

A toolbox of sedimentary indicators for assessing the geomorphic structure, function and condition of endangered Temperate Highland Peat Swamps on Sandstone (THPSS), Blue Mountains, NSW.

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Key Points

- Five structural and functional measures derived from a study of swamp stratigraphy are used as indicators of swamp condition in Temperate Highland Peat Swamps on Sandstone (THPSS) in Blue Mountains, NSW.
- Structural indicators of condition include sediment type and distribution, texture thickness and presence of contemporary sediments.
- Functional indicators of condition include Carbon: Nitrogen ratios and gravimetric moisture content.
- Understanding both structural and functional elements of fluvial systems is essential for evaluation and monitoring of ecosystem health.

Abstract

An understanding of the physical structure of fluvial systems is essential for explaining a range of ecosystem functions. Changes to system structure often lead to changes in function such as flow regime, water quality and nutrient cycling. Assessing functional attributes without examining system structure can lead to poorly designed management programs that only treat the symptoms of degradation rather than the causes.

Temperate Highland Peat Swamps on Sandstone (THPSS) are located on low relief plateaus of the Sydney Basin. They are sediment accumulation zones with high water tables and high soil carbon content. We examined the sediment structure of twelve swamps in the Blue Mountains, NSW from which five structural and functional indicators of swamp impairment were identified. Sediment type and distribution, texture thickness and presence of contemporary sediments are important structural indicators while carbon: nitrogen (C: N) ratios and moisture content are significant functional indicators. An assessment matrix was developed from these indicators for use in analysis of the condition of these systems. The indicators used are easily measured and can provide a relatively rapid assessment of both the structure and function of these systems. This provides a critical physical template for designing rehabilitation programs for these endangered swamp systems.

Keywords

sediment texture, carbon to nitrogen ratio, gravimetric moisture content, channelised fill, intact swamp, peat forming potential

Introduction

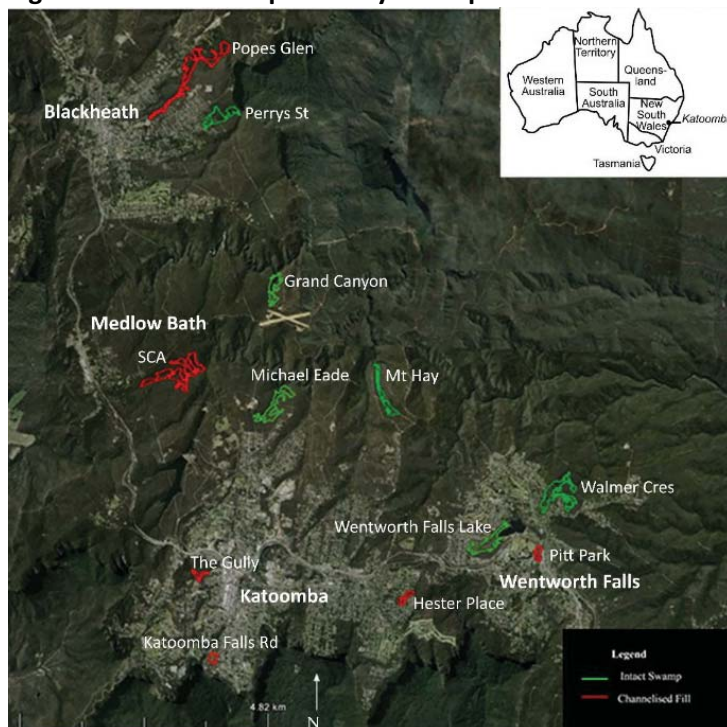
The geomorphic structure and function of fluvial systems can be seen as a template atop which biotic structure and function can be understood (Bellmore and Baxter, 2014, Brierley and Fryirs, 2009, Chessman et al., 2006, Cowley et al., in press, 2016). Changes to system structure can have multi-scalar impacts on both biotic and abiotic system function including sediment storage, flow regimes, water quality and nutrient cycling (Brierley et al., 1999, Chessman et al., 2006, Patil et al., 2013, Vietz et al., 2014). Ecosystem health

assessment, restoration and monitoring programs that focus solely on function without considering structure can overlook key origins of system impairment (Benda et al., 2004, Brierley et al., 2010, Korbel and Hose, 2011). Appropriate indicators for use in assessing ecosystem health therefore need to address both structural and functional elements of ecosystems, and include analysis of geomorphic attributes if successful assessment of health are to be made (Fryirs, 2015).

