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Intrinsic and extrinsic controls on the geomorphic condition of upland swamps in Eastern NSW

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ABSTRACT

Temperate Highland Peat Swamps on Sandstone (THPSS) are a distinctive feature of low-relief plateaus in eastern Australia and are listed as an endangered ecological community under state and federal policy. A significant proportion of these 'upland swamps' occur within the World Heritage Blue Mountains of NSW. Here, long wall mining, coal seam gas extraction and catchment urbanisation are impacting on the conservation and protection status of these systems. Here we undertake a geomorphic condition assessment of these systems and analyse the range of intrinsic and extrinsic controls operating upon them. Of the 458 sites assessed, 120 (26%) were channelised fills and 338 (74%) were intact swamps. For intact swamps, 49% remain in good geomorphic condition compared to only 28% for channelised systems. Incision of these upland swamps cannot be explained by intrinsic controls such as catchment area, swamp slope, swamp size or shape relations alone. A range of interrelated extrinsic impacts associated with urbanisation are key controls on the condition and sensitivity of these systems. The most significant relationships occur between those swamps in good and moderate condition and percent of impervious area in a swamp catchment (<10% coverage), distance to stormwater pipes and groundwater bores (both <500 m distant), and the extent of stormwater connectivity (contain no stormwater outlets). In general, once the condition of a swamp deteriorates past good or moderate, it is impacted. In a swamp management context, identifying 'thresholds of concern' and treating extrinsic controls associated with human-disturbance (through either conservation or rehabilitation) has the potential to significantly impact swamp type and condition into the future.

1. Introduction

River management and rehabilitation is ultimately about improving river condition and sustaining the benefits derived from healthy river systems. Frameworks for assessing river condition (or in this case, swamp) constitute a core part of the river management process, providing a critical platform for environmental decision-making and associated actions (Fryirs et al., 2008; Fryirs, 2015). Concepts of threshold spotting, tipping points and thresholds of probable concern (c.f. Newson, 2010, Piegay and Schumm, 2003) have been used in an attempt to identify, and then target, abiotic and biotic attributes of the ecosystem that require manipulation through rehabilitation practice with the objective of improving ecosystem condition. However, to date in both the geomorphic and ecological fields, thresholds of typology change and transitions in condition have been poorly defined, therefore limiting the usefulness of the information gathered to make predictions of future river typology, condition or trajectory (Scheffer et al., 2001).

Temperate Highland Peat Swamps on Sandstone (THPSS) are a distinctive feature of low-relief plateaus in eastern Australia (Young, 1986; Young and Young, 1988; Dodson et al., 1994; Freidman and Fryirs, 2015; Fryirs et al., 2014a) and are listed as an endangered ecological community under the Environment Protection and Biodiversity Conservation Act 1999 (National level) and the Threatened Species Conservation Act 1995 (State level). The Blue Mountains and Southern Highlands of New South Wales (NSW), where THPSS are concentrated, reside within the water supply catchment for Australia's largest city, Sydney and play a key role in determining the quantity and quality of water in these catchments (Fryirs et al., 2014b). Despite playing a vital role in water supply and quality, and their ecological significance, THPSS are threatened by activities such as long wall mining, coal seam gas extraction and catchment urbanisation (Benson and Baird, 2012, Hensen and Mahony, 2010; Department of Environment and Climate Change (DECC), 2011, Kohlhagen et al., 2013).

In eastern Australia, upland swamps (including THPSS) were more prevalent at the time of European settlement than at present (Burrough et al., 1977; Buchanan, 1979; Prosser and Melville, 1988; Young and Young, 1988; Holland et al., 1992; Bell et al., 2005; Pemberton, 2005). As is the case internationally, many swamps have been drained or channelised as a result of agricultural activity and

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urban sprawl (Moore, 2002; Evans and Warburton, 2007; Gebhardt et al., 2010; Fenner et al., 2011; Kohlhagen et al., 2013; Robarts et al., 2013). Few examples of 'intact' swamps remain outside protected areas. Recent recognition of the value of these systems has prompted policy that places priority on the conservation and maintenance of intact swamps, and reinstatement of swamps where they have been degraded or destroyed (Hope et al., 2009; Blue Mountains City Council (BMCC), 2010; Kohlhagen et al., 2013). Understanding their geomorphic condition and controls on this condition remains limited. Consequently, conservation and rehabilitation planning as part of Catchment Action Plans and National Water Initiatives is occurring in the absence of such understanding.

Internationally, a range of discontinuous river courses have been described, reflecting local-scale controls on material availability and calibre, the prevailing flow regime, riparian vegetation cover, and slope controls, among other factors. Reported examples include chain of ponds (Eyles, 1977), swamplands (Bird, 1982, 1985), dells (Young, 1986), swampy meadows (Prosser et al., 1994), bogs (Crowe et al., 2008; Bragg and Tallis, 2001) and upland swamps (Fryirs and Brierley, 1998; Fryirs et al., 2014a). Equivalent features have been variously termed wadis or oued (e.g. Vita-Finzi, 1969), dambos or donga (Mackel, 1974; Botha et al., 1994).

There has been debate in the literature on the underlying controls on the triggers associated with incision and gullying into these valley fills (Valentin et al., 2005). Attention has been drawn to the crossing of some form of slope and/or runoff-related threshold, with numerous examples being given of both intrinsic (within-system) and extrinsic (external to the system) controls (e.g. Schumm and Hadley, 1957; Cooke and Reeves, 1976; Graf, 1979, 1983; Prosser and Slade, 1994; Montgomery and Dietrich, 1994).

