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Methane emissions from freshwater cypress (*Taxodium distichum*) swamp soils with natural and impacted hydroperiods in Southwest Florida

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ABSTRACT

Wetlands are natural sources of methane (CH_4) emissions, with the majority of those releases in tropical and subtropical regions. Land-use modifications can change a wetland's hydroperiod and flow-through conditions, among the most important factors controlling methanogenesis. The goal of this research was to determine and compare CH_4 fluxes from six subtropical cypress (*Taxodium*) swamps in southwest Florida with different hydroperiods and noticeably different land-use conditions. Three of the swamps were at a highly protected strand of cypress swamps in Corkscrew Swamp Sanctuary and three were on a university campus, which had been exposed to historical land-use and hydrologic modifications well before the campus was constructed in the 1990s. Gas samples were taken twice daily at 10 times over a year. Fluxes from the reference sites were significantly higher than fluxes from the disturbed sites. Mean CH_4 emissions (± standard error) were 25.9 ± 15.6, 22 ± 21.8 and 49.5 ± 24.7 mg CH_4-C m^{-2} d^{-1} for the reference bald cypress slough, pond cypress slough and cypress dome, respectively, and 4.0 ± 3.8, -1.4 ± 0.8, and 0.5 ± 0.5 mg CH_4-C m^{-2} d^{-1} for the disturbed pond cypress slough and two cypress domes, respectively. Deeper water and higher soil temperatures at the time of sampling, by themselves, did not explain higher CH_4 fluxes. More continuous surface flooding at the reference sites compared to seasonal flooding at the disturbed wetlands appear to be the main cause for the differences in methane emissions at the two sites.

1. Introduction

Methane is a greenhouse gas (GHG) that negatively influences the radiation balance of the Earth because it has a global warming potential (GWP) of 28 times that of carbon dioxide after 100 years when no climate-carbon feedbacks are considered (Pachauri et al., 2015). Methane has been estimated to have more than doubled from 720 ppb in preindustrial times to current levels over 1800 ppb; most of the sources for this increase (68–70%) are anthropogenic (Mitsch and Gosselink, 2015). Several studies have demonstrated that the atmospheric concentration of CH_4 has increased by about 13% between 1978 and 1999 (Khalil and Rasmussen, 1990; Dlugokencky et al., 2001; Cunnold et al., 2002). Nowadays, wetlands are described as the most important natural source of CH_4 emissions releasing 170 Tg CH_4 annually to the atmosphere (Whalen, 2005; Bloom et al., 2010; Bridgham et al., 2013). Recent studies have estimated that half or more of the wetland's CH_4 emissions originate from tropical wetlands (Bloom et al., 2010).

In wetlands, CH_4 is formed under anaerobic conditions by microbial decomposition of organic matter (van Amstel and Swart, 1994), and it is consumed by CH_4 oxidizing microbes in aerobic environments (Whalen, 2005). The net budget between production and consumption determines the rate of methane release into the atmosphere. From the several factors that determines wetland processes (i.e., hydrology, soil temperature, soil properties, microbial and vegetation community, etc.), hydrology is one of the most important (Moore and Knowles, 1989; Segers, 1998; Whalen, 2005; Kayranli et al., 2010). Flooding duration, depth, and intensity, also known as hydroperiod, regulate the exchange of electrons during the redox reactions that can lead to the release of methane (Mitsch and Gosselink, 2015).

Tropical and subtropical cypress swamps often have seasonal hydroperiods; that is, they have a period when they are inundated and a period when there is none or little water above ground (Mitsch et al., 2010). South Florida cypress wetlands expe-

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rience slow flows of water during the wet season; meanwhile over the dry season water, flow through these wetlands is not apparent (Bondavalli et al., 2000). Happell and Chanton (1993) found that water-level-controlled greenhouse gas emissions from Florida swamp forest soils. Soil temperature may be more important at higher latitudes where seasonal variation is well marked (Bartlett and Harriss, 1993; Bloom et al., 2010).

Land-use changes such as urban development, road construction and agriculture have a great impact on both the extent of wetlands and the function of remaining wetlands (Zedler, 2003; Torbick et al., 2006; Kettlewell et al., 2008; Sullivan and Fisher, 2011). Watershed disturbances cause change seasonal patterns of water level, which consequently influence the biogeochemical processes and transport pathways related to methane emissions (Hamilton, 2002; Torbick et al., 2006; Kettlewell et al., 2008; Erwin, 2009). To make responsible decisions related to climate change when land-use modifications are proposed, it is necessary to understand and consider both the emission of greenhouse gases and the sequestration of carbon in wetlands and their relative importance (Torbick et al., 2006; Erwin, 2009; Mitsch et al., 2013).

There are relatively few studies of methane emissions and carbon sequestration in subtropical and tropical wetlands despite their importance in the global carbon fluxes (Mitsch et al., 2010, 2013; Bloom et al., 2010; Mitsch, 2016; Li and Mitsch, 2016). The goal of this research was to determine and compare CH_4 fluxes from six subtropical cypress swamps in southwest Florida with different hydroperiods and two noticeably different land-use conditions (i.e., reference and disturbed). The disturbance we refer to is primarily hydrological and has been long-term, not necessarily recent. The "reference" cypress swamps in our study are located in Corkscrew Swamp Sanctuary, a forested wetland slough unique in Florida or maybe the world as much of it has never been logged or hydrologically disturbed. Almost anywhere else in SW Florida where cypress strands/sloughs/domes exist including our second site would have to be considered "disturbed" relative to that reference benchmark. In the case of our "disturbed" cypress swamps on the FGCU campus, the site used to be part of a similar flowway just as found in Corkscrew Swamp Sanctuary, but it has been logged, mined, and drained extensively for perhaps 100 years or more before it was converted into a university campus. Now there is a great deal of conservation activity for the wetlands and sloughs that are left and the designers of the campus did a wonderful job of including, restoring, and creating wetlands as part of the campus.