THPSS are located in the headwaters of low order streams on plateaus of the Blue Mountains NSW (Cowley et al., in press, 2016, OEH, 2013). They are found in low slope-low energy conditions and comprise valley fills that are several metres thick. Perched water tables and organic soils are found in these un-channelised systems (Evans and Lindsay, 2010, Fryirs et al., 2014b, Humphreys, 2007, Loisel et al., 2013). THPSS are located within the Blue Mountains World Heritage Area (WHA) and are listed as Endangered Ecological Communities in both state and federal legislation due to impacts from urbanisation, agriculture and longwall mining (OEH, 2013). The focus of this paper is the identification of a range of geomorphic indicators that provide a signal about the structure and function of these systems, and to demonstrate how this can be used in assessment of swamp condition.

Field sites and methods

Figure 1. Location map of study swamps



Source: (Cowley et al., in press, 2016)

The study draws on data collected from six intact (un-channelised) and six channelised fill swamps located in the Blue Mountains of NSW (Cowley et al., in press, 2016). Intact swamps are characterised by the lack of a defined channel, discontinuous, preferential drainage lines, hydrophilic, native vegetation and waterlogged, organic soils (Fryirs et al., 2016). Channelised fills have a defined channel with associated geomorphic units and processes such as bank attached bars, undercutting and channel widening (Fryirs et al., 2016). Swamp surface desiccation is also a feature of channelised fills as is exotic vegetation. Processes involved in channel incision of these swamps are associated with impacts arising from urbanisation such as increasing impervious surface area within the swamp catchment, stormwater connectivity and groundwater usage (Fryirs et al., 2016).

Sampling and analysis

Sediment cores were recovered from two locations in each swamp using a Russian D-corer. Texture and grain size analysis was undertaken in the field for each stratigraphic layer in the profile. Samples for the analysis of total organic carbon (TOC) and Total Kjeldahl Nitrogen (TKN) bulk density, organic matter content and gravimetric moisture content were taken from all major sedimentary layers within the cores. Carbon to nitrogen (C: N) ratios were derived from the ratio of TOC to TKN for each sample, which provides an indication of organic matter breakdown and subsequent peat forming potential (Kuhry and Vitt, 1996). Carbon to nitrogen ratios greater than 25-30 are indicative of organic matter accumulation that exceeds decomposition whereas soils with C: N ratios of 16-25 are in equilibrium. High C: N ratios also indicate slow carbon turnover and long term carbon accumulation (Briones et al., 2014). For more detail on sampling and analysis methodology see Cowley et al. (in press, 2016).

Statistical analysis and assessment matrix

Comparison of structural and functional indicators derived from texture classification and sample analysis was determined using 1-way ANOVA in Minitab® (version 17.2.1). Levels of impairment were derived from the medians for each indicator with the exception of C:N ratios where peat forming potential is indicated at 27-29 (Kuhry and Vitt, 1996).

Results and Discussion

Sediment texture classes

Five distinct texture classes were identified that were consistent across the swamps included in this study. The physical characteristics of bulk density, grain size and texture thickness generally agreed with the texture classifications found in Fryirs et al. (2014a).

The surficial organic fines (SOF) layer consisted of highly porous super-saturated fine sands and silts with bulky, fibric, living organic matter in the sediment. SOF was found in both intact swamps and channelised fills however texture thickness in the channelised fills swamps was half that of intact swamps (**Table 1**).

The contemporary sands (CS) layer was found in almost all channelised fills and in only one location in one intact swamp. This textural unit comprises two sub-units; the upper unit are grey-brown silts and fine sands, the lower unit are orange-yellow coarse sands. These sediments are low in organic matter content, relatively low moisture content and are associated with anthropogenic catchment disturbance and urban development.(Chin, 2006, Fryirs et al., 2016) (**Table 1**).

