observed as open stands with scattered individuals of varying size and form, often with large buttresses at water level and otherwise stunted growth (Klimas 1987).

Water depth, tree diameter, height, and tree condition (poor to healthy) were measured along transects, and variations in these parameters were assessed by elevational gradient. Additionally, increment cores were collected from 14 trees to determine approximate age; however, the small sample size and issues associated with aging baldcypress from growth rings proved inadequate for identifying continuity of stands across sites. Daily lake level data for the period from 1933 to 1987 were also examined to identify characteristics of annual and long-term fluctuations related to observed elevational variation in baldcypress age, distribution, and stand structure.

Klimas (1987) noted that tree height and condition generally declined as water depth increased. However, comparisons of baldcypress condition and long-term lake stage data suggested a more complex relationship than a direct reduction in baldcypress quality with increasing water depth. However, trees that were identified as permanently inundated since construction of the dam in 1914 exhibited extremely slow radial growth (8.9 and 3.8 cm in 70 years, $n=2$).

Additionally, Klimas (1987) identified conditions and distribution of pre-1914 trees consistent with previous studies (e.g., Penfound 1949, Egglar and Moore 1961). Penfound (1949) noted low baldcypress mortality after 4 years of flooding on Lake Chicot, Louisiana, following a dam construction where trees were subjected to as much as 3 m of water when the lake was at spillway elevation. However, Egglar and Moore (1961) identified greater than 50% mortality of baldcypress on substrates 0.6 to 3 m below the spillway after 18 years. These findings were similar to those by Harms et al. (1980) that reported 50% mortality of baldcypress in north Florida that were flooded for 3 years to depths of 1.2 m or greater.

Using aerial photos, Klimas (1987) found very little mortality in areas permanently inundated for the 26 years prior, suggesting that the period of mortality was likely similar to those reported by Egglar and Moore (1961), i.e., occurring in the first 20 years of permanent inundation. However, Klimas (1987) noted that existing stands were continuing to decline.

The general trend observed following permanent inundation was a period of rapid mortality (i.e., exceeding 50%) follow by a long and gradual period of decline. Klimas (1987) concluded that the baldcypress trees subject to the deepest water conditions were unlikely to survive for another 50 years following an additional impact (i.e., the proposed increased storage capacity).

3 Conclusion and Management Considerations

3.1 Conclusions

The goal of this report was to provide data related to growth and establishment for baldcypress, including the effects of hydroperiod and salinity on the species. Details on the autecology of baldcypress are also provided to inform management of the species. Collectively, the information herein should be used to assist with future management considerations within the Wallisville Lake Project.

The baldcypress ecosystem encompasses approximately 1,600 acres within the project area, providing a variety of wildlife, ecological, and aesthetic values. Any future management decisions that result in alterations in water levels require careful consideration of the potential resulting impacts to baldcypress health, persistence, and recruitment. While this report does describe salinity effects on baldcypress, it provides no management considerations since this problem can be alleviated by a saltwater barrier.

During the initial site visit in August 2018, the observed baldcypress forests appeared healthy. Trees along the shoreline of the Trinity River, Lake Charlotte, and Mac Lake possessed full crowns and lacked any apparent signs of dieback, chlorosis, or other visual indicator of plant stress. In areas of deeper water (e.g., lakeward areas of Lake Charlotte and Mac Lake), the health and stature of the baldcypress trees were markedly reduced. Trees subject to increased water levels and permanent inundation often exhibit sparse and broken canopies, with only scattered trees persisting due to higher rates of mortality (Klimas 1987).

The primary management concern was the lack of baldcypress regeneration within the project area. The lack of recruitment of baldcypress presents a management challenge regarding future conditions and regeneration success. As a result, resource managers should consider (1) the establishment and regeneration of baldcypress within the project area and (2) potential consequences to existing trees resulting from increased water levels. This is particularly true for areas that are permanently inundated, where baldcypress regeneration is not possible under current operational conditions and where increasing water levels will likely exacerbate health concerns of established baldcypress trees.

The lack of observed baldcypress regeneration, while not known, may result from a flood regime that lacks periods of low water for successful recruitment of seeds onto bare, saturated soils. Ideally, a drawdown period from flooded areas from late February to early May would allow for baldcypress germination. Furthermore, seed transport and dispersal during low water periods (i.e., suitable soil conditions for epigeal germination) is not known. While baldcypress fruits were commonly observed on trees and along the ground during the initial site visit, an examination of the effectiveness of seed dispersal would provide valuable insight for future management. A field-based study using floating seed traps would provide the opportunity to assess the seed density and the effective dispersal for baldcypress trees under current water levels in winter months.

