ESTIMATING CARBON STOCKS IN UNEVEN-AGED BOTTOMLAND HARDWOOD FOREST STANDS IN SOUTH LOUISIANA

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Abstract—This study reports growth and carbon storage of four bottomland hardwood forest sites in the Lower Mississippi Alluvial Valley (LMAV) of southern Louisiana. Forest growth and carbon sequestration rates at the four sites were highly variable because of differences in stand composition, age, structure, and site hydrology. Mean annual carbon assimilation rates ranged from 1.9 - 3.4 Mg/ha/yr during a seven year period. The highest sequestration rates occurred in trees on the drier, ridge site. Remnant mature trees accounted for a large proportion of total carbon assimilated and stored and at each site. The carbon sequestration rates reported in this study are generally less than those reported by previous research of carbon storage capacity of bottomland hardwood forests in the LMAV.

INTRODUCTION

Bottomland hardwood (BLH) wetlands are riparian wetland forests located in river floodplains and seasonally wet areas throughout the southeastern U.S. (Hodges 1997). The typical location of BLH forests in floodplains causes seasonal flooding and sediment deposition that contributes to highly productive soils. The largest expanse of BLH forests in the southeastern US are in the Lower Mississippi Alluvial Valley (LMAV). Historically, the LMAV contained approximately 10 million hectares of BLH forests, but now only 2.8 million hectares remain because of widespread conversion to agriculture (King and Keeland 1999). The loss of BLH forests results in the loss of ecosystem service function values including carbon storage, water quality, wildlife habitat, and flood control (Jenkins and others 2010). Federal and state conservation programs have recently encouraged afforestation to restore BLH forest area mainly for restoration of wildlife habitat (Gardiner and Oliver 2005), and the economics of carbon sequestration have also attracted the interest of landowners and private investors (Shoch and others 2009).

Bottomland hardwood species distribution within floodplains is largely the result of floodplain microtopographic variation. These minor topographic variations have a large effect on site hydrology, which is the major allogenic force determining species presence and natural patterns of ecological succession and productivity (Hodges 1997). Although BLH forests are highly productive forest ecosystems (Messina and Conner 1998) with a high capacity to sequester carbon (Brinson 1990), there is a scarcity of published growth and yield studies, and conflicting results for those studies that do exist (Shoch and others 2009). For example, some research suggests high productivity in transitional BLH forests located between cypress-tupelo swamps and upland forests (Conner and Day 1976; Taylor and others 1990), while other studies have shown the physiological stresses of anaerobic soils and drought outweigh the benefits of periodic flooding (Mitsch and Rust 1984; Megonigal 1997).

Much of the published work with regard to the sequestration capacity of these forests has focused on afforested stands and plantation forests. However, cutover and naturally regenerated stands make up the majority of bottomland hardwood forests in the LMAV. These stands are not amenable to simple modeling by age due to their structural diversity (Smith and others 2006; Shoch and others 2009; Covey and others 2012). Several studies have documented carbon storage of even aged stands, forest plantations, and naturally regenerated stands of known ages (Smith and others 2006; Heath and others 2011) throughout the United Sates. Shoch and others (2009) examined carbon storage rates in BLH forests of northern reaches of the LMAV and concluded that the Smith and others (2006) table for the south-central U.S. region underestimates carbon storage in live-tree biomass of bottomland hardwood stands in the LMAV aged 20-90 years. A full understanding of forest growth and carbon storage in bottomland sites requires more information from natural stands.

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The purpose of this study was to measure carbon stocks and sequestration rates in bottomland hardwood stands in the LMAV in south Louisiana. We hypothesized that forest stands across varying micro topographical environments store carbon at different rates based on stand characteristics and site hydrology. We compare carbon stored in live aboveground woody biomass at the stands using two sets of allometric equations.

Field-Site Description

This research was carried out at two bottomland hardwood sites near Baton Rouge and St. Gabriel, Louisiana, owned by the Louisiana State University (LSU) Agricultural Center (fig. 1). Both sites are in the floodplain of the Mississippi River but have not been flooded by river water for more than a century because of flood control levees. Flooding at the research sites is by rainwater and stormwater runoff from the surrounding uplands.