The alternating organic sands (AOS) layer contained black, highly organic loamy sands and sandy loams and was the dominant layer in terms of occurrence and thickness. C: N ratios were well within peat forming range and were the highest of all the layers indicating that this layer is a key location for peat formation and subsequent carbon storage function. High moisture content in this layer is a function of the high rates of organic matter within the sediment matrix and as such, is closely coupled to the structural attributes of the layer(Lucchese et al., 2010).The presence of both key swamp functions in this layer emphasises the importance of the AOS to swamp function (**Table 1**).

The fine cohesive sands (FCS) occurred below the AOS in only two intact swamps and consisted of fine sandy clays and clayey sands. Moisture content, organic matter content and C: N ratios were very low indicating that this layer is not an important functional unit of these swamps (**Table 1**).

Basal sands and gravels (BSG) layers occurred at the base of all intact swamps and consisted of grey coarse sands and gravels with low moisture content and low organic matter content. C: N ratios were within peat forming range at 29 which may be more an indication of the unit grading into the AOS above (**Table 1**).

Table 1. Sediment characteristics of each textural unit

Texture	Surficial Organic Fines (SOF)	Contemporary Sands (CS)	Alternating Organic Sands (AOS)	Fine Cohesive Sands (FCS)	Basal Sands and Gravels (BSG)
Photo					
Sediment Characteristics	Red-brown fine sandy silts	Orange/yellow coarse sands and gravels	Black highly organic loamy sands/sandy loams	Fine white sandy clay or clayey sands	Grey coarse sands and gravels
Mean texture thickness (m)	0.22	0.29	1.04	0.06	0.1
Mean bulk density g/cm ³	0.56	1.24	1.09	1.74	1.43
Mean moisture content g/g	2.27	0.66	0.79	0.19	0.37
Mean organic matter content %	21	8	11	3.4	3.7
Mean C: N Ratio	23	21	35	16	29

Structural Indicators

There are clear structural differences in the stratigraphy of intact swamps and channelised fills. All swamps had SOF above AOS and all intact swamps had a BSG layer below the AOS. The presence and thickness of contemporary sands (CS) within channelised fill sediments is a primary structural difference between the two swamp types and as such, a clear measure of impairment. The CS layers have low C: N ratios and low moisture content, indicating low peat forming potential and water holding capacity. The structure of the CS layer therefore inhibits swamp function. The presence of CS is therefore a clear structural indicator of swamp impairment that affects the fundamental carbon and water storage functions of THPSS (Figures 2a & b).