Notably, the impacts of nutria within the project area may also yield insight into the paucity of seedling establishment. Sites with nutria have been previously reported to exhibit greater than 90% seedling mortality within 4 months of planting baldcypress (Conner and Toliver 1990). Therefore, baldcypress seedling survival is potentially correlated with nutria density. Population survey techniques could be used to evaluate potential impacts from non-native nutria on baldcypress regeneration.

3.2 Management considerations

The Wallisville Lake Project is uniquely positioned to hold and release water at specific times of the year. This capability provides an opportunity to create conditions that promote the establishment of baldcypress. For example, the ability to disperse floating seeds via floodwater and to ensure that saturated soil conditions are maintained is a valuable management option not available in most areas. The capacity to coordinate water releases from upstream sources (e.g., Lake Livingston) in tandem with the Wallisville dam operations provides opportunities to implement management alternatives that promote and enhance baldcypress habitat within the Wallisville Lake Project. According to 'Other special operations,' of the Wallisville Project Operation Plan,^{*} special gate operations can be implemented to create desired conditions for wildlife or environmental management by the District's environmental staff. Enhancing site suitability for

^{*} Operations Plan for Hydraulic Structures. August 2, 1999 (unpublished, internal report provided by USACE Galveston District).

baldcypress seedling establishment is recommended and includes the following management considerations:

1. *Decrease pool levels to improve baldcypress growth and promote seedling establishment.*

Creating drawdown areas would expose soils in late winter/early spring to create germination sites for baldcypress establishment. The success of baldcypress establishment will be contingent on the occurrence of an adequate seed rain by baldcypress trees in the previous fall/winter period, and on conditions where the exposed soils maintain a saturated, but not inundated, state given effective seed dispersal. As these exposed areas are typically inundated, these sites should provide areas of reduced competition and be particularly effective in bordering areas around lake margins within the project area. This approach may also improve the growth of existing trees. Implementing this management strategy will require that areas considered for seeding establishment not be inundated during the first growing season to prevent established seedling mortality.

2. *Increase pool levels to encourage seed dispersal and decrease competition.*

This may be the easiest method to employ given increased water levels as typically observed in late winter. The ability to increase holding capacity of water within the project area affords the opportunity to flood adjacent bottomland forested areas immediately surrounding current baldcypress habitats. This management strategy could be used to expand areas of baldcypress by flooding these areas during active seedfall (late fall/early winter) and reducing water levels in late winter/early spring. This would create saturated soil conditions for seeds dispersed from floodwater following the springtime drawdown that are ideal for germination sites. This management technique would likely consist of several years of flooding and lowering water levels as deemed necessary to both establish adequate baldcypress regeneration and slowly reduce competition in newly generated areas.

3. *Manage water levels to select for baldcypress habitat.*

If successful baldcypress regeneration on-site can be implemented using strategies listed above, increasing water levels during portions of the year could create additional acreage for the expansion of baldcypress habitat. Specifically, light can be increased and competition decreased, which would promote the survival and expansion of baldcypress seedlings into adjacent bottomland hardwood forests. If additional growing space is required to expand the baldcypress ecosystem, adjusting water levels in the growing season will remove lower flood-tolerant species and expand the baldcypress forest extent. However, to improve baldcypress habitat within

the Wallisville Lake Project, the highest priority is to identify the flood frequency, duration, and periodicity required to establish baldcypress seedlings. Establishing new areas of baldcypress tree dominance would further enhance the baldcypress ecosystem and would provide a pathway to prepare the project area to hold additional water (as may be required with increased municipal demands) while avoiding negative impacts to baldcypress communities.

4 Summary

Management of water levels at the Wallisville Lake Project has potential implications for baldcypress forests. While much research has investigated the response of baldcypress to patterns of inundation, flooding, and water quality, questions persist regarding the implications of reservoir management for baldcypress forests. As noted, the ability to control water in these areas directly adjacent to the baldcypress swamps is unique. Therefore, the project area provides an ideal opportunity to investigate management actions (e.g., the timing and duration of inundation) to maximize baldcypress establishment, regeneration, and growth. Field-based observations are needed to document the effects of these management considerations; a detailed study plan should be developed to measure and assess project outcomes. Successfully establishing baldcypress regeneration remains a challenge, particularly in areas with altered flood regimes. However, the Wallisville Lake Project represents the best possible location to evaluate techniques for modifying water levels to improve and expand baldcypress forest habitat.

