REPORT

Flooding Facility Helps Scientists Examine the Ecophysiology of Floodplain Species Used in Bottomland Hardwood Restorations

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ABSTRACT

Bottomland hardwood ecosystems, important for their unique functions and values, have experienced considerable degradation since European settlement through deforestation, development, and drainage. Currently, considerable effort is underway to restore ecological functions on degraded bottomland sites. Restoration requires a better understanding of the biological components, especially plants, and their interactions with other biotic and abiotic components of the ecosystem. Previous experimental approaches have focused on the effects of stress on floodplain plant species in controlled, small-scale studies or large, uncontrolled ecosystem-scale studies. We describe a facility, named the Flooding Research Facility (FRF), where hydrologic regimes can be manipulated to study ecophysiology of floodplain species. Key features of the FRF include the ability to establish experiments on a scale larger than would be possible in a greenhouse, but small enough to control key abiotic variables, such as flood frequency, duration, and light availability on native bottomland soil. Design of the FRF allows for random and replicated treatment applications. Additionally, we provide an example of ongoing research on the effects of flooding and light availability on pondberry (*Lindera melissifolia*), a federally endangered shrub found in the southeastern United States.

Keywords: bottomland hardwood forests, *Lindera melissifolia*, ecophysiology, Flooding Research Facility, Lower Mississippi Alluvial Valley

Bottomland hardwood forests in the southern United States are generally defined as deciduous forests on sites subject to surface water flow at some period during most years (Putnam and others 1960, Turner and others 1981, Taylor and others 1990). These floodplain forests are usually associated with alluvial soils, which distinguish them from other forested wetlands, such as seeps, bogs, upland cypress ponds, and the like (Braun 1950, Hodges 1995). It is estimated that about 50 million acres (20 million ha) of bottomland hardwoods existed across the southern United States prior to European settlement (U.S. Forest Service 1988, The Nature Conservancy 1992). The Lower Mississippi Alluvial Valley (LMAV) alone contained about 25 million acres (10 million ha) of bottomland hardwood forests (National Research Council 1992, Hefner and Brown 1985), which has been reduced to about 5 million acres (2 million ha) (MacDonald and others 1979). From the late 1950s until the mid-1970s, annual deforestation in the LMAV exceeded 300,000 acres (120,000 ha) in response to high soybean prices and a prolonged drought that gave a false sense of security to those farming normally wet, heavy clay soils (Sternitzke 1976, Spencer 1981, Schoenholtz and others 2001, Stanturf and others 2001, Haynes 2004). The large loss and fragmentation of remaining LMAV bottomland hardwood forests (Rudis 1995), combined with alteration of surface and subsurface water flow patterns from drainage ditches and levees, places the LMAV bottomland hardwood forests as one of the most endangered ecosystems in the United States (Noss and others 1995).

During the last decade, recognition of their unique functions and values has driven interest in restoring bottomland hardwood ecosystems across the southern United States (Walbridge 1993, Schoenholtz and others 2001, Stanturf and others 2001, Haynes 2004, Stanturf and others 2004). To date, more than 490,000 acres (196,000 ha) in the LMAV have been removed from agricultural production and enrolled in programs that target restoration of bottomland hardwood forests (Gardiner and Oliver 2005). However, since altered hydrologic regimes and degraded soil quality are characteristics of many of these afforestation sites, establishment of bottomland tree species can be problematic and often results in plantation failures (Stanturf and others 2001,

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Lockhart and others 2003, Patterson and Adams 2003).

Researchers have for some time recognized that a basic understanding of how hydrologic regimes influence the ecophysiological processes of plant species endemic to bottomland hardwood ecosystems is fundamental to developing future restoration and management strategies for these systems. In this paper we describe a large-scale impoundment system that was designed to study floodplain plant responses to experimentally manipulated hydrologic regimes. We provide a brief review of traditional experimental approaches used to research the ecophysiology of floodplain species; describe our large-scale research facility, called the Flooding Research Facility (FRF); and provide an example of the type of research that can be conducted in the facility.

Figure 1. Location of the Flooding Research Facility in Sharkey County, Mississippi, USA.

