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Research article

Potential tree and soil carbon storage in a major historical floodplain forest with disrupted ecological function

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ABSTRACT

Floodplain forests are extremely productive for agriculture and historical floodplain forests have been converted to prime agricultural land throughout the world, resulting in disruption of ecosystem functioning. Given that flooding may increase with climate change and reforestation will increase resiliency to climate change, we tested whether reforested floodplains also have great potential to store carbon and the effects of even modest increases in forested acreage on carbon storage. To calculate potential aboveground biomass in the Lower Mississippi River Alluvial Valley (LMAV) of the United States, we determined current and historical tree biomass used density estimates and diameter distributions from tree surveys and relationships between diameter and biomass from current forests. To calculate potential soil organic carbon if the landscape was forested, we used soil organic matter from soil surveys of the agricultural landscape, and multiplied the carbon by a factors of 1.25, 1.5, and 1.75 based on published reports of soil carbon increases due to afforestation. Our results showed that area-weighted mean biomass density (trees ≥12.7 cm in diameter) for historical forests was 300 Mg/ha, ranging from 228 Mg/ha to 332 Mg/ha by ecological subsection, based on the most conservative diameter distribution. Mean biomass density for current forests was 97 Mg/ha, ranging from 92 Mg/ha to 111 Mg/ha. Mean carbon density for agricultural soils was 96 Mg/ha, whereas combined tree and soil carbon densities varied from 169 Mg/ha to 317 Mg/ha; soil carbon accounted for 0.5–0.7 of total carbon density. Historical forested carbon storage in the Missouri LMAV was about 234 TgC, with the most conservative diameter distribution and assuming 80% forest coverage. Current forested carbon storage in the Missouri LMAV is about 2% of historical storage, at 5 TgC in 30,000 ha of forests, but may reach 23 TgC if forested extent almost triples, with the addition of 50,000 ha of marginal agricultural land, and carbon storage increases in trees and soil. The entire LMAV currently stores 97 TgC in forests and reasonable carbon storage for the entire LMAV may be about 335 TgC, based on increased carbon storage and reforestation of 600,000 ha of marginal agricultural land, which would double the current forested extent. Although 335 TgC storage for the LMAV is only about 1.5 times greater than historical carbon storage of the Missouri LMAV, doubling the forested extent will increase other ecosystem functions, including carbon storage, flood abatement, and reduction of fertilizer pollution in the Gulf of Mexico.

Introduction

Floodplain forests have been converted to agriculture and other land uses globally (Gore and Shields, 1995; Zedler and Kercher, 2005). Accompanied by reduction in floodplain forests, loss of ecological function interrupts ecosystem services including flood abatement, biodiversity support, water quality improvement, and carbon management (Zedler and Kercher, 2005). Both carbon and nutrient capture (i.e., sequestration) and retention (i.e., storage) are limited without the presence of long term vegetation ground cover. For example, agricultural fertilizers move through floodplains to coastal waters, creating dead zones as algal blooms deplete oxygen (Turner and Rabalais, 2003; Zedler and Kercher, 2005). Increased long term biomass through reforestation of floodplain forests will contribute to carbon and nutrient storage along with other ecosystem services.

Carbon storage currently is unrealized in historical floodplain forests. The Mississippi River Basin drains six major watersheds

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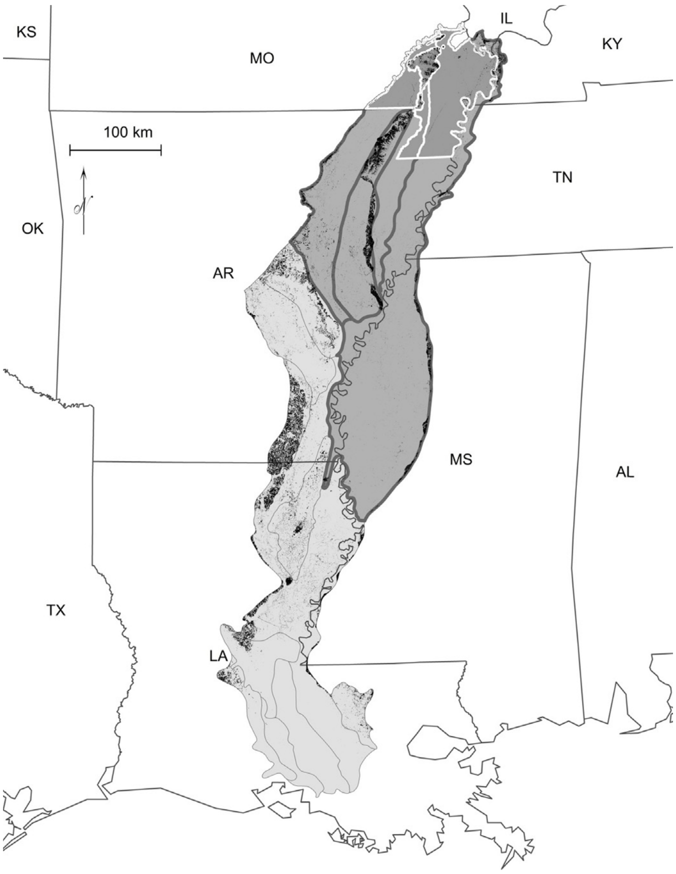