The Baton Rouge site consists of approximately 300 acres of forest at the Ben Hur Agricultural and Forest research station, approximately 3 km south of the LSU main campus, and is bordered by agricultural fields and private residential developments. Two general forest habitat types—ridge and swale—exist at the site, with tree species present heavily influenced by local hydrology. The ridge habitat (BHR) is dominated by oaks, hickories, and sugarberry while the swale habitat

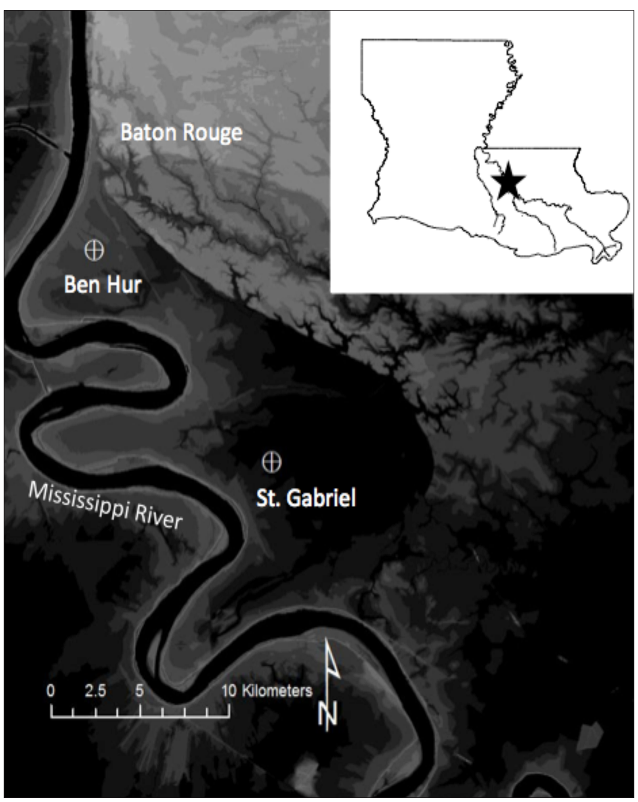

Figure 1—Map of study sites (crosses in circles) and surrounding area in Louisiana, USA. Background shading indicates elevation.

(BHS) is dominated by cypress and tupelo. The sites are mixed-species, multicohort, uneven-aged stands in the understory reinitiation stage of stand development (Oliver and Larson 1996). Ridges and swales are well defined and occur successively approximately every 25-30 m so that that the swales are functional drainages while the ridges are rarely breached by floodwaters. Water enters the site in the form of precipitation and from the overflow of a drainage ditch that runs along the western edge of the forest adjacent to a suburban housing development. The swale site is composed of poorly-drained Schriever clay (very-fine, smectitic, hyperthermic Chromic Epiaquert) typical of meander scar landforms. Parent material is clayey alluvium to 152 cm and the typical depth to water table for this series is 0-61 cm (NRCS 2011). The ridge site is composed of Thibaut clays (clayey over loamy, smectitic over mixed, superactive, nonacid, hyperthermic Vertic Epiaquept) that are the dominant soil type of ridges formed from clayey over loamy alluvium parent material. Typical depth to water table for this series is 46-91 cm.

The St. Gabriel site is located approximately 18 km southeast of LSU main campus on the LSU AgCenter Reproductive Biology Center campus. The approximately 200 acre forest is composed of mixed bottomland hardwood species that has not been managed in recent years. The area was heavily logged or cleared for pasture in the middle part of last century and the study sites are composed of naturally regenerated multi-cohort stands in the stem exclusion stage of stand development (Oliver and Larson 1996). A number of spoil banks and canals affect hydrology and overall ecosystem function of the forest by impounding water during periods of high rainfall. As is the case at Ben Hur, species composition of the forest results from the frequency and duration of inundation. Impounded areas that are drier for longer periods, the St. Gabriel flats (SGF), are composed of mixed bottomland oaks (Quercus spp.), American elm (Ulmus americana), and sugarberry (Celtis leavigata), while the wetter areas, the St. Gabriel swale (SGS), are dominated by baldcypress (Taxodium distichum) and water tupelo (Nyssa aquatica). The micro topography at St. Gabriel is composed of much broader features than the well-defined ridges and swales at the Ben Hur site. The St. Gabriel sites are both classified as backswamp landforms composed of Schriever clay, but the swale site floods more frequently.