Bottomland Hardwood Ecophysiology Research

The key to restoring bottomland hardwood ecosystems is a basic understanding of the role various stress factors, especially the hydroperiod, play on the establishment, physiology, growth, and development of woody and non-woody floodplain species (Kozlowski and others 1991, Lassoie and Hinckley 1991). Past research on floodplain species has primarily involved small-scale studies on the effects of one or two stress factors, singly or in combination (Hook and others 1970, Kennedy, Jr. 1970, Hook and Brown 1972, Zang and Kozlowski 1984, Kludze and others 1994, Angelov and others 1996, McLeod and others 1999, King and Grace 2000). These studies have been conducted using floodplain species in growth chambers, greenhouses, and hydroedaphytrons under controlled or partially controlled environments. They provide basic information about how plants tolerate, acclimate, or avoid stresses related to floodplain environments. Other studies have been conducted to observe the effects of stress or disturbance at ecosystem scales, although with little or no control over environmental conditions (Day 1982; Walbridge and Lockaby 1994; Aust and others 1997; Lockaby and others 1997a, 1997b; Messina and others 1997; Perison and others 1997; King and others 1998; Burke and Eisenbies 2000). Although both approaches provide important information on basic responses of floodplain plants to stress factors, the application of their results are limited by experimental controls and scale issues. A critical need in bottomland hardwood ecosystem research is the design and development of research areas that combine the controlled conditions of small-plot studies with the practical applications of large-plot field studies.

Flooding Research Facility

The Flooding Research Facility is located in Sharkey County, Mississippi on the Theodore Roosevelt National Wildlife Refuge Complex, 2 miles (3.2 km) east of the Sunflower River and 5 miles (8 km) east of Anguilla (Figure 1). It is adjacent to the headwaters of Dowling Bayou, which flows into the Big Sunflower River.

Prior to deforestation for agriculture in the 1960s, the site of the FRF was part of a vast bottomland hardwood forest that covered much of the LMAV (Barry 1997, Fickle 2001). In 1993, the site was placed under the management of the U.S. Fish & Wildlife Service, which made it available for research. Initial construction of the FRF began in 1994 using a bulldozer, trackhoe, dragline, and farm tractors with dirt pans at a cost of about $65,000 (Mr. Tim Wilkins, U.S. Fish & Wildlife Service, pers. comm.). The FRF was used for three years and then idled because funds were not available to support additional research and maintenance of the facility. Recently, the FRF has been upgraded and is now fully operational.

The FRF contains 12 cells that can be artificially and independently flooded to desired levels for specific periods of time (Figures 2 and 3). The interior of each cell is 660 feet (201 m) long (oriented north/south) by 60 feet (18.3 m) wide (Figure 3) and is surrounded by an 8-foot (2.4-m) tall levee on each interior side. A 10-foot (3-m) tall levee surrounds the outside perimeter of the facility. This levee height was based on the high water mark of the 1973 Mississippi River flood

