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Modeling current and future freshwater inflow needs of a subtropical estuary to manage and maintain forested wetland ecological conditions

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ABSTRACT

Riverine input is essential for the sustainability of the estuaries, wetlands, and swamps into which they flow. An existing coastal ecosystem model was used with forested wetland and fish habitat indicators to evaluate current environmental conditions as well as future restoration projects via 50-year simulations of riverine flow with sea level rise and subsidence. The objective of this study was to utilize the Integrated Compartment Model developed for the Louisiana Coastal Protection and Restoration Authority's 2017 Coastal Master Plan to understand how alternations of riverine flow from existing rivers and future restoration projects may influence the spatial and temporal distribution of wetland habitats and suitability of fish habitats. The model was applied to the Lake Maurepas ecosystem where the Amite River flows into the lake and supports vital fisheries for surrounding communities, as well as a unique and valuable recreational resource. Additionally, the Amite River nourishes the marshes and swamps around Lake Maurepas that are essential for storm surge protection for the broader region. Modeling results suggest that the major contributing factor to the freshwater conditions to the Lake Maurepas area is the challenge of relative sea level rise − the combination of rising seas and subsidence. Fresh forested areas comprised of bald cypress (*Taxodium distichum*) and tupelo gum (*Nyssa aquatica*) in Maurepas Swamp decrease significantly under all future climate and relative sea level rise simulations except when future restoration projects are utilized. An estimated ~1000 km^2 of fresh forested wetland could be maintained over a 50-year period when considering certain restoration projects that increase freshwater flow and under climate change-related rainfall patterns, sea level rise and subsidence. However, modeled results indicate that more than 100% of the current riverine flows into the Maurepas Swamp region are still not sufficient to fully counteract the impacts of the assumed future sea level rise scenario and maintain the current forested wetlands surrounding Lake Maurepas. The higher salinities and more estuarine open water areas provide additional habitat in the future that will likely be more suitable for spotted seatrout (*Cynoscion nebulosus*), and adult bay anchovy (*Anchoa mitchilli*) than largemouth bass (*Micropterus salmoides*). Modeled future conditions of this ecosystem can inform restoration agencies and organizations by helping to prioritize and plan for future decades by incorporating critical factors such as sea level rise, subsidence and precipitation patterns, including the possible need to plan and prepare for changes in the fish communities and consider how that might influence the well-being of local communities.

1. Introduction

Freshwater bodies and estuaries worldwide are undergoing drastic change due to alteration of freshwater flow that impacts their ecology (Abrantes and Sheaves, 2010; Alber, 2002; Kimmerer, 2002; Sklar and Browder, 1998). Freshwater input serves many essential ecological functions, including the regulation of salinity and delivery of nutrients and sediments from the watershed (Alber, 2002; Baron et al., 2002). Without an adequate supply of fresh water, certain estuaries, wetlands, and swamps will be unable to provide key ecosystem services that support coastal communities, such as fisheries, flood protection, and recreation. In coastal communities around the world, demands on freshwater supply are increasing and future uncertainties (i.e., sea level rise and subsidence) threaten coastal communities (Doyle et al., 2007; Whitfield and Taylor, 2009). The determination of the freshwater inflow needs and the use of estuarine indicators is necessary to maintain

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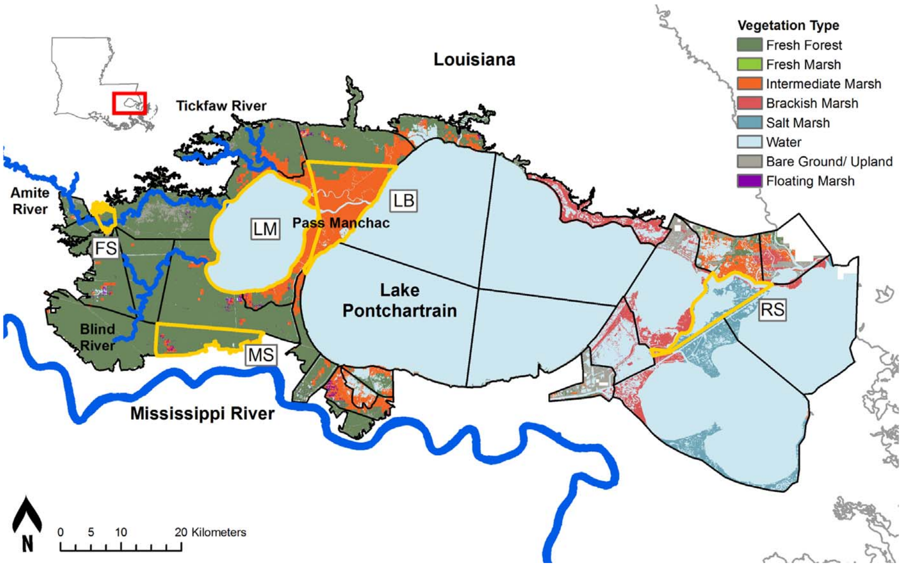

Fig. 1. Location of Lake Maurepas (LM) and Lake Pontchartrain in southern Louisiana, USA,. Current habitats and future restoration projects are labeled. Three rivers (Tickfaw, Amite, and Blind) that discharge into LM are labeled. Black lines indicate model compartment boundaries and gold lines highlight the compartments of interest, FS = French Settlement, LM, LB = land bridge, MS = Maurepas Swamp, RS = Rigolets.

the provision of these ecosystem services.