We explore the influence of water levels and soil temperatures on CH_4 fluxes by analyzing the fluxes from each site relative to the environmental variables. Three research hypotheses were addressed: (1) cypress swamps with longer flooded phases and higher water levels will result in higher CH_4 emissions than those having shorter and lower flooded phases and water levels, respectively, (2) methane emissions from cypress swamps with steady-flow hydroperiods will be higher than those from swamps with a seasonally pulsed flow, and (3) higher soil temperature, by itself, caused higher methane emissions.

2. Methods

2.1. Study sites

This study was carried out in Lee and Collier County, Florida, USA, southwest of Lake Okeechobee and east of the Gulf of Mexico (Fig. 1). This region's landscape is a mosaic of urban, agricultural and natural patches. Within this region, two major wetland areas with a total of six researched or sampling swamps were chosen to represent reference and disturbed cypress (*Taxodium distichum*) swamps. The disturbance category was determined by land-use/land-cover historical changes while the selection of the individual swamps was based on the hydrogeomorphology of cypress swamps as summarized by Mitsch and Gosselink (2015).

2.1.1. Reference site—Corkscrew Swamp Sanctuary

The National Audubon's Society Corkscrew Swamp Sanctuary (CSS; 5260 ha) contains the largest and most-preserved stand of mature *Taxodium distichum* [L.] Rich. (bald cypress) in Florida (Duever et al., 1984; Gunn, 1997; Villa and Mitsch, 2014). The Sanctuary is in the top of its watershed that, including the upstream reaches of the basin and the wetlands themselves, is 29,500 ha; of that area 30%, or 9000 ha, is "inundated for more than 6 months each year" (Duever et al., 1978). The surface soils in the watershed are primarily fine, relatively impermeable sands with organic accumulations in depressions. The surface soils are underlain by occasional clay lenses and more frequently by extensive shell deposits (Duever et al., 1978). While we consider the wetlands at CSS to be our reference (not disturbed) sites, recent analysis of the hydroperiods since 1959 suggests a decrease on the magnitude of flooding by 23–47% beginning just after 1999–2000 and continuing to the present day, thought to be caused by some combination of increased water management from agriculture (particularly citrus), increased well field withdraws, and increased efficiency of canals downstream of the Sanctuary (S. Clem, Corkscrew Swamp Sanctuary, personal communication, March 28, 2017).

Nevertheless, this unlogged cypress forest is considered an ideal site for researching ecological relationships in undisturbed forested wetlands and thus, three sites in Corkscrew Swamp Sanctuary were selected as reference wetlands in this study. These swamps were designated as (1) reference bald cypress slough; (2) reference pond cypress (*T. distichum* var *imbricarium* [Nutt.] Croom) slough, and (3) reference cypress dome. The bald cypress slough is a slow-flowing wetland with low erosive power that allows for a build-up of peat. Our sampling site is located at the center of the strand, in which the ground-depression has high water levels and thick peat soils, often deeper than 25 cm. The understory vegetation is sparse with emergent macrophytes like *Thalia geniculata* and *Peltandra virginica*, the subcanopy is represented by *Annona glabra* and *Fraxinus caroliniana* and the canopy is composed by mature *T. distichum*. The reference pond cypress slough is at the edge of the strand, where water levels and peat deposits are shallower. Peat in this site was approximately 8 cm deep, followed by sandy soils. *Sagittaria graminea* and *Ludwigia* spp. cover the understory, while a dense stand of small-diameter *T. distichum* var *imbricarium* forms a closed canopy. The reference cypress dome has considerable peat deposits (down to 20 cm depth) overlying sandy soils with *Pontederia cordata*, *P. virginica* and *Crinum americanum* dominating the groundcover, *A. glabra* and *Cephalanthus occidentalis* in the sub-canopy, and *T. distichum* in the canopy.

2.1.2. Disturbed site—FGCU Campus Wetlands

Florida Gulf Coast University's (FGCU) campus (307 ha), located in Lee County at the headwaters of the Estero River that flows to the Gulf of Mexico, is a combination of academic and conservation areas; the latter including remnant and restored patches of relatively young cypress (*T. distichum*) swamps and freshwater marshes and hydric pine flatwoods dominated by slash pine (*Pinus elliottii*) and/or pond pine (*Pinus serotina*). This landscape and its surroundings have undergone several land changes through time, due to agriculture, urbanization, and campus expansion. The flowways through the campus area were intermittent, with shorter hydroperiods than at Corkscrew Swamp. These FGCU areas prior to the campus construction was hydrologically disturbed in the mid1970s, leading to less flooding and a rapid invasion by the non-native tree *Melaleuca quinquenervia*. Wetland hydroperiods were reduced by 80% and normal seasonal high water was lower by

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