METHODS

Two pairs of 100 × 20 m plots were established at each site. Trees greater than 3cm in diameter were tagged and diameter at breast height (DBH) measured. Tree cores were taken from a random subsample of trees at each site to determine the ages of trees in the stand. The number of tree cores taken at each site was 14 (BHR), 18 (BHS), 16 (SGF), and 14 (SGS). Stem production was estimated for 2009 and 2010 from annual changes in woody biomass calculated based on tree rings.

Tree biomass was estimated using allometric equations derived from Megonigal (1997) and Jenkins and others (2003). Carbon was calculated as 50 percent of tree biomass (Swift and others 1979). Two different sets of allometric equations were used because previous work has shown that differences in equation forms and species groupings may cause differences at small scales depending on tree size and forest species composition (Jenkins and others 2003). The equations used from Jenkins and others (2003) were for the mixed hardwoods species group and the oak/hickory species group.

Trees were cored with a 5.15-millimeter diameter increment borer to estimate recent growth rates. Cores were taken at breast height, dried at 60 °C, mounted on wooden frames, and sanded to expose tree rings. Ring width was measured to the nearest 0.01 mm on a sliding stage, and converted to basal area increment. Carbon storage was estimated based on accumulated basal area. The study did not account for tree mortality or other carbon pools such as litter, dead wood, non-woody vegetation, and soils.

RESULTS

Stand Structure

Study sites were composed of mixed bottomland hardwood communities typical of the LMAV. Diameter distributions were generally dominated by small trees (the "inverse J" shape; fig. 2) befitting natural stands with complex disturbance history.

Tree cores from each of the sites provided an estimate of the relative stand ages. The Ben Hur ridge site contained older trees compared to the other sites, several of which dated back to the early 20th century from 1899-1926. One tree at the Ben Hur swale site dated to 1876 and another to 1927 but the majority dated from the 1960s. The St. Gabriel flat site is composed of younger trees dating back to the 1970s with several older oaks dating back to the early 1960s. The St. Gabriel swale site consists of overstory trees that date back to the 1940s and 1950s.
Basal area at the Ben Hur sites increased by 1.3 m^2/ha from 2009 to 2010, while basal area increased by approximately half this amount at the St. Gabriel sites (table 1).

Carbon Storage

Total carbon storage in tree biomass increased from 2009 to 2010 at all sites (table 1). A greater increase