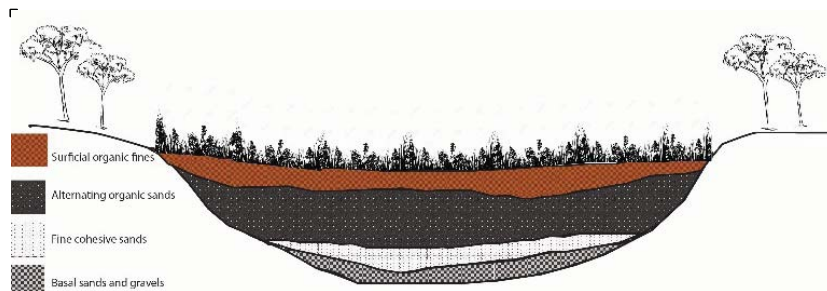


Figure 2a. Stratigraphy of an intact swamp

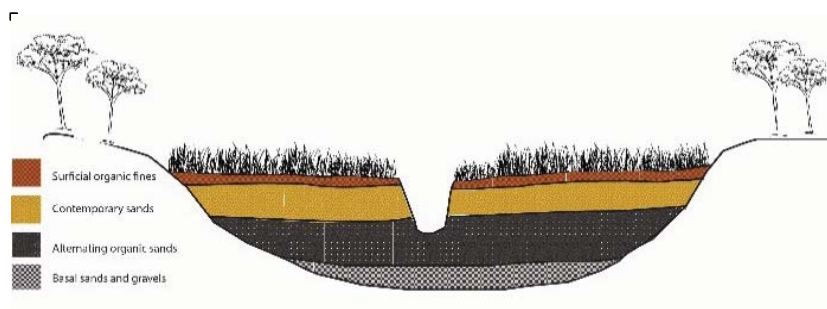
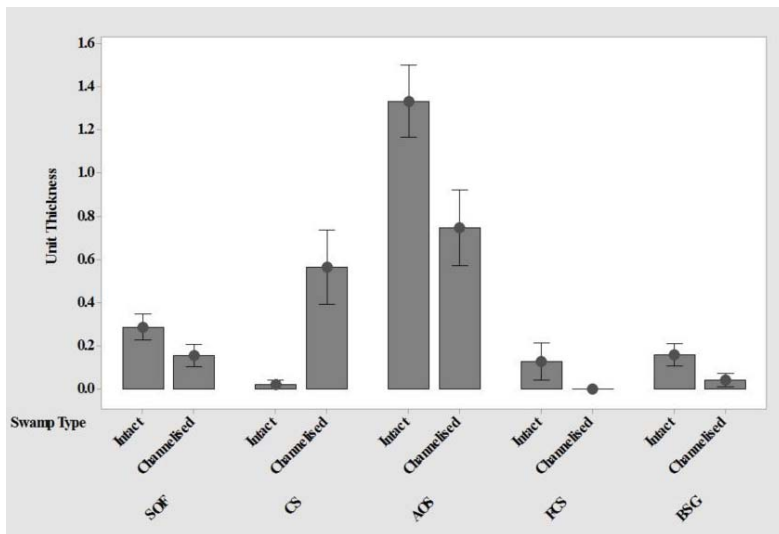


Figure 2b. Stratigraphy of a channelised fill



There were significant differences in texture thickness of the AOS between the two swamp types. Mean texture thickness of AOS in intact swamps was double that of channelised fills (Figure 3). Given that the AOS layer is the primary carbon storage layer in THPSS, lowered carbon storage capability will occur in channelised fills when AOS volume is compromised.

Figure 3. Unit thickness differences between intact swamps and channelised fills

Functional Indicators

C:N ratios were 25% higher in the AOS layer in intact swamps than in channelised fills. (Figure 4). Moisture content for intact swamps was 30% higher than that of channelised fills with moisture content of the SOF layer in intact swamps more than twice that of channelised fills (Figure 6). Lower moisture content and lower C: N ratios within channelised fill sediments are both functions of lower, more variable water tables (Ballard et al., 2011, Holden et al., 2011, Parry et al., 2014, Wilson et al., 2013).

Differences in C:N ratios with depth between swamp types were also apparent. Intact swamps' C: N ratios were within the peat forming range from 0.5m and generally continued within peat forming range for the remainder of the profile. Only half the channelised fills were within peat forming range by 1.4m. (Figure 5a & b).

