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Sediment deposition and sources into a Mississippi River floodplain lake; Catahoula Lake, Louisiana

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ABSTRACT

Floodplain lakes are important wetlands on many lowland floodplains of the world but depressional floodplain lakes are rare in the Mississippi River Alluvial Valley. One of the largest is Catahoula Lake, which has existed with seasonally fluctuating water levels for several thousand years but is now in an increasingly hydrologically altered floodplain. Woody vegetation has been encroaching into the lake bed and the rate of this expansion has increased since major human hydrologic modifications, such as channelization, levee construction, and.

dredging for improvement of navigation, but it remains unknown what role those modifications may have played in altering lake sedimentation processes. Profiles of thirteen ^{137}Cs sediment cores indicate sedimentation has been about 0.26 cm y^{-1} over the past 60 years and has been near this rate since land use changes began about 200 years ago (^{210}Pb, and ^{14}C in Tedford, 2009). Carbon sequestration was low (10.4 g m^{-2} y^{-1}), likely because annual drying promotes mineralization and export. Elemental composition (high Zr and Ti and low Ca and K) and low pH of recent (< ~60 y) or surface sediments suggest Gulf Coastal Plain origin, but below the recent sediment deposits, 51% of sediment profiles showed influence of Mississippi River alluvium, rich in base cations such as K^+, Ca^{2+}, and Mg^{2+}. The recent shift to dominance of Coastal Plain sediments on the lake-bed surface suggests hydrologic modification has disconnected the lake from sediment-bearing flows from the Mississippi River. Compared to its condition prior to hydrologic alterations that intensified in the 1930s, Catahoula Lake is about 15 cm shallower and surficial sediments are more acidic. Although these results are not sufficient to attribute ecological changes directly to sedimentological changes, it is likely the altered sedimentary and hydrologic environment is contributing to the increased dominance of woody vegetation.

1. Introduction

The majority of lakes on floodplains are abandoned channels formed by river meandering (Ashworth and Lewin, 2012), but depressional or impounded floodplain lakes are common on floodplains of some major rivers (Hudson et al., 2006; Hudson, 2010; Hupp, 2000; King et al., 2012; Lewin and Ashworth, 2014; Mertes et al., 1996; Penny, 2006; Phillips, 2013). Floodplain lakes are generally recognized as biodiversity hotspots (Bornette et al., 2008; Sparks, 1995) but are susceptible to ecological change due to hydrological management that alters hydrological and sedimentological connectivity. These linkages have been explored for abandoned channel lakes (Croke et al., 2013; Phillips, 2013; Kupfer et al., 2015; Kaase and Kupfer, 2016) and oxbow lakes in the floodplain of the Mississippi River (e.g., Cooper and McHenry, 1989; Miranda and Lucas, 2004). Depressional floodplain lakes, other than those which are abandoned former channels, are fundamentally different than oxbow lakes in terms of connectivity. However, a paucity of information exists regarding the relationships between depressional floodplain lake hydrology, sedimentation, and ecology.

One of the largest of the few impounded floodplain lakes on the Mississippi River floodplain (Smith, 1996) is Catahoula Lake, which encompasses 120 km^2 on the western edge of the floodplain in central Louisiana, USA. The lake is connected to several rivers and is highly influenced by regional surface water variations. As a consequence,

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water level in the lake fluctuates > 6 m, the flooded area varies by 90% annually, and the majority of the lake bed is exposed for several months each year during the low-flow season in the fall. Catahoula Lake is bounded by Tertiary uplands to the west, and impounded by alluvial ridges within the Mississippi Alluvial Valley (MAV) around the remainder of its perimeter. To the north, the lake is impounded by a natural levee from a mid-Holocene, abandoned channel of the Arkansas River and to the south and east by a series of Pleistocene alluvial ridges formed by a braided alluvial fan from the Mississippi River (Saucier, 1994). The reason the Catahoula Lake Basin has persisted as a locally rare, lacustrine and unalluviated basin is not clear. Fisk (1944) suggested the basin was a graben, similar to the case of Reelfoot Lake, the largest floodplain lake in the lower Mississippi River Valley (Hildenbrand, 1985). However, Saucier (1996) noted the lack of evidence for a fault zone in the area. The basin may be a relict feature from the earlier Holocene (> 5000 YBP), when this region of the Mississippi River floodplain was characterized by lakes and multi-channel streams (Aslan and Autin, 1999). Pollen and phytolith evidence suggest the basin has been a lake for the past ~3000 years (Tedford, 2009).

Catahoula Lake is ecologically important because of its large size, unusual hydrologic variability, and productive plant communities that support internationally recognized migratory bird populations. The variably-inundated lakebed is occupied by herbaceous plants that are important for waterfowl (Wills, 1965), and woody plants—mainly water-elm (*Planera aquatic* J.F. Gmel.), swamp-privet (*Forestiera acuminata* (Michx.) Poir.) and baldcypress (*Taxodium distichum* (L.) Rich.)—occupy slightly higher elevations on the lake margins (Brown, 1943). These vegetation communities appear to have existed for several thousand years according to Tedford's (2009) phytolith assemblage study. However, for at least the past 80 years areal coverage of woody plants has increased (Bruser, 1995) and Doerr et al. (2015) analyzed historic aerial imagery and found the rate of expansion is faster in recent decades than it was > 50 years ago.