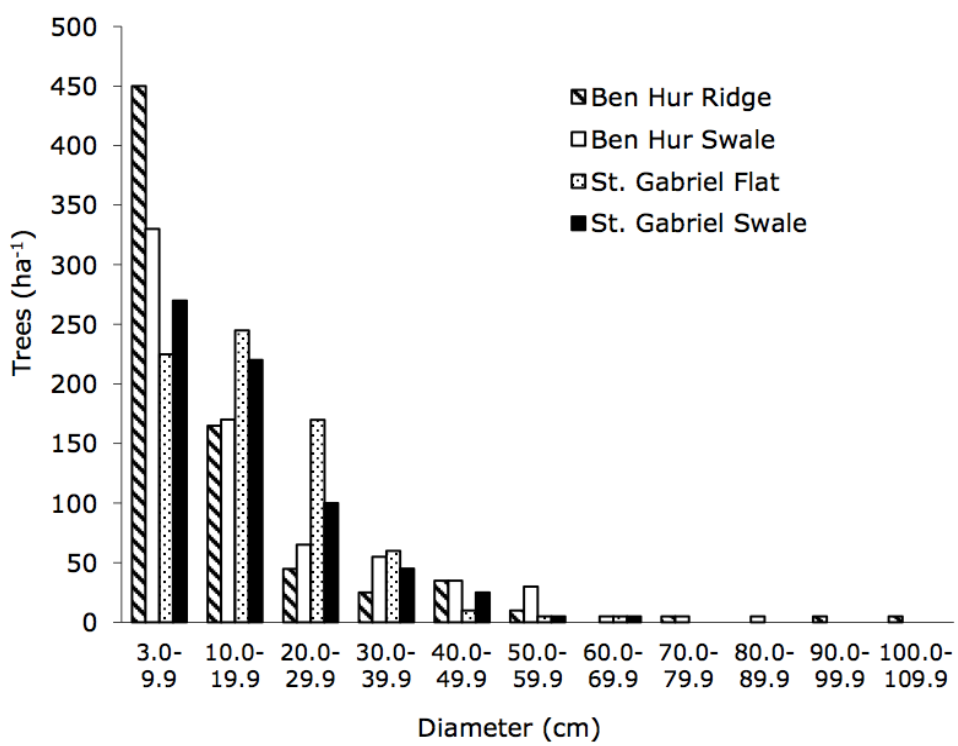

Figure 2—Distribution of trees by diameter at breast height for each site.

Table 1—Basal area and carbon storage at each of the study sites using allometric equations by Megonigal and others (1997) and Jenkins and others (2003)

	Basal Area		Megonigal-C			Jenkins-C		
	(m^3/ha)[1]		(Mg/ha)[1]		(Mg/ha/yr)[2]	(Mg/ha)[1]		(Mg/ha/yr)[2]
Site	2009	2010	2009	2010	2003-2010	2009	2010	2003-2010
Ben Hur Ridge	31.1	32.4	133	140	3.4	131	136	3.0
Ben Hur Swale	31.2	32.5	91	96	2.4	104	109	2.7
St. Gabriel Flat	23.6	24.3	74	76	2.3	72	73	2.3
St. Gabriel Swale	21.2	21.8	63	63	1.9	64	65	1.9

[1]Caclulated from diameter measurements
[2]Calculated from tree rings

in carbon storage was measured at the Ben Hur sites than at the St. Gabriel sites. Carbon storage in woody biomass was greater at the Ben Hur site than at the St. Gabriel site. The Ben Hur ridge site contained more carbon than the Ben Hur swale site. The St. Gabriel flat site contained more carbon stored in woody biomass than the St. Gabriel swale site.

The application of the Jenkins and others (2003) allometric equations led to a slightly higher estimate of carbon storage for the swale sites while estimated carbon storage at the Ben Hur ridge site and St. Gabriel flat site was higher when equations from Megonigal (1997) were applied. At all sites, carbon stored in the ten largest trees was greater than 50 percent of all live woody biomass carbon. The ten largest trees at the Ben Hur ridge site contained 73 percent of live woody biomass while the ten largest at the Ben Hur swale contained 54 percent. The proportion of carbon stored in the ten largest trees at the St. Gabriel flat site was 89 percent and 54 percent at the St. Gabriel swale site. The higher percentages of carbon in the ten largest trees at the Ben Hur ridge site and St. Gabriel flat site are a result of remnant mature trees present in the multi-cohort stands.

The uneven-aged stands examined in this study-sequestered carbon at variable mean annual rates ranging from 1.9 MgC/ha/yr to 3.4 MgC/ha/yr from 2003-2010. The ridge site sequestered carbon at the highest mean annual rate. Carbon sequestration rates at all the sites were within 1 MgC/ha of each other, on average, during the study period. Carbon sequestration rate variability within sites ranged from 0.2 – 0.6 MgC/ha/yr. Carbon sequestration and storage at the sites was the combined result of variable species composition within sites, differences in stand age and density across sites, and estimates varied depending on the allometric equation used.

Trends in BAI 2003-2009 were highly variable across sites by diameter class (fig. 3). However, similar patterns in tree growth size classes within sites occurred. In general, BAI was higher at BHR for all tree size classes than at any other site. The larger trees in the stand are generally growing at a faster rate than the smaller trees and are storing carbon in larger quantities and assimilating at a greater rate.

Estimated carbon storage rate in live woody biomass was greater using the Megonigal (1997) equations at the BHR and SGF site while the Jenkins and others (2003) equations produced greater estimates of carbon storage at BHS and SGS (fig. 3). The differences in these calculations were the result of species composition and tree sizes at the study sites. The Megonigal equations produced greater estimates for most species with the exceptions of bald cypress, water tupelo, Quercus species (oaks), and Carya species (hickories). The presence of bald cypress and overcup oak at the SGS site accounted for slightly higher carbon estimates when using the Jenkins equations. The presence of a greater number of large bald cypress and water tupelo at BHS led to higher estimates using the equations from Jenkins and others. (2003). The two sets of equations applied to the BHR site yielded approximately equal estimates of carbon storage.

