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Geomorphic controls on fluvial carbon exports and emissions from upland swamps in eastern Australia

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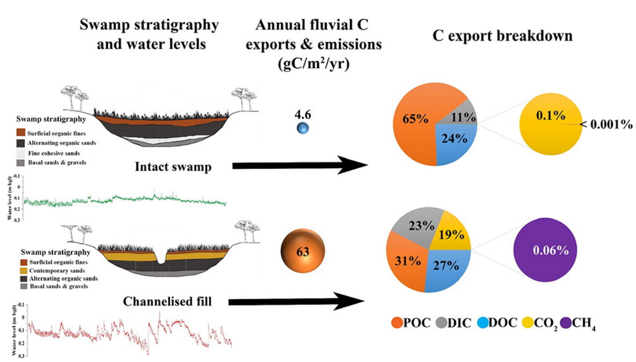
HIGHLIGHTS

- Geomorphic structural changes of upland swamps lead to changes in fluvial carbon exports and emissions.
- Carbon exports in channelised swamps are up to 18 times that of intact swamps.
- The channel in channelised swamps was the dominant source of carbon dioxide and methane emissions.
- Structural changes of upland swamps alters the carbon balance, increasing fluvial exports and greenhouse gas emissions.

GRAPHICAL ABSTRACT



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ABSTRACT

Temperate Highland Peat Swamps on Sandstone (THPSS) are a type of upland wetland, similar to fens in the Northern Hemisphere and are found at the headwaters of low-order streams on the plateaus of Eastern Australia. They are classified as endangered ecological communities under State and National legislation. Previous works have identified particular geomorphic characteristics that are important to carbon storage in these low energy sediment accumulation zones. Changes in the geomorphic structure of THPSS, such as channelisation, may have profound implications for carbon storage. To assess the effect of channelisation on carbon budgets in these ecosystems it is essential to identify and quantify differences in carbon export, emissions and stocks of carbon of intact swamps and those that have become channelised. We undertook seasonal sampling of the perched swamp aquifers and surface waters of two intact swamps and two channelised fills in the Blue Mountains of New South Wales, Australia, to investigate differences in carbon exports and emissions between the two swamp types. We found that channelised fills' mean CO_2 emissions were almost four times higher than intact swamps with mean CH_4 emissions up to five times higher. Annual fluvial carbon exports for channelised fills were up to 18 times that of intact swamps. Channelised fill exports and emissions can represent up to 2% of the total swamp carbon stocks per annum which is 40 times higher than the intact swamps. This work clearly demonstrates that changes in geomorphic structure brought about by incision and channelisation results in profound changes to the carbon storage function of THPSS.

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1. Introduction

The geomorphic structure of fluvial systems provides the physical structure for a range of abiotic functions such as water, sediment and carbon storage (Brierley and Fryirs, 2009; Chessman et al., 2006; Cowley et al., 2016; King and Hobbs, 2006; Vietz et al., 2014). Changes to this structure can significantly alter these abiotic functions, resulting in knock-on changes to biotic functions such as ecosystem metabolism (Brierley et al., 1999; Corenblit et al., 2007; Crawford et al., 2013; Jeffrey et al., 2016). Recent work on carbon storage in fluvial landscapes has emphasised the importance of geomorphic characteristics on carbon retention and export (Scott and Wohl, 2017; Sutfin et al., 2016). Scott and Wohl (2017) found that geomorphology controlled organic carbon storage in sub alpine lake deltas, with less storage capacity in steeper, more confined valley settings. Battin et al. (2008) found that metabolism rates for organic carbon in freshwater ecosystems are mediated by geomorphic processes that influence the residence times and spatial distribution of sediments and organic matter, suggesting that geomorphology exerts a strong control on fluvial CO_2 emissions to atmosphere.

Peatlands have been regarded as a globally significant carbon store, accounting for ~30% of Earth's soil organic carbon stocks (Bispo et al., 2016; Danevčič et al., 2010; Nichols et al., 2014). Peatlands generally function as atmospheric carbon dioxide sinks, yet sources of atmospheric methane (Belyea and Malmer, 2004; Chimner and Karberg, 2008; Gorham, 1991). Geomorphic changes in peatlands due to anthropogenic activities such as urbanisation (Cowley et al., 2016) and agriculture (Parry et al., 2014; Turner et al., 2013), as well as climate change (Nichols et al., 2014), have resulted in the degradation of the carbon storage function of peatlands.

Temperate Highland Peat Swamps on Sandstone (THPSS) are a type of upland wetland, occupying valley bottoms at the headwaters of low-order streams on the escarpments of eastern Australia. They are largely Holocene features whereby low slope-low energy environments combine with a high rainfall-low evaporation climate to produce persistently high water tables and high rates of sediment accumulation and organic matter storage (Fryirs et al., 2014). The geomorphic structure, evolution and age of THPSS are similar to fens in the Northern Hemisphere (Charman, 2002; Evans and Warburton, 2007).