Two related processes may be responsible for the recent shifts in woody coverage and expansion rate at Catahoula Lake: i) hydrologic modification and ii) changes in sedimentation. Hydrologic modifications to nearby rivers have been extensive and have presumably affected Catahoula Lake. These hydrologic changes, including cutoffs, log jam removals, channelization, and levee construction began as early as the late 1800s and intensified in the 1930s (Hudson et al., 2008; Mossa, 2013). Natural inflows were from the Little River (6215 km^2 watershed) and backwaters from rivers downstream (Black, Red, and Mississippi rivers), while outflows were mainly via the French Fork of Little River. Modifications to the Black River for navigation include the addition of a series of locks and dams built in 1926, followed by another series in 1972, which necessitated construction of the 20-km Diversion Channel and a sill in the French Fork to allow for drainage of Catahoula Lake (Fig. 1). Although the water control structure at the head of the Diversion Channel has been managed to emulate pre-modification seasonal drainage, management has not fully captured the range of pre-modification hydrologic variability. For example, high water events in the lake have decreased because incision of the Atchafalaya River (base level lowering) has reduced backwater from the Mississippi and Red rivers from about 207 days per year in 1880 to 120 days per year in 2010 (Dugué, 2015), and late-summer flooding has been largely eliminated because the Diversion Channel allows more rapid drainage than did the original channels (Bruser, 1995). The effects of these changes on sediment budgets have not been investigated, although Fisk (1938), Bruser (1995), and Willis (2009) all assumed that sedimentation has reduced because of decreased connectivity with the Mississippi River.

Current sedimentation rates and sources are not known at Catahoula Lake despite their ecological relevance (Hupp, 2000), and historical rates and sources are poorly constrained. Tedford (2009) estimated sedimentation increased from ~0.08 cm y^{-1} prior to European settlement (estimated using ^{14}C) to ~0.14–0.48 cm y^{-1} during the period 1800 CE–2004 CE (estimated using ^{210}Pb), and attributed this increase to anthropogenic impacts for the past 200 years. However, the temporal resolution of these estimates is not sufficient to assess whether recently accelerating ecological change is associated with changes in sedimentation rates or sources.

Aside from quantity of sedimentation, hydrologic management may have altered sources and chemical composition of the sediments. Catahoula Lake is at the margin of the Mississippi River Alluvial Valley, in which surficial sediments are alluvial, Holocene age, and generally neutral to alkaline (Martin, 1991). However, the watershed of the tributary Little River is in the western Gulf Coastal Plain, in which surficial sediments are Pleistocene and Tertiary terraces that are generally acidic due to weathering and leaching of basic cations (Kilpatrick et al., 1986; Mange and Otvos, 2005). Additionally, hydrologic management and land use may have altered nutrient budgets in the lake, which could be particularly influential on plant communities (Bedford et al., 1999; Koerselman and Meuleman, 1996).

Our general objective was to determine whether the sedimentation regime in the lake has changed in the era of greatest hydrologic alteration. The first specific objective was to estimate recent sedimentation rates and to examine spatial variability of recent deposition around the lake for evidence of controlling processes. The second specific objective was to determine whether there are any patterns in the nature of sediments (elemental composition, particle size, and pH) that may indicate physical processes and changes affecting the ecosystem.

2. Materials and methods

2.1. Field methods

We collected 37 sediment profiles for analysis during the annual low water period when the lake bed was exposed. The first 12 profiles were collected to a depth of 1 m with a Giddings Probe soil corer. Another 25 profiles were collected to a depth of 0.5 m. Twelve of these were collected by digging pits and cutting slices out of the profile, and 13 were collected in 10 cm diameter aluminum tubes. Profiles were sampled in the zone of expansion of woody plants and chosen for site accessibility (Fig. 2). Samples were obtained during low water in falls of 2011 and 2012.

2.2. Laboratory methods

All samples were subsampled into nominally 3 or 5 cm depth increments (the actual depth per subsample varied in practice for each core), oven-dried to 105 °C, weighed to obtain dry bulk density, and disaggregated with a Humboldt soil grinder or mortar and pestle to pass a 2 mm sieve. We analyzed particle size on 25 g subsamples using the pipette method, first using hydrogen peroxide to eliminate excess organic matter and sodium hexametaphosphate to de-flocculate clays (Gee and Bauder, 1986). We determined total C and N using a flash combustion system (Costech ECS 4010). For this analysis, sediment samples were combined into 9–10 cm depth increments, and 8–9 mg of each sample was combusted. Sediment pH from every 10 cm of each profile to a depth of 50 cm was measured using 6–9 g of dried sediment in a 1:1 slurry with deionized water using a bench-top pH meter (Thermo Scientific 3-Star Plus).

We used fallout ^{137}Cs, which is a common tracer for dating recent sediments in lakes and wetlands (Pennington et al., 1973) to measure recent sedimentation. This allowed us to compare recent sedimentation to longer-term rates estimated by Tedford (2009) using ^{210}Pb and ^{14}C. We analyzed the 13 cores collected in aluminum tubes and compared them to three other ^{137}Cs profiles analyzed by Tedford (2009). Subsamples were analyzed at 3 cm increments for ^{137}Cs with a lithium-drifted germanium detector and multichannel analyzer (DeLaune et al., 1978). Peaks in ^{137}Cs concentration with depth were