References

- Allen, J. A., J. L. Chambers, and D. McKinney. 1994. "Intraspecific Variation in the Response of Baldcypress (*Taxodium distichum*) Seedlings to Salinity." *Forest Ecology and Management* 70(1-3):203-214.
- Allen, J. A., S. R. Pezeshki, and J. L. Chambers. 1996. "Interaction of Flooding and Salinity Stress on Baldcypress (*Taxodium distichum*)." *Tree Physiology* 16(1-2):307-313.
- Blanck, C. E. 1980. *An Ecological Study of Baldcypress, Taxodium distichum (L.) Rich., in Eastern North Carolina*. Master's Thesis. Greenville, SC: East Carolina University.
- Browder, J., B. Murphy, and P. Schroeder. 1974. "Effect of Light Intensity on Growth of Baldcypress Seedlings." in *Cypress Wetlands for Water Management, Recycling, and Conservation*. First Annual Report to the National Science Foundation (RANN) and The Rockefeller Foundation, Center for Wetlands, University of Florida, Gainesville, FL, pp 398-419.
- Brown, C. L., and G. N. Montz. 1986. *Baldcypress: The Tree Unique, The Wood Eternal*. Baton Rouge, LA: Claitor's Publishing Division.
- Burns, R. M., and B. H. Honkala. 1990. *Silvics of North America. Volume 1. Conifers*. Agriculture Handbook 654. Washington, DC: U.S. Department of Agriculture (USDA). https://www.srs.fs.usda.gov/pubs/misc/ag_654_vol1.pdf.
- Clarke, P. J., M. J. Lawes, J. J. Midgley, B. B. Lamont, F. Ojeda, G. E. Burrows, N. J. Enright, K. J. E. Knox. 2013. "Resprouting as a Key Functional Trait: How Buds, Protection and Resources Drive Persistence after Fire." *New Phytologist* 197(1):19-35.
- Coladonato, M. 1992. "*Taxodium ascendens, T. distichum*." *Fire Effects Information System: Index of Species Information*, Web Page. Washington, DC: USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. <https://www.fs.fed.us/database/feis/plants/tree/taxspp/all.html>.
- Conner, W. H. 1994. "The Effect of Salinity and Waterlogging on Growth and Survival of Baldcypress and Chinese Tallow Seedlings." *Journal of Coastal Research* 10(4):1045-1049.
- Conner, W. H., and M. Brody. 1989. "Rising Water Levels and the Future of Southeastern Louisiana Swamp Forests." *Estuaries* 12(4):318-323.
- Conner, W. H., and J. W. Day. 1976. "Productivity and Composition of a Baldcypress-Water Tupelo Site and a Bottomland Hardwood Site in a Louisiana Swamp." *American Journal of Botany* 63(10):1354-1364.
- Conner, W. H., and L. W. Inabinette. 2005. "Identification of Salt Tolerant Baldcypress (*Taxodium distichum (L.) Rich*) for Planting in Coastal Areas." *New Forests* 29(3):305-312.

