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Identifying key sedimentary indicators of geomorphic structure and function of upland swamps in the Blue Mountains for use in condition assessment and monitoring

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ABSTRACT

Temperate Highland Peat Swamps on Sandstone (THPSS) are located at the headwaters of streams on low relief plateaus of Eastern Australia. Swamp sediment structure has a direct link to the high water tables, element cycling and carbon sequestration that are the characteristic functions of these systems. By comparing the sediment structure of intact swamps and channelised fills, we can gain an understanding of how changes in swamp geomorphology change both swamp structure and function. We examined the sedimentology of six intact and six channelised fill swamps in the Blue Mountains NSW, Australia. There were significant differences in texture, unit thickness, Carbon: Nitrogen (C:N) ratios and moisture content between intact swamps and channelised fills. The presence and thickness of unmodified contemporary sand layers in almost all channelised fills and its absence in almost all intact swamps was a distinctive structural difference. The two functional swamp layers, in terms of water and carbon storage were almost double the mean thickness in intact swamps than in channelised fills. Moisture content was 30% higher in intact swamps than in channelised fills. Mean C: N ratios for channelised fills were 25% lower than that of intact swamps. Peat forming potential, as defined by C:N ratios >27, started at a greater depth in the sediment profile (0.9 m lower) in channelised fills than in intact swamps. It is clear from this study that these structural and functional indicators are important for assessing swamp condition and can also be useful in designing monitoring programs for management and rehabilitation that target key structural attributes that produce and maintain swamp function.

1. Introduction

Understanding the geomorphic structure and function of fluvial systems provides a basis for understanding a range of biotic interactions (Bellmore and Baxter, 2014; Brierley and Fryirs, 2009; Brierley et al., 2002; Chessman et al., 2006; King and Hobbs, 2006; Southwood, 1977; Vietz et al., 2014). Anthropogenic changes to geomorphic structure can have profound impacts on hydrological and biotic functions such as flow variability, water quality, carbon sequestration and nutrient cycling (Brierley et al., 1999; Brierley and Fryirs, 2005; Chessman et al., 2006; Patil et al., 2013; Sullivan et al., 2006). These functional alterations are often the focus of management and rehabilitation efforts in ecosystem-based approaches to river repair (Brierley and Fryirs, 2008; Feio et al., 2010).

The identification of key structural indicators operating on system function can be difficult. Both biotic and abiotic structural and functional elements are inherently interdependent with complex feedback loops in operation (Bellmore and Baxter, 2014; Brierley et al., 1999; Corenblit et al., 2011; Hobbs and Harris, 2001; Tabacchi et al., 1998) (Fig. 1). Because of this interdependence, assessing structure without assessing function, or assessing function without structure, will fail to capture ecosystem health as a whole (Korbel and Hose, 2011).

Sediment accumulation is a distinctive feature of peat forming systems in Australia and globally (Chimner and Ewel, 2005; Evans and Warburton, 2007; Fryirs et al., 2014a; Sorensen, 1993). Biotic processes such as organic matter accumulation within the sediment matrix, are fundamental to the water and carbon storage functions that are distinctive features of these peat forming systems (Grover and Baldock, 2012; Grover and Baldock, 2013; Parry and Charman, 2013). These functions are inherently inter-related (Frolking et al., 2010). Carbon accumulation occurs when rates of deposition exceed the rates of microbial decomposition, which is common in anoxic environments of permanently saturated sediment such as swamps (Clymo et al., 1998; Grover and Baldock, 2013). However, sediment saturation, and thus high water tables, can only occur with sufficient organic matter accumulation, in part

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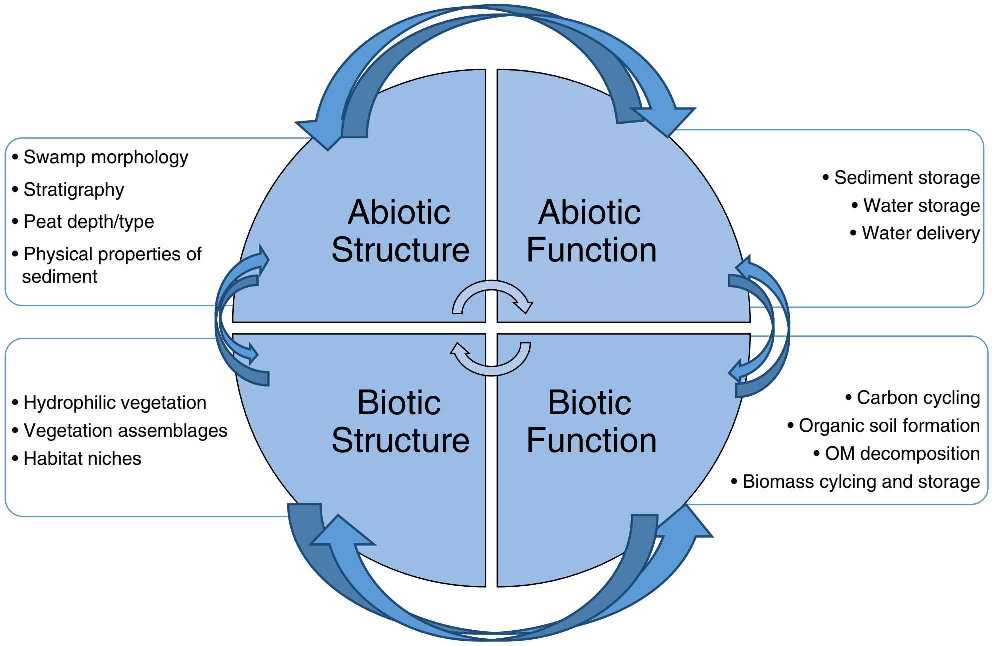