Almost all water of THPSS is contained within an aquifer approximately 0.2 m below ground level. There is little surface water within the intact swamps except during rainfall events. The permanently saturated anoxic sediments of the swamp aquifer combined with high organic matter accumulation and low temperatures provide an environment where slow decomposition rates results in high rates of carbon sequestration (Cowley et al., 2016; Fryirs et al., 2014; Hope et al., 2009). A number of studies have found high carbon to nitrogen ratios within THPSS sediments indicating peat formation and high carbon storage capacity (Cowley et al., 2016; Freidman and Fryirs, 2015). Hope and Nanson (2015) found that Australian Snowy Mountains' peatlands covered over 7000 ha and stored around 3560 Gg of carbon. THPSS are classified as endangered ecosystems under Australian Federal and State legislation, and have been impacted by urbanisation, mining and agriculture over the past ~100 years (Freidman and Fryirs, 2015; Fryirs et al., 2016), resulting in significant biotic and abiotic structural changes to sediments and vegetation assemblages (Benson and Baird, 2012; Cowley et al., 2016).

Swamp channelisation can occur when intrinsic or extrinsic thresholds are breached and headcut and gullying processes are initiated (Fryirs et al., 2016; Schumm, 1979). This occurs in THPSS swamps receiving higher discharge and more concentrated flows from urban areas with high runoff coefficients and stormwater connectivity (Cowley et al., 2016; Fryirs et al., 2016), and in areas where underground mining is causing subsidence and swamp drainage (Jankowski, 2010; Krogh, 2007). Approximately 26% of THPSS in the Blue Mountains have been channelised (Fryirs et al., 2016). Channelised swamps, henceforth called channelised fills, generally exhibit lower, highly variable water tables produced by increased water table flows towards the channel. This can give rise to sedimentological changes, increased organic matter decomposition, lowered carbon storage as well as increased carbon emissions and carbon exports (Cowley et al., 2016; Evans et al., 2016; Fryirs et al., 2012; Holden et al., 2012; Huotari et al., 2013). Fryirs and Hose (2016) documented 3208 individual swamps in five regions of eastern Australia with a total area of 101 km^2. Given the relatively high areal carbon storage capacity of these systems, structural changes that interfere with this function may lead to increased carbon emissions to atmosphere relative to intact swamps.

A number of studies have found that the draining of peatlands leads to higher CO_2 and CH_4 flux to the atmosphere and shifts in fluvial carbon export, due to lowered, more variable water tables as well as changes in hydrology and soil chemistry (Gatland et al., 2014; Moore and Knowles, 1989; Yang et al., 2013). Other research has indicated lowered CH_4 emissions after peatlands are drained (Abdalla et al., 2016; Danevčič et al., 2010). These conflicting results suggest that the response of peatland carbon cycling to drainage may be site specific. There has been no research into fluvial carbon exports and emissions from THPSS.

We undertook seasonal and diurnal sampling for the partial pressures of carbon dioxide (pCO_2) and methane (pCH_4), dissolved organic carbon (DOC), dissolved inorganic carbon (DIC) and total organic carbon (TOC) as well as physico-chemical parameters of the swamp aquifers, swamp discharge waters and the channels in two intact swamps and two channelised fills in the Blue Mountains region of Eastern Australia to quantify the fluvial carbon exports and emissions from these upland swamps. We hypothesised that fluvial carbon exports and emissions would be higher in the channelised fills, than those of intact swamps due to increased carbon transport from the swamp aquifer towards the channel, altering carbon cycling of channelised THPSS ecosystems.

2. Regional setting

The study sites are situated within the Blue Mountains World Heritage Area, approximately 100 km west of Sydney (Katoomba 33°42′51 S, 150°18′36E) (Fig. 1). The Blue Mountains plateau is a low-relief, deeply incised tableland of Triassic quartz sandstones and interbedded claystones (Pickett, 1997; van der Beek and Pulford, 2001). Elevations on the plateau range between 220 m above sea level (asl) to over 1000 m above sea level (asl). Rainfall is typically higher in summer with an annual mean of 1400 mm at Katoomba (Bureau of Meteorology, 2016), located central to the study area. Summer and winter temperatures range from 13 to 23 °C, and 3 to 9 °C, respectively (Bureau of Meteorology, 2016). THPSS is the dominant wetland type in the Blue Mountains. Of the 10,000 km^2 that comprise the Greater Blue Mountains, there are approximately 458 THPSS swamps on the Blue Mountains plateau with an area totalling 11.4 km^2, 26% of these swamps are channelised (Department of Environment and Energy, 2017; Fryirs et al., 2016).

2.1. Study sites

Four swamps, two intact and two channelised, located in Wentworth Falls and Katoomba, were chosen for the sampling program (Fig. 1). These swamps range in elevation between 860 and 950 m asl. The first intact swamp (Walmer Crescent; WC) is 900 m to the north of Wentworth Falls Township, is 146,000 m^2 in area and is located within a moderately elongate, steep sided v-shaped north facing catchment of 612,600 m^2. WC discharges to a small stream via a bedrock step. Vegetation on the swamp margins consists of sclerophyll woodland with sedge, heath and shrub vegetation occupying the swamp centre (Gorissen et al., 2015). The channelised fill at Wentworth Falls (Pitt Park; PP) is 24,000 m^2, within a south facing catchment 135,600 m^2

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