ECOLOGICAL ENGINEERING 34 (2008) 311–323

available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/ecoleng

A comparison of soil carbon pools and profiles in wetlands in Costa Rica and Ohio

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ARTICLE INFO

Article history:
Received 6 August 2008
Received in revised form
21 September 2008
Accepted 22 September 2008

Keywords:
Carbon sequestration
Tropical wetlands
Temperate wetlands
Wetland hydrology
Wetland hydrogeomorphology
Climate and wetlands
Wetland soils

ABSTRACT

Wetlands are large carbon pools and play important roles in global carbon cycles as natural carbon sinks. This study analyzes the variation of total soil carbon with depth in two temperate (Ohio) and three tropical (humid and dry) wetlands in Costa Rica and compares their total soil C pool to determine C accumulation in wetland soils. The temperate wetlands had significantly greater ($P < 0.01$) C pools (17.6 kg C m^{-2}) than did the wetlands located in tropical climates (9.7 kg C m^{-2}) in the top 24 cm of soil. Carbon profiles showed a rapid decrease of concentrations with soil depth in the tropical sites, whereas in the temperate wetlands they tended to increase with depth, up to a maximum at 18–24 cm, after which they started decreasing. The two wetlands in Ohio had about ten times the mean total C concentration of adjacent upland soils (*e.g.*, 161 g C kg^{-1} were measured in a central Ohio isolated forested wetland, and 17 g C kg^{-1} in an adjacent upland site), and their soil C pools were significantly higher ($P < 0.01$). Among the five wetland study sites, three main wetland types were identified – isolated forested, riverine flow-through, and slow-flow slough. In the top 24 cm of soil, isolated forested wetlands had the greatest pool (10.8 kg C m^{-2}), significantly higher ($P < 0.05$) than the other two types (7.9 kg C m^{-2} in the riverine flow-though wetlands and 8.0 kg C m^{-2} in a slowly flowing slough), indicating that the type of organic matter entering into the system and the type of wetland may be key factors in defining its soil C pool. A riverine flow-through wetland in Ohio showed a significantly higher C pool ($P < 0.05$) in the permanently flooded location (18.5 kg C m^{-2}) than in the edge location with fluctuating hydrology, where the soil is intermittently flooded (14.6 kg C m^{-2}).

1. Introduction

Accumulation of organic matter in wetland soils depends on the ratio between inputs (organic matter produced *in situ* and *ex situ*) and outputs (decomposition and erosion; Albrecht and Rasmussen, 1995; Gorham, 1998). Two of the key factors that enhance carbon accumulation in wetland soils are the anaerobic conditions produced by the presence of standing water and the high productivity of wetland ecosystems (Mitsch and Gosselink, 2007). Productivity in wetlands is influenced by hydrology, landscape setting, and climate, which in turn affect the vegetation and consumer communities (Trettin and Jurgensen, 2003). In most wetlands, water level fluctuates seasonally instead of being stable (hydroperiod), a property that accounts for wetlands being highly productive environments (Odum et al., 1995; Mitsch and Gosselink, 2007). Decomposition in wetlands is a complicated process that involves a combination of aerobic and anaerobic processes

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doi:10.1016/j.ecoleng.2008.09.005

(Gorham, 1998). Organic matter decomposition is often incomplete under anaerobic conditions and for that reason the lack of oxygen is one of the main factors determining plant detritus turnover. Consequently, plant remains and other organic matter coming from outside the system (allochthonous) and from the wetland productivity itself (autochthonous) accumulate in wetlands at different decomposition stages (Collins and Kuehl, 2001; Holden, 2005), creating a net retention of organic matter (Mitsch and Gosselink, 2007). Decomposition rates in wetlands vary as a function of climate (temperature and moisture) and the quality (chemical composition) of the organic matter entering the system (Schlesinger, 1997).

The goal of this study is to provide estimates and comparisons of the carbon stored in wetland soils in different climates and hydrogeological settings. The objectives are to compare the total soil carbon profiles of three types of wetlands located in one temperate (Ohio) and two tropical (Costa Rica) climates, and to identify relative differences in their soil carbon pools to better understand the factors influencing carbon sequestration in wetland soils. In this study, we define soil carbon profile as the distribution of carbon concentration (g C kg^{-1} soil) or carbon density (kg C m^{-3}) in the soil with depth. The soil carbon pool is the amount of carbon contained in the soil for a given depth (kg C m^{-2}) and is estimated by integrating the area under the carbon density profile curve. Two hypotheses were tested as part of this study: H1: Wetlands in the tropics have greater carbon pools in their soil than do temperate zone wetlands, and H2: Isolated forested wetlands have the highest soil carbon pool of any wetland type.

