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Understanding the characteristics of riparian zones in low relief, sandy catchments that affect their nutrient removal potential

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ABSTRACT

Riparian zones are considered to improve stream condition by providing a buffer between waterways and agricultural land that can intercept nutrients, but is their efficacy universal? This paper develops a conceptual model comparing the interactions of slope, soil, hydrology, vegetation and nutrient dynamics between 1) the riparian zone of an intermittent stream in a low-relief (1.6%) catchment with deep sands of low reactivity (Bingham Creek) and 2) a perennial stream in a sloped (10%) catchment with reactive soils over an impermeable layer (Lennard Brook), with a view to compare and contrast their riparian functionality. This study compared the attributes of groundwater (three rows of nested piezometers) (0.5 m,1.5 m and 2.5 m depth), stream, soil and vegetation across a transect from the stream, through the riparian zone to agricultural paddocks. In the low-relief catchment, water did not flow through the riparian zone as in a sloped catchment. Porous soils, together with a lack of slope or a confining layer meant water oscillated vertically through the soil profile over the season, with minimal horizontal movement and limited interaction with the active root zone of riparian vegetation; the intermittent stream discharged P-rich water into the riparian zone during the first flush of winter rains. The highly unreactive sands resulted in trivial P or C uptake resulting in high dissolved concentrations in adjacent streams (0.6–0.9 vs 0.001–0.002 mg/L TP, 58 vs 3 mg/L DOC for flat vs sloped catchments respectively). The high DOC in slow-moving groundwater resulted in highly reducing conditions, promoting P solubility and potentially denitrification. Litterfall from vegetation marginally improved riparian soils with better P retention relative to the adjacent paddock (3620–268 kg TP/ha storage) and reduced FRP in the groundwater relative to the stream (27 vs 80%). The conceptual model developed highlights an alternative functionality of riparian zones for low-relief catchments that challenges the assumption of riparian efficacy.

1. Introduction

Vegetated riparian zones are universally considered a best management practice to maintain or improve stream condition (Hoffmann et al., 2009; Dosskey et al., 2010) by providing a buffer between waterways and agricultural land that can intercept nutrients. However, to be effective as a nutrient filter, riparian zones need to intercept the main pollution transport pathways (Dosskey, 2001; Dosskey et al., 2010). Key elements driving this interaction are soil type, slope and flow pathways (Hoffmann et al., 2009; Dosskey et al., 2010). Evidence for the effectiveness of riparian zones as a nutrient reduction tool is largely based on landscapes that have soils with a good nutrient-holding capacity, a marked slope towards the stream channel and perennial stream flow (Verry et al., 2004). This paper questions whether riparian vegetation can be effective in environments that do not share these characteristics.

Low relief, sandy catchments, common throughout the world, have been associated with high nutrient export, e.g. the coastal plains of Australia (Peters and Donohue, 2001) and the south-east of the United States of America (Butler and Coale, 2005). Such landscapes lack slope towards the stream, have deep sand regolith with limited reactivity towards nutrients and often stream flow is intermittent. In south Western Australia, the Ellen Brook catchment provided an ideal site to investigate whether vegetated riparian zones in low relief, sandy, coastal catchments function as predicted based on current understanding.

Nutrient uptake at any particular site depends on the site characteristics of slope, soil and vegetation, but effective nutrient removal depends on one or more of these elements having features that promote uptake. Previous studies on sloped catchments in south Western Australia have shown that sands promote flow in the subsurface layer rather than in B horizons or surface flow and residence times are very short (McKergow et al., 2006). Weaver and Summers (2014) showed

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that in deep sand terrain in south-western Australia, water bypassed the riparian zone and entered the stream from directly beneath the streambed from deep groundwater flow. In the deep sand terrain, the presence of riparian vegetation did not reduce P concentrations of water in streams and in fact P in these streams was dominated by dissolved rather than particulate P (McKergow et al., 2003). This can be attributed to the poor capacity for P retention by soils and through the lack of sorption sites in stream sediment (McKergow et al., 2003; Summers et al., 2014). Each of these studies suggest riparian functionality in sandy catchments of low relief is different to the typical riparian paradigm.

This paper investigates the hydrology and nutrient dynamics of riparian zones 1) in a low relief catchments with deep sands of low reactivity and 2) in a sloped catchment with reactive soils over an impermeable layer, with a view to compare and contrast their riparian functionality. The purpose is to use inductive reasoning through multiple lines of evidence to develop a conceptual model of nutrient removal pathways in sandy catchments of low relief that can be tested in future studies. For example, the conceptual model could be used to investigate specific processes of nutrient flux and transformation and to devise improved plans for nutrient management in agricultural catchments. The conceptual model was developed through investigating the effect of, and interactions between, hydrology, slope, soil type and vegetation in the riparian zone on the nutrient dynamics and retention in the different catchment types. It is useful to review how these interactions could potentially affect nutrient retention in these different catchments.

Nutrients are primarily transported in water, so the relative proportions of water flowing above and below the ground and their rates of flow determine riparian nutrient removal performance (Vidon and Hill, 2004; Dosskey et al., 2010). Surface flow through the riparian zone primarily facilitates the removal of particulate-bound nutrients, whereas subsurface flow through the root zone facilitates uptake of dissolved nutrients (Tabacchi et al., 2000; Hoffmann et al., 2009) or the transformation and discharge of nutrient into the atmosphere in gaseous forms.