Morphometric studies of incision into intact valley fill surfaces have focussed largely on intrinsic threshold relationships between catchment area and valley slope, suggesting that as catchment area increases, incision is triggered on a progressively lower slope (e.g. Patton and Schumm, 1975, 1981; Begin and Schumm, 1979; Schumm et al., 1984). Oversteepened valley floor surfaces which are approaching the threshold for incision are considered to be the most sensitive to change (Brunsden and Thornes, 1979; Desmet et al., 1999; Perroy et al., 2012). In these systems, older (Holocene at least) phases of cut-and-fill are also evident, with seemingly little accordance in the timing of incision across the landscape (Prosser and Winchester, 1996). This has been used to infer the dominance of intrinsic controls on swamp incision associated with vegetation cover, substrate character, and flow regime (e.g. Dietrich et al., 1992; Prosser et al., 1994; Prosser and Slade, 1994; Prosser and Winchester, 1996; Faulkner, 2008; Perroy et al., 2012).

Elsewhere a range of extrinsic controls associated with climate, and direct or indirect human disturbance have been documented (e.g. Bragg and Tallis, 2001; Tomkins and Humphreys, 2006; Banaszuk and Kamocki, 2008; Hensen and Mahony, 2010; Kohlhagen et al., 2013). In these cases, climate-induced changes to hydrological regime and disturbances associated with vegetation removal, swamp draining and undermining have been considered key controls on the extent of incision and the condition of these systems (Valentin et al., 2005).

In this paper we adapt and apply a geomorphic condition approach for assessment of these swamps systems. We then investigate the impact of intrinsic and extrinsic controls on the type (i.e. intact versus channelised) and geomorphic condition of 458 THPSS in the semi-urbanised Blue Mountains region of NSW, Australia.

2. Regional setting

The study area (33° 30′ S; 150° 30′ E) is located 100 km west of metropolitan Sydney, NSW within the World Heritage Listed Blue Mountains National Park (Fig. 1). The Blue Mountains rise to 1100 m above sea level (a.s.l.) and are incised by steep dendritic gorges (Holland et al., 1992). The plateau rises steadily, westerly to Wentworth Falls where a transition from Hawkesbury Sandstone to the Narrabeen Group occurs (Stockton and Holland, 1974). The Narrabeen Group comprises chert sandstone, quartzose sandstone, shale and claystone. The plateau is separated from a narrow coastal plain by a prominent escarpment (Holland et al., 1992). Adjacent to the valley-bottom THPSS, hillslopes comprise tall eucalypt forests progressing to silt and sand rich peat swamps on valley floors (Holland et al., 1992; Hensen and Mahony, 2010). The majority of the swamps are <2000 m^2 in area, and occur at between 500 and 1050 m a.s.l. (Hensen and Mahony, 2010). Katoomba is located within the study area and receives 1100–1,300 mm of rainfall annually (BOM (Bureau of Meteorology), 2013). The mean maximum temperature is 23 °C and 10 °C, and mean minimum is 12 °C and 3 °C in the summer and winter months, respectively (BOM (Bureau of Meteorology), 2013).

3. Methods

3.1. GIS mapping and statistical analysis

Mapping of valley-bottom upland swamps across the Blue Mountains was undertaken using orthorectified aerial photography in ARCGIS 10.2. Each swamp was mapped as a discrete polygon so that attribute analysis could be undertaken. A two metre contour map was provided by the Blue Mountains City Council. From this, a range of physical attributes were measured using automation tools. Each measure was assigned as an intrinsic or extrinsic control. Forms of intrinsic control on geomorphic condition include catchment area draining into the swamp, catchment length, catchment elongation, swamp area, swamp elevation, swamp slope, swamp length and swamp elongation (Table 1). Analyses of vegetation coverage and quality are incorporated into the condition assessment (among other indicators). Forms of extrinsic control on geomorphic condition include stormwater connectivity, urban interface connectivity, percentage of impervious area in catchment, distance to stormwater pipes, distance to groundwater bores and distance to urbanisation (Table 1). Extrinsic control data were derived from GIS shp file layers received from Blue Mountains City Council and Greater Sydney Local Land Services. Percent impervious area within swamp catchments was derived from 2002 SPOT raster imagery imported to ARCGIS in which vegetated colourations were removed and impervious area defined by two colour values and converted to vector polygons. The polygons were then intersected with the catchment area layer and impervious area calculated from which percentages were derived. Distance to groundwater bores, urbanisation and stormwater, stormwater connectivity and urban interface connectivity were calculated by joining the final swamp condition layer with the aforementioned layers in ARCGIS.

Principal components analysis was used to visualise the relationships between intrinsic and extrinsic variables with swamp type and condition. This analysis was done using Primer-E v. 6.1.15 (Primer-E Ltd., UK). Partial binary and ordinal logistic regression analysis was used to determine the relative contribution of intrinsic and extrinsic variables to explain variation in probability (log odds) of swamp type and geomorphic condition (intact or channelised, each analysed separately). Two-way ANOVA was used to compare the mean values of the various intrinsic and extrinsic controls between swamp types and geomorphic condition class, with condition being considered orthogonal to swamp type. Data were tested for homogeneity of variance using Levene's test. For instances where this assumption was not satisfied, data were analysed with a modified significance level (α) of 0.01. Simple histograms were drawn for the means of statistically significant controls against the swamp type and geomorphic condition. For the most significant extrinsic controls, we used previously published categories to determine the conditions under which transitions occur