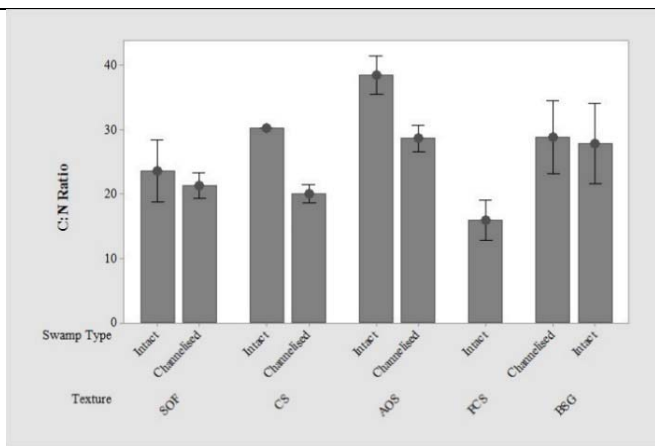


Figure 4. C:N ratios for swamp type and texture class

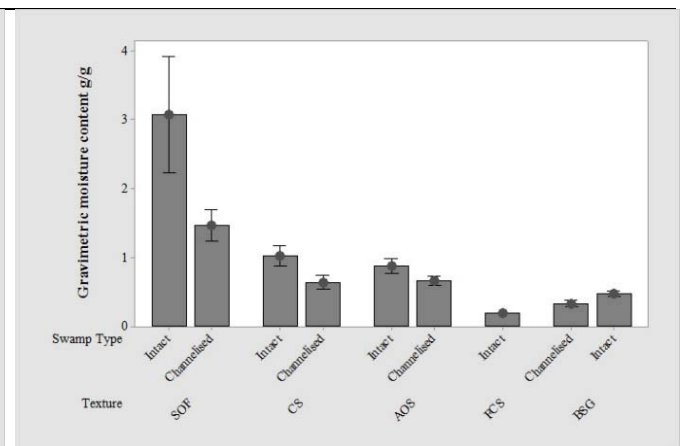


Figure 5. Gravimetric moisture content for swamp type and texture class

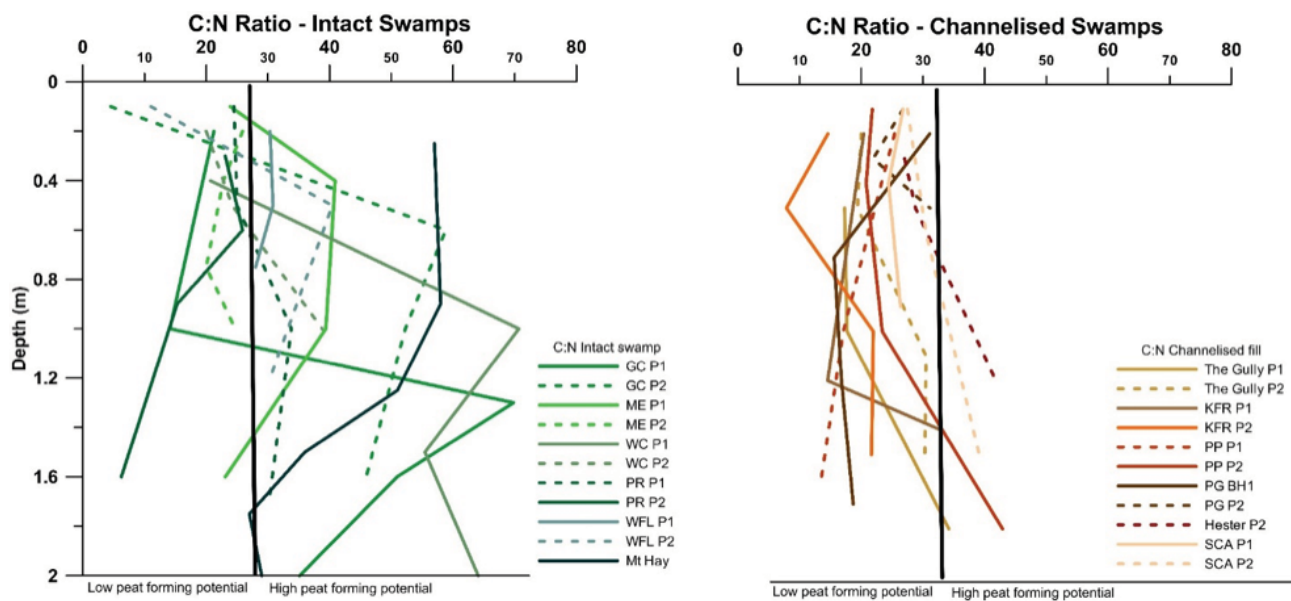


Figure 5a and b. a) C: N ratio with depth for intact swamps and b) C: N ratio with depth for channelised fills

Assessment Framework

The assessment framework (Table 2) developed from the above structural and functional indicators is applied to three swamps from the study (Table 3). Grand Canyon at Medlow Bath is a reference site with low levels of impairment across all indicators. Wentworth Falls Lake, an intact swamp located within a highly urbanised catchment has structural indicators that are moderately impaired while the functional indicators show low levels of impairment. This is a good example of how assessing structure may anticipate future functional impairment. Assessment programs that focus solely on function may miss important structural indicators of impairment that will impact on function down the track (Brierley et al., 1999, Corenblit et al., 2011, Fryirs, 2015, Hobbs and Harris, 2001). By using the matrix as a prioritisation tool, rehabilitation efforts can be targeted at swamps with moderate structural impairment and moderate to good function to maximise restoration efforts.