Slope promotes water movement, and determines the partitioning of flow between surface and subsurface flow from the field to the stream (Hoffmann et al., 2009). Dosskey (2001) reviewed studies with varying degrees of slope, and identified how slope affected flow and nutrient interception in riparian zones; however, an optimal slope for nutrient interception in riparian zones was not defined. Where there is limited slope, horizontal flow may be diminished, decreasing the supply of catchment groundwater that can interact with the active root zone of riparian plants (Burt et al., 2002; Sovik and Syversen, 2008).

Soil type, particularly soil texture, influences porosity, pore size distribution, water holding capacity and permeability (Coyne and Thompson, 2006). For example, sands have a large grain size and are usually more loosely packed than clays, and so have higher infiltration rates. Highly permeable sands are synonymous with rapid subsurface flow, whereas clays can be nearly impermeable, leading to very slow subsurface flow (Coyne and Thompson, 2006). The rate of vertical flow, together with soil water holding capacity, determines the residence time of water in the soil (Rawls et al., 2003). Fast flow or limited water holding capacity limits the opportunity for nutrient uptake or nutrient transformation processes such as denitrification (Wohlfart et al., 2012). The depth of the water table, which is defined as the level below which the ground is saturated with water, can dictate groundwater interaction with plant roots (Vidon and Hill 2004, 2006; Sovik and Syversen, 2008).

As well as slope and soil type, the presence of a subsurface impermeable layer can promote flow through the riparian root zone (Sovik and Syversen, 2008). The presence of this layer, which occurs in duplex soil profiles or with shallow bedrock, restricts the downward passage of water (Sharma et al., 1996; Heinen et al., 2012). Being unable to penetrate (or able to penetrate very slowly) to the lower layer, water preferentially travels horizontally through the highly permeable upper layer (Vidon and Hill, 2006). This throughflow ensures water remains in the root zone of the riparian vegetation but may also promote surface flow (Vidon and Hill, 2006). In soil types lacking this impermeable layer, such as deep sands, water often infiltrates through the soil profile to beneath the active roots of riparian vegetation and rises and falls over time (Heinen et al., 2012).

Riparian vegetation improves water quality through physical, chemical and biological processes (Verry et al., 2004; Dosskey et al., 2010). Physically, vegetation increases hydraulic roughness, decreasing surface flow and increasing infiltration rates, which in turn increases sediment and nutrient deposition in riparian zones (Vought et al., 1994; Naiman and DeCamps, 1997). Chemically, riparian vegetation modifies redox potential and facilitates transformation of nutrients (Tabacchi et al., 2000). This can result in nutrient loss (Hoffmann et al., 2009), nutrient release (Scalenghe et al., 2002) or render nutrients less available for plant uptake (Rutterberg and Heinrich, 2003). Biologically, riparian zones reduce nutrient concentrations through the assimilation of nutrients into plant biomass or through microbial immobilisation (Naiman and Decamps, 1997). Biological stores are, however, only temporary stores from which nitrogen and phosphorus may be released (Hoffmann et al., 2009). Nitrogen can be permanently removed through biologically-mediated denitrification, particularly from slow-flowing subsurface water with high organic matter loads and low oxygen concentrations (Dosskey et al., 2010). Groundwater-fed surface pathways are also important denitrification hotspots, especially when the surface flow occurs diffusively (Shabaga and Hill, 2010).

Considering these interactions, our hypothesis is that riparian zones have limited capacity to intercept nutrients, when the catchment soils are deep sands with low reactivity to nutrients and the landform has low relief. The key question is: How do nutrient and flow dynamics differ between an intermittent stream in a low-relief, sandy landscape and a perennial stream in a nearby sandy landscape with slope and reactive soils?

2. Materials and methods

2.1. Study sites

Ellen Brook is a relatively large sub-catchment (664 km^2) of the Swan-Canning Estuary, north east of the city of Perth, Western Australia. The climate is Mediterranean, with hot, dry summers and mild, wet winters, with most rainfall occurring from May through October. Streams within the catchment are mainly ephemeral, with 40% of the discharged flow from baseflow from groundwater (Barron et al., 2008). Stream flow occurs mainly in late winter and spring.

Ellen Brook contributes 7% of the total flow into the Swan-Canning system, yet it contributes upwards of 39% of total phosphorus and 28% of total nitrogen annually (Swan River Trust, 2009). The main nutrient sources identified in the catchment are fertilisers, animal waste and soil-bound nutrients (Barron et al., 2008). Land use in the catchment is dominated by pasture for extensive grazing by cattle. Much of the Ellen Brook catchment is characterised by poor nutrient deficient soils so fertiliser is required to achieve agricultural production. Unfortunately, the soils have low phosphorus retention and high leaching capacity (Barron et al., 2008): as a consequence, nutrient release and loss into waterways is high where fertilisers are used.

The Ellen Brook catchment is predominantly underlain by highly permeable sands of the Bassendean Dune System (Bleached Orthic Tenosol; Isbell, 1996), although there are also regions with duplex soils (sands over clays and loams over clays). The topography of the catchment is flat on the west side (mainly comprised of coastal dunes) but in the east, it slopes up towards an escarpment. Two riparian zones within the Ellen Brook catchment were chosen to provide contrasting slopes and soil types: Bingham Creek and Lennard Brook. Bingham Creek is in the south-west of the catchment and Lennard Brook is at the top of the