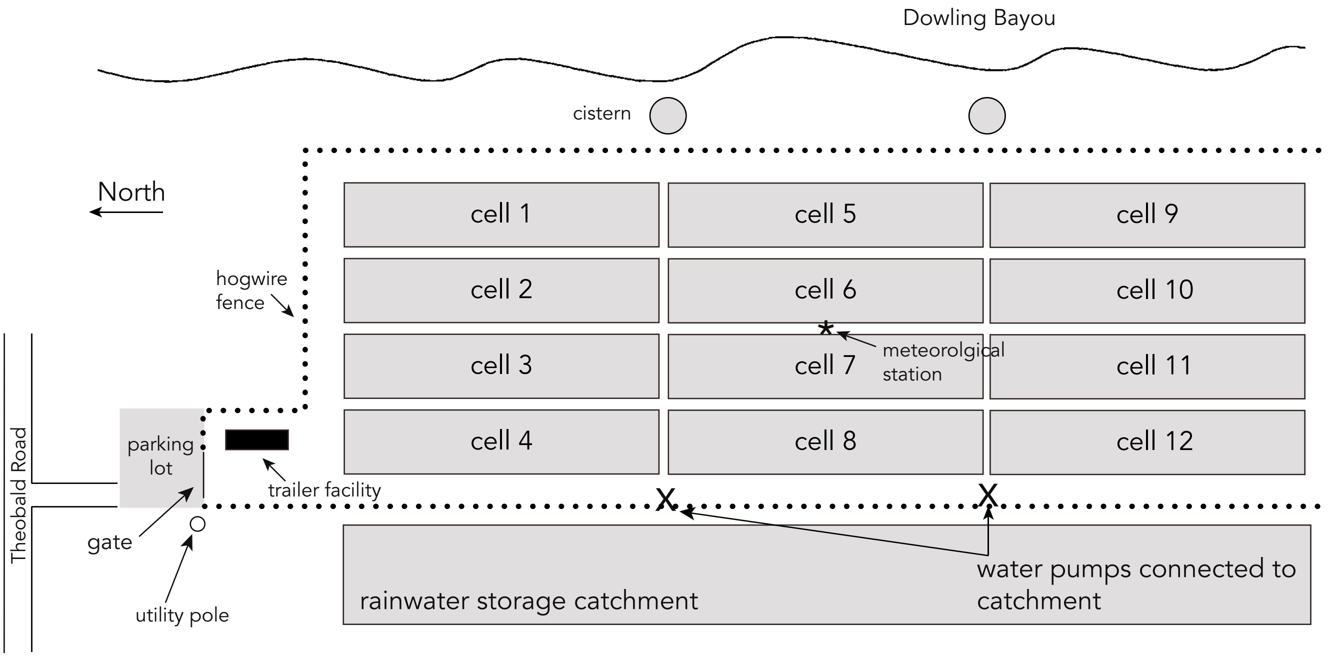

Figure 2. Layout of the Flooding Research Facility including the location of the cells, pumps, and levees.

Figure 3. Looking southwest across the Flood Research Facility. The structures in the slightly flooded cells are shade houses. *Photo courtesy of Brian R. Lockhart*

and is designed to exclude floodwater from the facility. A 10-foot tall hogwire fence was built on the outer edge of the levee to keep white-tailed deer and feral hogs off the site. Trenches, 10 feet wide by 4 feet (1.2 m) deep, run the lengths of the east sides of the three west cells, the west sides of the three east cells, and both the east and west sides of the six interior cells to facilitate the removal of excess water. A LiCor meteorological station, including a quantum sensor, an air temperature sensor, a relative humidity sensor, and a rain gauge, is located near the center of the facility (Figure 2).

When building the levees and ditches, care was taken to avoid disturbing the soil in cells. As a result, the soil surface in each cell is the original soil surface at the time agriculture ceased. Soil on the FRF is Sharkey clay—the predominant soil in the LMAV, occuring on more than one million acres (400,000 ha) in Mississippi and three million acres (1.2 million ha) nationwide (Pettry and Switzer 1996). The Sharkey series (very-fine, smectitic, thermic Chromic Epiaquerts) consists of very deep, poorly and very poorly drained, very slowly permeable soils that formed in clayey alluvium from the Mississippi River and its tributaries.

A key design feature of the FRF is the ability to control water to desired levels through a water storage-pump-drainage system. A rainwater storage catchment on the wide side of the impoundment cells is capable of holding about 880,000 ft^3 (26,400 m^3) of rainwater (Figure 2). Two portable Gorman-Rupp self-priming centrifugal pumps with attached Kohler 15-hp engines are also located on the west levee between each row of cells (Figure 2) and are connected to an underground network of 3-, 4-, and 6-inch PVC pipes and associated reducers and control valves that allow water to be added to each cell independently. The pumps have a maximum flow rate that is sufficient to fill a given cell to a 4-inch (10-cm) depth in about five hours. In addition to stored rainwater, a separate electrical pump can draw subsurface water for storage in the catchment if needed (Figure 2). Drainage is accomplished through a series of underground 12-inch PVC pipes perpendicular to each cell (Figure 4). These pipes slope from west to east to drain excess water by gravity. An overflow valve is located at an opening in the pipe near one trench in each cell. This valve is closed to maintain water at the desired depth. Drainage water flows off the FRF into one of two cisterns located on the outer edge of the east levee (Figure 2). Water flows through the cistern and then out another 12-inch pipe into a natural drainage channel on the site. The pipe leading into the cistern and the one exiting the cistern have shutoff valves to prevent water from flowing into the FRF in the event the natural channel is flooded. Should the channel be flooded, four additional pumps would be used to move excess water out of each cistern and into the drainage channel.

The design features of the FRF provide opportunities for large-plot experimental manipulations that cannot be addressed through either small-plot experimentation or field research in bottomland hardwood ecosystems. Independent flooding and drainage of each cell permits randomized replication of treatments. The large size of the impoundments also allows for testing of multiple stress effects and their interactions through the use of split-plot designs. A variety of hydrologic regimes can be established as treatments ranging from no surface flooding to standing floodwater at desired depths to con-