Changes in carbon storage occurred at different rates across each of the sites (table 1). The mean annual rate of carbon storage was greatest at BHR, as was total change in carbon storage from 2003-2010. BHR was the only site where the Megonigal equation produced greater estimated rates of change and total change in carbon storage over time. Mean annual rates of carbon accumulation were within 0.5 MgC/ha at all sites for both sets of allometric equations. Total estimated carbon accumulation across the 7-year period at the Ben Hur site was higher using the Megonigal equation (23.4 MgC/ha) as opposed to the Jenkins equation (20.8 MgC/ha).

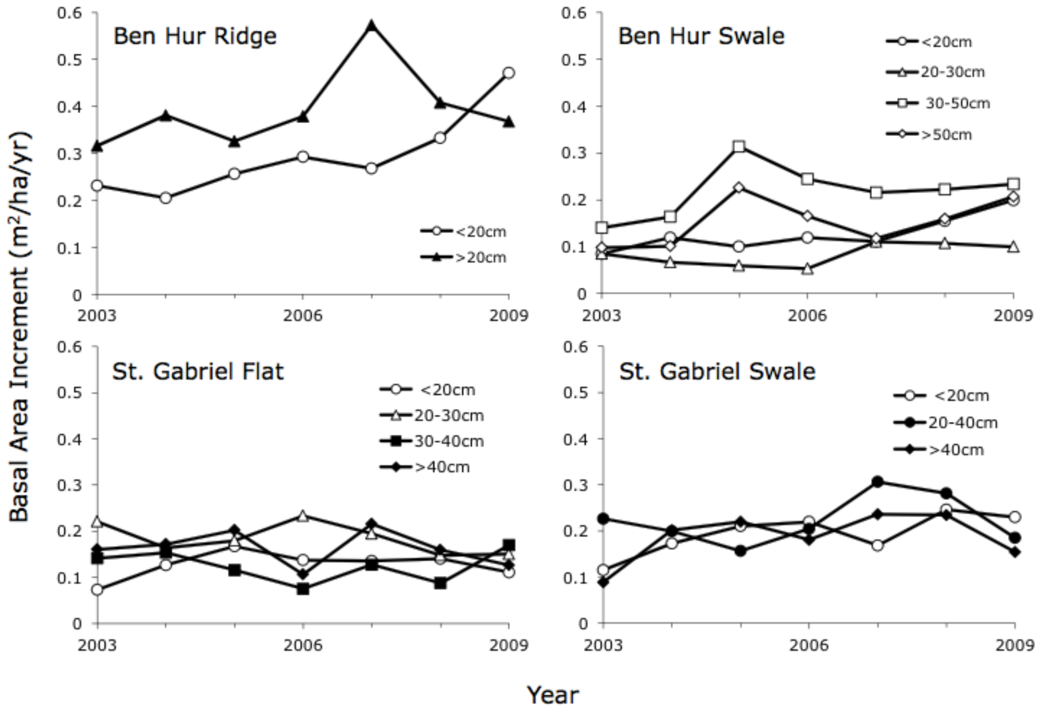

Figure 3—Basal area increment for each site reconstructed from tree rings.

DISCUSSION

There was no evidence in bias between the Megonigal and Jenkins equations, but results varied with respect to species composition at each of the sites. Variability of forest carbon sequestration rates is a result of several factors, including stand age, composition, density, and hydrology (Megonigal 1997; Ryan and others 2010). Based on this study, one hectare of bottomland hardwood forest stores between 63-140 MgC in live aboveground woody biomass.

Species composition and micro topographic variations were typical of the LMAV (Hodges 1997). Results of this study are consistent with previous studies, in that changing elevation by <2 meters had a marked difference on site quality, species occurrence, and stand development (Hodges and Switzer 1979; Wharton and others 1982; Hodges 1997).