- Conner, W. H., K. W. McLeod, and J. K. McCarron. 1997. "Flooding and Salinity Effects on Growth and Survival of Four Common Forested Wetland Species." *Wetlands Ecology and Management* 5(2):99-109.
- Conner, W. H. and J. R. Toliver. 1990. "Long-Term Trends in the Bald-Cypress (*Taxodium distichum*) Resource in Louisiana (USA)." *Forest Ecology and Management* 33-34:543-557.
- DeLaune, R. D., W. H. Patrick, Jr., and S. R. Pezeshki. 1987. "Foreseeable Flooding and the Death of Coastal Wetland Forests." *Environmental Conservation* 14(2):129-133.
- Demaree, D. 1932. "Submerging Experiments with *Taxodium*." *Ecology* 13(3):258-262.
- Eggler, W. A., and W. G. Moore. 1961. "The Vegetation of Lake Chicot, Louisiana, after 18 Years Impoundment." *The Southwestern Naturalist* 6(3-4):175-183.
- ESA (U.S. Endangered Species Act). 16 USC §§1531-1544.
- Hardin, J. W., D. J. Leopold, and F. M. White. 2001. *Harlow & Harrar's Textbook of Dendrology*. 9th ed. New York: McGraw-Hill, Inc.
- Harms, W. R., H. T. Schrueder, D. D. Hook, C. L. Brown, and F. W. Shropshire. 1980. "The Effects of Flooding on the Swamp Forest in Lake Ocklawaha, Florida." *Ecology* 61(6):1412-1421.
- Hook, D. D. 1984. "Waterlogging Tolerance of Lowland Tree Species of the South." *Southern Journal of Applied Forestry* 8(3):136-149.
- Javanshir, K., and K. Ewel. 1993. "Salt Resistance of Bald Cypress." in *Towards the Rational Use of High Salinity Tolerant Plants. Vol. 2: Agriculture and Forestry Under Marginal Soil Water Conditions*. Tasks for Vegetation Science 28. Boston, MA: Kluwer Academic Publishers, pp 285-291.
- Keeland, B. D., and P. J. Young. 1997. "Long-Term Growth Trends of Baldcypress (*Taxodium distichum* (L.) Rich.) at Caddo Lake, Texas." *Wetlands* 17(4):559-566.
- King, S. L., D. J. Twedt, and R. R. Wilson. 2006. "The Role of the Wetland Reserve Program in Conservation Efforts in the Mississippi River Alluvial Valley." *Wildlife Society Bulletin* 34(4):914-920.
- Klimas, C. V. 1987. "Baldcypress Response to Increased Water Levels, Caddo Lake, Louisiana-Texas." *Wetlands* 7(1):25-37.
- Krauss, K. W., J. L. Chamber, J. A. Allen, D. M. Soileau, Jr., and A. S. DeBosier. 2000. "Growth and Nutrition of Baldcypress Families Planted under Varying Salinity Regimes in Louisiana, USA." *Journal of Coastal Research* 16(1):153-163.
- McLeod, K. W., J. K. McCarron, and W. H. Conner. 1996. "Effects of Flooding and Salinity on Photosynthesis and Water Relations of Four Southeastern Coastal Plain Forest Species." *Wetlands Ecology and Management* 4(1):31-42.
- Megonigal, J. P., and F. P. Day. 1992. "Effects of Flooding on Root and Shoot Production of Baldcypress in Large Experimental Enclosures." *Ecology* 73(4):1182-1193.

- Mitsch, W. J. and J. G. Gosselink. 2015. *Wetlands*. 5th ed. New York: John Wiley & Sons.
- Nature Conservancy, The. 1992. *Restoration of the Mississippi River Alluvial Plain as a Functional Ecosystem*. Hammond, LA: Southeastern Louisiana University.
- Neufeld, H. S. 1983. "Effects of Light on Growth, Morphology, and Photosynthesis in Baldcypress (*Taxodium distichum* (L.) Rich.) and Pondcypress (*T. ascendens* Brongn.) Seedlings." *Bulletin of the Torrey Botanical Club* 110(1):43-54.
- Penfound, W. T. 1949. "Vegetation of Lake Chicot, Louisiana in Relation to Wildlife Resources." *Proceedings of the Louisiana Academy of Science* 12:47-56.
- Pezeshki, S. R. 1990. "A Comparative Study of the Response of *Taxodium distichum* and *Nyssa aquatica* Seedlings to Soil Anaerobiosis and Salinity." *Forest Ecology and Management* 33/34:531-541.
- Pezeshki, S. R., R. D. DeLaune, and H. S. Choi. 1995. "Gas Exchange and Growth of Baldcypress Seedlings from Selected U.S. Gulf Coast Populations: Responses to Elevated Salinities." *Canadian Journal of Forest Research* 25(9):1409-1415.
- Pietrzykowski, M., W. L. Daniels, and S. C. Koropchak. 2015. "Microtopographic Effects on Growth of Young Bald Cypress (*Taxodium distichum* L.) in a Created Freshwater Forested Wetland in Southeastern Virginia." *Ecological Engineering* 83:35-143.
- Pulliam, W. M. 1992. "Methane Emissions from Cypress Knees in a Southeastern Floodplain Swamp." *Oecologia* 91(1):126-128.
- Sharitz, R. R. and L. C. Lee. 1985. "Limits on Regeneration Processes in Southeastern Riverine Wetlands." paper presented at the first North American Riparian Conference, *Riparian Ecosystems and Their Management: Reconciling Conflicting Uses*. Tucson, AZ, April 16-18, 1985. pp 139-160.
- Sharitz, R. R. and W. J. Mitsch. 1993. "Southern Floodplain Forests." Chapter 8. in *Biodiversity of the Southeastern United States/Lowland Terrestrial Communities*. New York: John Wiley & Sons, Inc., pp 311-371.
- Souther, R. F., and G. P. Shaffer. 2000. "The Effects of Submergence and Light on Two Age Classes of Baldcypress (*Taxodium distichum* (L.) Richard) Seedlings." *Wetlands* 20(4):697-706.
- USDA-NRCS (U.S. Department of Agriculture – Natural Resources Conservation Service). 2002. *Bald Cypress Taxodium distichum* (L.) L.C. Rich. Plant Fact Sheet. Washington, DC: USDA Natural Resources Conservation Services. https://plants.usda.gov/factsheet/pdf/fs_tadi2.pdf.
- USFWS (U.S. Fish and Wildlife Service). 1990. Consultation pursuant to Section 7(a)(2) or the Endangered Species Act for the proposed Wallisville Reservoir project on the bald eagle (*Haliaeetus leucocephalus*). Consultation No. 2-13-90-F-I. Houston, Texas: U.S. Department of the Interior, Fish and Wildlife Service.