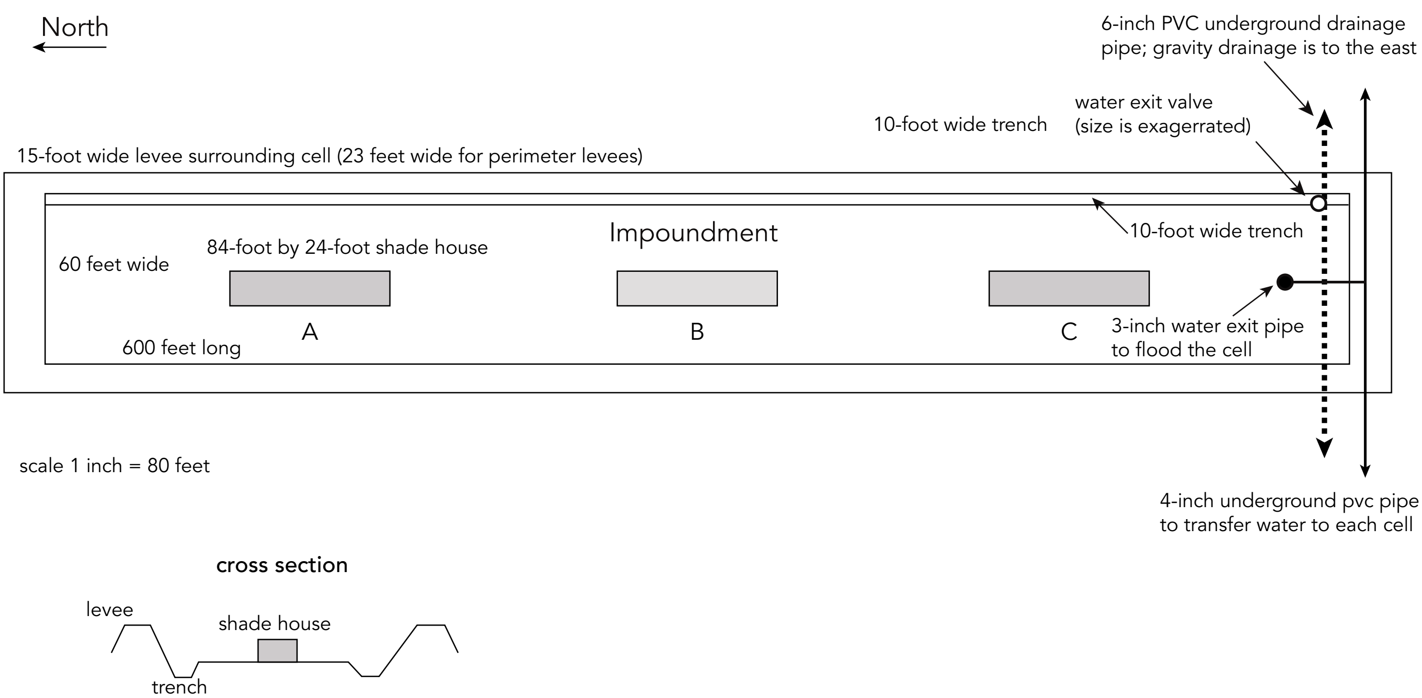

Figure 4. Schematic layout of an individual cell at the Flooding Research Facility including shade houses (A, B, C) and the flooding and drainage system.

tinuously flowing floodwater at desired depths. Floodplain plants can be established in native soil enabling observations of plant and soil interactions directly applicable to issues raised by land managers in the LMAV. In addition, the large size of the cells allows for extended experimentation on floodplain plants ranging from seedlings to saplings and small trees.

Research Application–Pondberry

Julian Steyermark (1949) described pondberry (*Lindera melissifolia*) as one of the rarest shrubs in the United States. This dioecious rhizomatous, deciduous shrub grows to 1 to 6 feet (0.3-1.8 m) tall in bottomland hardwood forests and on the edges of sinks, ponds, and depressions in the southeastern United States (Radford and others 1968, U.S. Fish & Wildlife Service 1993, Devall and others 2001). Pondberry is considered shade tolerant (Tucker 1984, Wright 1990, U.S. Fish & Wildlife Service 1993), although it has also been observed to grow well in forest gap environments (McCartney and others 1989, Devall and others 2001).

Pondberry occurs in isolated populations in six states across the southeastern United States (U.S. Fish & Wildlife Service 1993). Though the current and historical extents of pondberry are unknown, the U.S. Fish & Wildlife Service speculates that the present rarity of the species is due to habitat alterations from drainage modification, especially ditch building, with subsequent changes in hydroperiod and conversion of the habitat to other uses (U.S. Fish & Wildlife Service 1993). Other disturbances, including domestic animal grazing and rooting, and other mechanical equipment operations, may also affect pondberry densities (Wright 1990, U.S. Fish & Wildlife Service 1993, Devall and others 2001). Due to its rarity and reduced habitat, the U.S. Fish & Wildlife Service listed pondberry as a federally endangered species in 1986 (U.S. Fish & Wildlife Service 1986). A subsequent Recovery Plan was developed in 1993 (U.S. Fish & Wildlife Service 1993), which documented the need for additional knowledge on the biology and ecology of the species.