Successful rehabilitation depends on well-designed monitoring programs (Florsheim et al., 2006). Timeframes over which structural and functional processes operate need to be taken into account when designing monitoring programs to ensure that indicators will give reliable information about condition (Brierley et al., 2010). The structural indicators at The Gully, Katoomba, a swamp undergoing rehabilitation, are assessed as moderate to high, with high and low impairment scores for C:N ratios and gravimetric moisture content respectively. This demonstrates how the assessment matrix might be used within a monitoring program to assess which functional indicators are most sensitive to restoration efforts and timescales that may be involved in restoring system function (Brierley et al., 2010).

Table 2. Swamp condition assessment matrix based on indicators of structure and function

Measure/indicator	Level of impairment for both intact swamps and channelised fills			What it tells us about structure and/or function of THPSS
	Low	Moderate	High	
Structural Indicators				
Appropriate distribution of sediment classes in the valley fill	SOF – AOS – FCS/BSG	SOF – CS – AOS – BSG	CS – AOS – BSG	Structural changes to swamp sediments
Presence of CS (m)	None	0.0 – 0.3	> 0.3	Anthropogenic impacts on swamp structure
Thickness of AOS (m)	> 1.2	0.7 – 1.2	< 0.7	Structural change to primary functional textural layer
Functional Indicators				
C:N ratios of upper AOS layer	>29	27 – 29	< 27	Carbon storage functionality
Moisture content of surficial layers (g/g)	> 1.6	1 – 1.6	<1	Water storage and infiltration capacity

Table 3. Assessment matrix for four swamps. Note: greyed out boxes represent indicators measured for each site.

Grand Canyon, Medlow Bath				
Structural Indicators	Level of impairment			
	Low	Moderate	High	
Appropriate distribution of sediment classes in the valley fill	SOF – AOS – FCS/BSG	SOF – CS – AOS – BSG	CS – AOS – BSG	
Presence of CS (m)	None	0.0 – 0.3	> 0.3	
Thickness of AOS (m)	> 1.2(1.25)	0.7 – 1.2	< 0.7	
Functional Indicators				
C:N ratios of upper AOS layer	>29 (36)	25 – 29	< 25	
Moisture content of surficial layers (g/g)	> 1.6 (3.2)	1 – 1.6	<1	
Wentworth Falls Lake, Wentworth Falls				
Structural Indicators	Low	Moderate	High	
Appropriate distribution of sediment classes in the valley fill	SOF – AOS – FCS/BSG	SOF – CS – AOS – BSG	CS – AOS – BSG	
Presence of CS (m)	None	0.0 – 0.3 (0.1)	> 0.3	
Thickness of AOS (m)	> 1.2	0.7 – 1.2 (1)	< 0.7	
Functional Indicators				
C:N ratios of upper AOS layer	>29 (36)	25 – 29	< 25	
Moisture content of surficial layers (g/g)	> 1.6 (4.8)	1 – 1.6	<1	
The Gully, Katoomba				
Structural Indicators	Low	Moderate	High	
Appropriate distribution of sediment classes in the valley fill	SOF – AOS – FCS/BSG	SOF – CS – AOS – BSG	CS – AOS – BSG	
Presence of CS (m)	None	0.0 – 0.3	> 0.3(0.6)	
Thickness of AOS (m)	> 1.2	0.7 – 1.2 (0.7)	< 0.7	
Functional Indicators				
C:N ratios of upper AOS layer	>29	25 – 29	< 25 (24)	
Moisture content of surficial layers (g/g)	> 1.6(2.3)	1 – 1.6	<1	

Conclusions

Five measures of sediment structure and function were identified for use in the assessment and monitoring of swamp condition. Sediment type and distribution, texture thickness of the key functional layer, alternating organic sands and the presence of contemporary sands are indicators of structural impairment while

moisture content and C:N ratios were useful indicators of carbon and water storage function. Assessment of both structural and functional elements is essential for effective and successful conservation and rehabilitation programs.

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