1.1. *Factors that influence carbon accumulation in wetland soils*

The chemical composition of soil organic matter consists of a living (microbes and soil fauna), a labile (fresh plant materials that decompose quickly) and a resistant fraction (materials that remain for long periods of time in the soil). The resistant fraction accumulates deeper in the soil profile over time, whereas the majority of the labile compounds that are deposited in the soil surface decompose within several months (Odum and Pigeon, 1970; Schlesinger, 1997; Wolf and Wagner, 2005). The chemical composition of organic matter depends on the original type of vegetation that produced it: plant detritus from woody species contains more complex structures (lignin and cellulose) that are often harder to degrade and accumulate for long periods of time (Schlesinger, 1997). Isolated forested wetlands are considered systems of moderate productivity compared to flow-through or slow-flow wetlands (Watt and Golladay, 1999; Cronk and Fennessy, 2001) yet they are likely to store more organic matter for longer periods of time because of their hydrologic isolation. Carbon accumulation in forested wetland soils is greater than in upland forest soils due to the presence of saturated soil water, but it is not usually differentiated from the upland forest pool in literature (Trettin and Jurgensen, 2003). However, there is a strong correlation between climate and soil carbon pools where organic carbon content decreases with increasing temperatures (Kirschbaum, 1995; Albrecht and Rasmussen, 1995) because, depending on the soil, decomposition rates approximately double with every 10 °C increase in temperature (Schlesinger, 1997; Hartel, 2005). Dick and Gregorich (2004) compared relative decomposition rates of organic matter in tropical (Nigeria) and cold dry climates (Canada) and found that decomposition rates were 10 times faster in their tropical sites. Hence, tropical wetlands have greater carbon production than wetlands in temperate climates, but also greater decomposition. It is therefore unclear if the net carbon accumulation would be greater in temperate or in tropical wetlands.

1.2. *Wetlands in the global carbon cycle*

The balance between carbon input (*e.g.*, organic matter production and carbon inflows) and output (decomposition, methanogenesis, etc.) and the resulting storage of carbon in the wetland depends on several factors, such as the topography and landscape position of the wetland, the hydrologic regime, the type of plants present, the temperature (and therefore climate) and soil moisture, the pH and salinity, and the morphology of the wetland (Collins and Kuehl, 2001). Wetlands represent a significant sink for carbon and are a key element to consider when managing and weighing earth's carbon pool. The total soil organic carbon pool (1 m depth) is estimated to be 1550 Pg (petagrams = 10^{15} g; Lal, 2007) and wetlands are responsible for 450 Pg, one-third of this pool (Mitsch and Gosselink, 2007), despite the fact that they cover only 6–8% of the land and freshwater surface (Roulet, 2000; Mitsch and Gosselink, 2007). Hence, wetlands represent one of the largest biological carbon pools and play a decisive role in the global carbon cycle (Chmura et al., 2003; Mitra et al., 2005). Research in this area is needed to quantify more accurately the extent of wetlands soil carbon pool worldwide and the importance of wetland type, hydrological fluctuations, and climate on these pools.

2. Methods

2.1. *Study sites*

The five natural wetland sites involved in this study are located in Ohio and Costa Rica (Fig. 1) and are described in more detail below. These wetlands represent three distinct climates (temperate humid, tropical humid, and tropical dry) and three wetland hydrogeomorphic types: riverine flow-through, slow-flowing slough, and isolated forested wetlands (Table 1).

2.1.1. *Ohio*

Old Woman Creek State Nature Preserve, a protected 230 ha park on the southwestern shores of Lake Erie, has a 56 ha flow-through wetland that receives its main inflow from the 69 km^2 Old Woman Creek watershed. The watershed is 75% agricultural cropland. The wetland also receives occasional water pulses from wind-driven seiches (Herdendorf et al., 2006). The wetland accumulates substantial amounts of sediments and nutrients from the watershed and seasonally serves as a phosphorus sink (Mitsch and Reeder, 1991). The climate of this region is temperate humid, with well below-zero (°C) temperatures in the winter, average annual temperatures of 10 °C, and average precipitation of 867 mm y^{-1} (Herdendorf et al., 2006). Water depths range from 0.4 to 1.4 m throughout the wetland