Fig. 1. Biotic and abiotic structural and functional components of peatland systems modified from Chimner and Karberg (2008); Fryirs et al. (2014a); Garneau et al. (2014); Holden et al. (2006); Holden et al. (2011); Lawrence et al. (2009); Parry et al. (2014); Straková et al. (2012); Wellock et al. (2011).

because of the strong capillary forces in highly organic sediments (Bauer, 2004; Clymo, 1984). The intersection of these processes leads to peat formation (Batjes, 2014; Belyea and Baird, 2006; Heathwaite, 1993). Anthropogenic alteration of catchment processes can disrupt the inter-relationship between these two functions (Komulainen et al., 1999; Wilson et al., 2010). For example, lower, more variable water tables produced by swamp channelisation and drainage can lead to oxidation of peat forming sediments which increases decomposition rates of organic matter and Carbon and Nitrogen mineralisation (Carroll et al., 2011; Grover and Baldock, 2012; Laine et al., 1996).

Temperate Highland Peat Swamps on Sandstone (THPSS) are located at the headwaters of low order streams, on low relief plateaus of eastern Australia such as those in the Blue Mountains and Southern Highlands in NSW (Fryirs et al., 2014a). They formed, and continue to form, in topographical low-points of the plateaus during the Holocene when, because of their low slope and low energy, mineral sediment accumulated in headwater drainage lines, leading to discontinuous drainage and waterlogging (Fryirs et al., 2014a). Organic matter accumulation occurs simultaneously, which favours vegetative growth and low decomposition rates (Fryirs et al., 2014a, 2014c; Humphreys, 2007). Fryirs et al. (2014b) found very low sediment accumulation rates of between 4 and 90 mm/100 y in intact swamps indicating low rates of sediment supply to these valley floors.

These structural aspects of sediment and vegetation accumulation lead to high water holding capacities and high organic matter storage within the swamp sediments, which differentiates these systems from other fluvial systems found in similar climates (Evans and Lindsay, 2010; Evans and Warburton, 2007; Loisel et al., 2013). THPSS are morphologically similar to fens found in the northern hemisphere (Evans and Warburton, 2007; Fryirs et al., 2014a). The water and carbon storage functions of Northern Hemisphere peatlands are also similar to THPSS (Clymo, 1984; Fryirs et al., 2014c; Garneau et al., 2014; Ingram, 1978). However, the primary difference between THPSS and peatlands in the Northern Hemisphere is the high degree of mineralisation of the peat forming layers of THPSS due to the underlying sandstone geology. THPSS sit low on the peat forming scale but because organic matter accumulation exceeds decomposition in these systems they still have peat forming potential (Fryirs et al., 2014c).

The sedimentology of THPSS is fundamental to swamp structure and function; the storage and movement of water through swamp sediments, unique to such ecosystems, is dependent on the physical properties of swamp stratigraphy (Fryirs et al., 2014a; Fryirs et al., 2014b). Therefore, altered sedimentation and erosion processes may compromise swamp hydrology. This has implications for element cycling, carbon sequestration and ecosystem function (Ballard et al., 2011; Daniels et al., 2008; Holden et al., 2006).

Impacts resulting from urbanisation, agriculture and mining can fundamentally change the sediment regimes of these systems and of fluvial ecosystems generally, with channelisation and channel widening occurring through higher, more concentrated flows, manual drainage and vegetation removal (Bledsoe and Watson, 2001; Booth, 1990; Evans and Warburton, 2007; Fryirs et al., 2016; Kohlhagen et al., 2013; Wheeler et al., 2005). Increases in catchment impervious surface area and urban stormwater connectivity, which is particularly the case in the Blue Mountains, have been associated with ecosystem degradation, including channelisation within swamp systems (Chin, 2006; Fryirs et al., 2016; Vietz et al., 2014; Walsh et al., 2005). Channelisation has been implicated in the impairment of both water and carbon storage functions within peat forming systems worldwide (Holden et al., 2006; Ramchunder et al., 2012; Turner et al., 2013).

In this paper, we examine the sedimentology of six intact (unchannelised) and six channelised fill swamps located in the Blue Mountains, NSW Australia. Measures of sediment texture, unit thickness and bulk density were chosen as indicators of sediment structure. Organic matter content and C: N ratios were selected as indicators of carbon storage function, and gravimetric moisture content was assessed as an indicator of water holding capacity. We hypothesise that there are significant structural differences in sedimentology between swamp types which will be concomitant with functional indicators such as C: N ratios, water holding capacity and organic matter content. We describe the most appropriate indicators that can be used to assess the geomorphic structure and function of these systems and discuss how assessing and monitoring these attributes should be a key management strategy for rehabilitation that is focussed on reinstating impaired swamp structure and function (Hensen and Mahony, 2010; Kohlhagen, 2010).