The FRF was recently prepared for a three-year project on pondberry ecophysiology in relation to hydrologic regimes and light availability. Studies will determine the effects of flooding and light availability on male and female steckling (transplanted young plants) survival, morphology, physiology, growth, and biomass accumulation. Three hydrologic regimes are randomly assigned to cells, thereby establishing four replications of each treatment. Treatments include 1) no flooding–all surface water will be removed from the cell including water following major rain events, 2) flooding from March 1 through April 14 (45 days) to an average depth of 2 to 4 inches (5 to 10 cm) above the ground; water will then be removed from the cell and it will be allowed to dry except during rain events, and 3) flooding March 1 through May 29 (90 days) to an average depth of 2 to 4 inches above ground. Water will then be removed from the cell and it will be allowed to dry with the exception of rain events. Water levels will be maintained by monitoring gauges placed in each cell, and adding or removing water as needed through the pump-drainage system.

Each cell was split to receive three light availability treatments—70 percent, 37 percent, and 5 percent of full sunlight. Light availability is controlled by the deployment of neutral density shade cloth (PAK Unlimited, Inc., Cornelia, Georgia) attached to shade houses 84 feet (25.6 m) long by 24 feet (7.3 m) wide by eight feet (2.4 m) tall. Individual shade houses were built for each light availability treatment within each hydroperiod treatment (three shade houses per cell for a total of 36 shade houses; Figures 2 and 3). Shade cloth completely encloses the top and sides of each shade house. A 2-foot (0.6-m), three-mesh, galvanized hardware cloth (0.29-inch openings with a 0.05-inch wire diameter) was placed around the base of each shade house, with the bottom 4 inches (10 cm) buried below the soil surface to prevent rodent and rabbit damage to pondberry stecklings.

Pondberry stecklings were planted in respective shade houses in April 2005. An example of the type of data being collected is found in Table 1. Flooding treatments were begun in March 2006, which gave the stecklings one growing season to establish themselves under the respective light availability treatments. The same flooding treatments as described above will be repeated March through May 2007.

Relevance of the Flooding Research Facility to Bottomland Hardwood Ecosystem Restoration Research

Restoration of degraded bottomland hardwood ecosystems requires a better understanding of the biology of the individual plant species and their interactions with other biotic and abiotic components of the ecosystem. The FRF provides a unique opportunity to study the long-term effects of hydroperiod and other environmental

Table 1. Mean number of flower buds on pondberry stems in February 2006 by light availability and gender at the Flooding Research Facility, Sharkey County, Mississippi. In March 2006, the plants were subjected to one of three hydroperiod regimes as described in the text.

Light availability (%)	Gender	Number of flower buds	Number of flower buds per centimeter stem length
70	female	21.0 ± 1.0 c[1]	0.4 ± <0.1 b
	male	27.7 ± 1.0 bc	0.5 ± <0.1 ab
37	female	32.8 ± 1.2 ab	0.5 ± <0.1 ab
	male	41.7 ± 1.3 a	0.6 ± <0.1 a
5	female	<0.1 ± <0.1 d	<0.1 ± <0.1 c
	male	<0.1 ± <0.1 d	<0.1 ± <0.1 c

[1]Means followed by a different letter within a column are different at $p \leq 0.05$. Analyses conducted with a split-plot design with light availability as the whole plot factor and gender as the split-plot factor.

factors on the ecophysiology of plant species in southern bottomland hardwood ecosystems. The FRF also allows for cooperative research with other federal, state, and private entities (contact Dr. Ted Leininger at 662/686-3178 for further information).

Current restoration efforts in the LMAV focus on the afforestation of former agricultural fields, but simply planting trees is not complete restoration (Stanturf and others 2001). One area of ecosystem restoration in the LMAV generally overlooked is the establishment and development of understory plant species. Understory plant species provide critical habitat for various wildlife species in addition to increasing ecosystem diversity. A better understanding of the environmental requirements of understory plant species, such as pondberry (Aleric and Kirkman 2005), will lead to greater establishment success and improved restoration of bottomland hardwood ecosystems in the LMAV.

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