1.1. Study area background

In coastal Louisiana, USA, the Amite River flows into Lake Maurepas, and supports a vital fishery for surrounding communities such as Ponchatoula and Manchac, while providing a valuable recreational resource (Shaffer et al., 2016) (Fig. 1). Additionally, the inflow of the Amite River nourishes the marshes and swamps around Lake Maurepas that are essential for flood protection for the broader region (Shaffer et al., 2016, 2009). Lake Maurepas is located in the Mississippi River Delta complex (Flowers and Isphording, 1990), located between New Orleans and Baton Rouge, LA (Effler et al., 2007). It is 21 km wide, but no more than 3 m deep (Effler et al., 2007). Lake Maurepas is an oligohaline coastal lake with three rivers, Tickfaw, Blind, and Amite currently discharging roughly 144 $m^3 s^{-1}$ of freshwater into the western shore (Flowers and Isphording, 1990). Lake Maurepas then drains through Pass Manchac into eastern Lake Pontchartrain (Hoeppner et al., 2008). The Amite River discharges the most freshwater into this system and drains a watershed that is 3434 km^2 and about 58% forested (Wu and Xu, 2006). It is a warm water, low gradient coastal stream with upper reaches in Louisiana characterized by faster flows with sand or gravel substrata, while the lower reaches closer to Lake Maurepas are meandering, bayou-like rivers with slower flow, silt sediments overlaying sand, and extensive riparian wetlands (Felley, 1992). The wet season, with 69% of the annual discharge, occurs in winter and spring, and summer and fall are lower discharge periods, although urbanization of the watershed near Baton Rouge has increased discharges by 55% during the last 40 years (Wu and Xu, 2006).

The Maurepas Swamp surrounds Lake Maurepas and is in the Lake Pontchartrain Basin that includes 16 Louisiana parishes and spans approximately 12,000 km^2. This area is the second largest contiguous coastal forest in Louisiana (Effler et al., 2007). The swamp includes 776 km^2 of freshwater forested wetlands and 52 km^2 of fresh and oligohaline marshes (Shaffer et al., 2016). Historically, the Maurepas Swamp in the Mississippi River Delta complex (Flowers and Isphording, 1990) was dominated by vast forests of bald cypress (*Taxodium distichum* (L.) Rich., Order: Pinales, Family: Cupressaceae) and tupelo gum (*Nyssa aquatica* L., Order: Cornales Family: Cornaceae) (Effler et al., 2007; Keddy et al., 2007; Shaffer et al., 2003)(Fig. 1). Although bald cypress was traditionally used by Native Americans for building huts and canoes, notable anthropogenic changes did not occur until post European colonization. Subsequently, bald cypress became the dominant cash crop in Louisiana. Massive deforestation became possible with the invention of pullboats in the 1890′s. Pullboats, in conjunction with canal excavations, increased the accessibility to interior swamps, providing a mechanism for large-scale systematic clearcutting, depleting the timber resource by the late 1920′s (Effler et al., 2007; Keddy et al., 2007). Although much deforested land regenerated as bald cypress-tupelo second growth, by the 1960′s ecological changes in the region had already begun to foster a transition to marsh (Barras et al., 1994). One of the major stressors to the bald cypress and tupelo gum swamps is soil-water salinity (Shaffer et al., 2016) that inhibits natural regeneration (Allen et al., 1997) because of the relative inability to exclude ions ($Na+$, $Cl-$) from tree leaf tissue or compartmentalize the ions in cell vacuoles for osmotic adjustment (Allen et al., 1996). Thus, the accumulation of ions is likely disrupting photosynthesis (Allen et al., 1996) and causing leaf and eventually tree mortality (Pezeshki et al., 1987). Swamp areas that have already experienced salinity induced-stress include the areas near Lake Maurepas (Pezeshki et al., 1987; Shaffer et al., 2016).

Lake Maurepas and surrounding swamp and marshes provide valuable habitat to flora and fauna, which are likely to undergo additional change in spatial distribution under future environmental conditions. Distribution habitat models of fresh and estuarine fish species can help inform where habitat hot spots are located now and in the future (Hijuelos et al., 2016). For example, the freshwater largemouth bass (*Micropterus salmoides* Lacepede, Order: Perciformes, Family: Centrarchidae), tends to prefer estuarine open water habitat of low salinities (Glover et al., 2013) whereas spotted sea trout (*Cynoscion nebulosus* Cuvier in Cuvier and Valenciennes, Order: Perciformes, Family: Sciaenidae), a local recreational fisherman favorite, and bay anchovy (*Anchoa mitchilli*, Valenciennes in Cuvier and Valenciennes, Order: Clupeiformes, Family: Engraulidae) are more suitable for high salinities (Peebles et al., 2007). Hydrological models that are linked to habitat suitability indices of these fishes can help reveal how altering environmental conditions might influence the spatial distribution of habitats and indicator species.

Currently, the Maurepas Swamp is in critical condition and considered severely degraded (Shaffer et al., 2016). Within the last several decades, factors such as canal construction, sea level rise, subsidence, and regional drought have increased the frequent and intensity of saltwater intrusion from the Gulf of Mexico. Salt stress, in conjunction with reduced riverine input compared to historical conditions, nutrient poor water, low soil strength, nutria herbivory, prolonged flooding of certain areas due to alterations of drainage, and low bald cypress-tupelo recruitment are accelerating the conversion of swamp to marsh or open water (Shaffer et al., 2016, 2009). However, the foremost cause of the

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