Fig. 1. The Lower Mississippi River Valley: the four ecological subsections in Missouri (outlined in white) cross state boundaries to form the entire White and Black River Alluvial Plains ecological section (shaded dark gray). Forests (shaded black) are present in areas with greater elevation.

that cover about 40% of the continental United States. One of the watersheds, the Lower Mississippi River Alluvial Valley (LMAV; Fig. 1) once contained the greatest area of floodplain forests. By 1978, only 2 million ha (Schoenholtz et al., 2001) of the historical 10.4 million ha forested extent remained (areal extent excludes open water; Fry et al., 2011). Currently, cooperative partnerships are in place to replant trees in portions of the LMAV, primarily within marginal agricultural lands that have hydric soils with poor drainage (King and Keeland, 1999; Frey et al., 2010).

In addition to unrealized carbon storage, floodplain forests may have greater potential to store carbon than other ecosystem types, particularly compared to surrounding upland forests in temperate zones (Suchenwirth et al., 2012). Deep alluvial soils are recognized for crop productivity, even though tree productivity has been less well-documented (Shoch et al., 2009). Although we are unaware of historical accounts of trees in the LMAV, directly north of LMAV, multiple trees within one ha had diameters of 2–5 m, exceeding current state record trees for species (in the Wabash River Valley; Jackson, 2006).

Decisions about land use in floodplains may become increasingly important as climate changes (Brown et al., 2014; Groffman et al., 2014). Temperatures in the midwestern United States may increase 3–5 °C by the end of the century (Pryor et al., 2014). Although longer growing seasons and rising carbon dioxide levels initially may increase yields of some crops, climate change eventually may decrease agricultural productivity due to wet springs, anomalous frosts, drought, and heat stress, particularly during pollination and reproductive development (Pryor et al., 2014). Heavy precipitation events will disrupt current infrastructure in place to control rivers, resulting in frequent flooding on agricultural lands on historical floodplains (Pryor et al., 2014). Ecosystem services of flood and erosion control and carbon storage provided by floodplain forests may become more valuable than agricultural lands vulnerable to flooding and that consequently will become less productive under climate change. Increased restoration of floodplain forests will increase resiliency to extreme events of climate change (Groffman et al., 2014).

In light of increased flooding expected under climate change, reforestation for a variety of ecosystem services may become a more viable land use in former floodplain forests. Mature, unharvested forests in floodplain forests are rare at the stand scale and non-existent at a landscape scale. Potential carbon storage of mature floodplain forests therefore is unknown for the LMAV and important for evaluating to benefits of land use conversion. Our aim was to test the (1) potential for the LMAV to store carbon in the major carbon pools of aboveground tree biomass and belowground soil carbon and (2) effects of even modest increases in forested acreage on above- and belowground carbon storage. We used historical tree surveys from the LMAV in Missouri to quantify and map forest aboveground biomass for four ecological subsections (Ecomap, 1993; Figs. 1 and 2, mean area = 1.45 million ha, SD = 1.20 million ha). We then calculated forested carbon storage potential for the Missouri LMAV and generalized our results to the entire LMAV. Under land use change from forest to crop and potentially restoration back to forest, we provide tree and soil carbon accounting valuable for management scenarios in a 10.4 million ha landscape and a method for soil carbon accounting applicable to other regions.

Methods

Study area

Missouri's LMAV landscape is about 1 million ha excluding open water, nearly 10% of the LMAV (Ecomap, 1993; Fry et al., 2011; Fig. 1). About 80% of land cover is cultivated crops, 4% is pasture or hay, 2.5% is forest, and 5% is forested wetlands. Crowley's Ridge, one of four ecological subsections (Ecomap, 1993) in the Missouri LMAV, is a loess-covered upland that rises above flatter alluvial plains and accounts for most of the landscape's pasture and forest. Pasture and forest comprise 24% and 14%, respectively, of land cover in Crowley's Ridge in Missouri. Roughly 80% of soils in the Missouri LMAV have limitations, primarily (66% of total soil) due to poor drainage. About 130,000 ha are classified as not prime farmland (including land that needs to be protected from flooding; Soil Survey Geographic Database, Natural Resources Conservation Service, http://soildatamart.nrcs.usda.gov), of which about 47,900 ha is cultivated crops and 13,800 ha is forest.

Tree surveys and density estimates

The United States General Land Office (GLO) was established in 1812 to survey, map, and sell land for settlement. The GLO surveys divided area into square townships measuring 9.6 km × 9.6 km, which were divided further into 36–1.6 km^2 sections. Surveyors selected two to four bearing trees at the intersection of section lines and midpoints between section corners. For each selected tree, surveyors recorded species, diameter, distance, and bearing to survey point. The GLO surveys contain bias because surveyors selected trees at survey points, resulting in non-random trees. Furthermore, selected trees were of moderate diameter, to increase longevity as section markers. We excluded trees with diameters