Although it is not possible to determine effects on forest growth from one year of hydrologic data, the wettest site—SGS—had the lowest carbon storage in the standing crop of woody biomass. There were many downed and broken trees at this site, which suggests that the site may be transitioning toward more water tolerant species. However, forest community response to environmental change often occurs over a number of years (Conner and others 2011), thus more comprehensive, longer term monitoring of the sites is needed to accurately describe the relationship between hydrology and productivity.

Our study focused only on carbon stocks of living trees, but woody debris is an important storage component in many forest ecosystems (Harmon and others 1986). There are few published estimates of carbon in dead wood (i.e., standing dead, understory snags, and forest floor litter) in LMAV bottomland-hardwood forests. The best published estimates have been by Smith and others (2006) and Cochran (2008), which suggest that the volume of coarse woody debris may have ranged from 7-23 m^3/ha while fine woody debris ranged from 2-5 m^3/ha, and that dry sites have less woody debris than wet sites (Cochran 2008). Extrapolating from those values and results of our study suggests that living trees generally account for 69-94 percent of the total woody biomass in natural BLH stands.

Stand structure is an important determinant of carbon storage. This is especially the case with regard to uneven-aged cutover forests with remnant mature trees, as has been demonstrated in this study. These large trees are the most important loci of carbon storage; more than 50 percent of the carbon stored in live woody biomass occurred in the ten largest trees at all sites in this study. This concurs with Ryan and others (2010), who reported that large diameter trees tend to account for a large proportion of the aboveground biomass in mature forests. Thus, foresters managing similar forests for carbon storage should consider the standing crop of remnant mature trees.

The carbon storage rates reported in this study are low in comparison to previous research conducted to assess the carbon storage capacity of bottomland hardwood forests in the LMAV (fig. 4). Previous research by Shoch and others (2009) focused on even aged stands that followed a sigmoid growth curve in regards to age. Carbon storage of the uneven-aged trees in our study sites may be better represented by the estimates of carbon storage rates of oak-gum-cypress stands in the south-central U.S., as suggested by Smith and others (2006).

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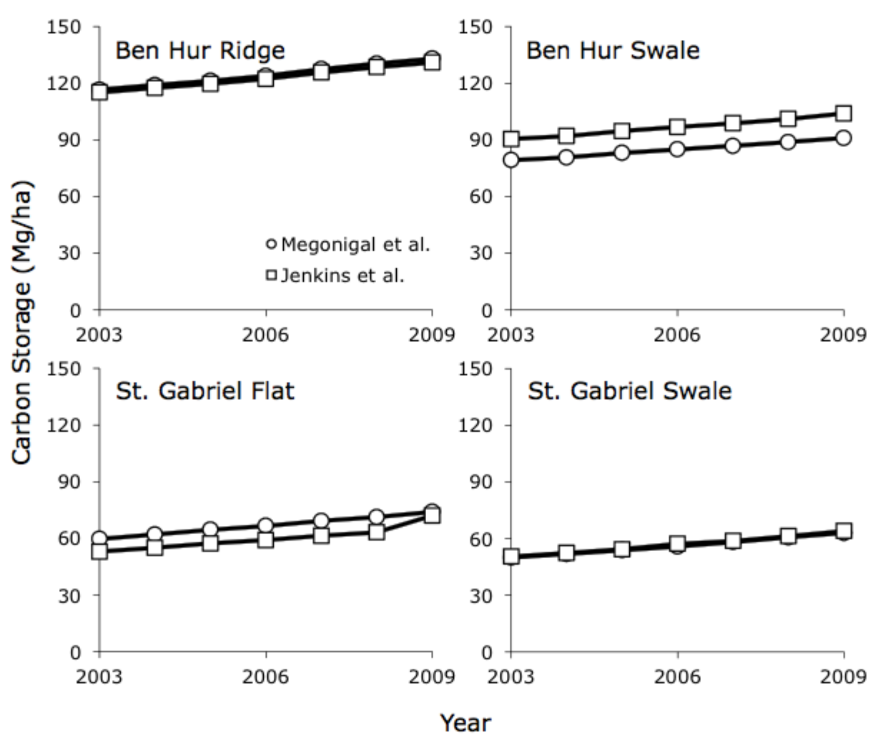

Figure 4—Carbon storage in live woody biomass at each site estimated using allometric equations by Megonigal and others (1997) and Jenkins and others (2003).

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