- Wakeley, J. S., R. W. Lichvar, and C. V. Noble. 2010. *Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Atlantic and Gulf Coastal Plain Region. Version 2.0*. ERDC/EL TR-10-20. Vicksburg, MS: Engineer Research and Development Center, Environmental Laboratory (ERDC-EL).
<http://hdl.handle.net/11681/6942>.
- Wang, C., C. Li, H. Wei, Y. Xie, and W. Han. 2016. "Effects of Long-Term Periodic Submergence on Photosynthesis and Growth of *Taxodium distichum* and *Taxodium ascendens* Saplings in the Hydro-Fluctuation Zone of the Three Gorges Reservoir of China." *PloS one*, 11(9):e0162867.
- Wharton, C. H., W. M. Kitchens, E. C. Pendleton, and T. W. Sipe. 1982. "The Ecology of Bottomland Hardwood Swamps of the Southeast: A Community Profile." FWS/OBS-81/37. Washington, DC: U.S. Fish and Wildlife Service.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
degrees Fahrenheit	$(F-32)/1.8$	degrees Celsius
feet	0.3048	meters
inches	0.0254	meters
miles (U.S. statute)	1,609.347	meters
yards	0.9144	meters

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY) 04/01/2020		2. REPORT TYPE Final Technical Report (TR)		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE Baldcypress (Taxodium distichum) at the Wallisville Lake Project: A Review of Applicable Literature and Management Considerations				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT	
6. AUTHOR(S) Nathan R. Beane				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Engineer Research and Development Center (ERDC) Environmental Laboratory (EL) 3909 Halls Ferry Road Vicksburg, MS 39180-6199				8. PERFORMING ORGANIZATION REPORT NUMBER ERDC/EL TR-20-3	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Corps of Engineers Galveston District 3904 Ave T Galveston, TX 77550				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES This work was funded via MIPR No. W45VAK81564878, "Baldcypress at the Wallisville Lake Project."					
14. ABSTRACT Changing hydropatterns within the Wallisville Lake Project, near the mouth of the Trinity River in Chambers and Liberty Counties, Texas, have the potential to alter baldcypress forest resiliency. Increasing water levels support saltwater barrier operations while maintaining navigation and recreational access. However, potential impacts of increased water levels on the baldcypress forests are of particular concern because these ecosystems provide unique ecological value and wildlife habitat. The maintenance, succession, and resiliency of baldcypress under various flooding, salinity, and inundation regimes remain poorly defined and pose challenges to resource managers. This report reviews available literature pertaining to salinity and inundation impacts to baldcypress forests. Specific emphasis is placed on the ecological effects of water quality and quantity on the health and persistence of baldcypress. The information gathered in this report is intended to supplement material in the Wallisville Lake Project Water Control Manual to improve management of baldcypress forest conditions and avoid negative ecological impacts. Additionally, this report provides management considerations designed to maintain or enhance baldcypress forests within the Wallisville Lake Project.					
15. SUBJECT TERMS Baldcypress, Environmental management, Wallisville Lake (Tex.), Forested wetlands, Wetland ecology, Water levels, Salinity					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (include area code)