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Patterns and bioavailability of soil nutrients and carbon across a gradient of inundation frequencies in a lowland river channel, Murray–Darling Basin, Australia

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ABSTRACT

The distribution of both carbon and nutrient stores in the landscape is not homogeneous, and is influenced by soil properties such as texture and organic content as well as spatial gradients such as inundation frequency. In this study the distribution of water extractable soil nutrients and water mobile dissolved organic carbon (DOC) and its bioavailability were investigated at specific levels along a cross-sectional gradient that extended from the baseflow level deep in the channel to the floodplain. The frequency with which these specific levels are inundated was modelled under three flow regimes to determine if flow change is likely to influence nutrient supply to the river. Soil surface litter and soil organic carbon content, DOC and SRP increased along a trajectory from the base of the channel onto the floodplain. Ammonium increased and nitrate decreased as in-channel height decreased. This reflects an increase in soil inundation frequency lower in the channel decreasing nitrification rates and increasing NO_3^- losses via mobilisation and denitrification. Bioavailable soil DOC (BDOC) was lowest in the most frequently inundated soils; however, overall soil BDOC did not relate to either changing soil properties or inundation frequency. There were no significant differences in nutrient and carbon supply to the river under the three modelled flow regimes (with flows extraction rules, without flow extraction rules and natural flows) explored as flow change was most marked in the channel bed region, where little organic matter was stored.

1. Introduction

Variations in hydrological connectivity drive spatial complexity in riverine floodplains (Ward et al., 1999, 2002 and contribute to riverine landscapes being amongst the most productive ecosystems on earth (Brinson et al., 1981). Riverine landscapes are overlain by an inundation frequency gradient; from frequently inundated areas, low and close to the river channel, to rarely inundated areas, distant and high in elevation (Huston, 1994). These gradients are key to the heterogeneity and productivity found in lowland riverine landscapes (Molles et al., 1998; Walling and He, 1998) and provide a strong theoretical paradigm to aid in our understanding of these systems (Spink et al., 1998).

In floodplain soils, inundation stimulates processes which result in the loss, addition or transformation of C, N and P (Pinay et al., 1992; Qiu and McComb, 1996; Bai et al., 2005) can stimulate the mineralisation of organic matter and the production of inorganic nutrients (Fierer and Schimel, 2002). The pattern and frequency of inundation may also be important in nutrient dynamics; frequent inundation can reduce a soils ability to retain P (Kerr et al., 2010) and cause the loss of N through coupled nitrification–denitrification (Baldwin and Mitchell, 2000; Bai et al., 2007).

Inundation can also influence carbon dynamics in soils. Cycles of wetting and drying can increase soil reserves of DOC which, on subsequent inundation, can be mobilised or the bioavailable fraction (BDOC) may be respired (Lundquist et al., 1999a). The overall effects of inundation on BDOC in soils are unclear as BDOC may be both consumed and produced during inundation. For

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instance, greater rates of soil metabolism associated with inundation may increase soil CO_2 fluxes therefore consuming bioavailable C (Valett et al., 2005; Wilson et al., 2011) which may, in the short term, be off-set by the liberation of DOC from bulk soil C stores (Wilson et al., 2011). In the longer term, repeated wetting and drying cycles and the associated production and consumption of bioavailable C may deplete the fraction of bulk soil C that is converted into DOC during inundation, reducing the supply of BDOC (Fierer and Schimel, 2002).

Patterns in soil properties relating to distance from the river bed have been found associated with geomorphic in-channel benches in Australian lowland rivers (Southwell and Thoms, 2011). In these systems benches are common geomorphological features that reflect the variable hydrology of Australia's lowland rivers (Puckridge et al., 1998); they are discontinuous, bank attached, accumulations of sediments, that occur singularly or in groups at multiple heights in the river channel (Erskine and Livingstone, 1999). Relationships between total soil carbon (C), nitrogen (N) and phosphorus (P), as well as soil texture, soil organic matter content and surface leaf litter load have been found with bench height (Woodyer et al., 1979; Sheldon and Thoms, 2006; Southwell and Thoms, 2011; Vietz et al., 2011). Due to their high soil organic matter content and surface leaf litter loads, benches have been highlighted for their potential role in subsidising exchanges of organic matter from terrestrial to aquatic ecosystems during flow pulse phases that do not extend onto the floodplain, thereby acting like 'mini-floodplains' and may be particularly important in rivers whose connectivity to their floodplains has been reduced by flow regulation (Sheldon and Thoms, 2006). On inundation, the mobility of soil nutrients (Baldwin and Mitchell, 2000), carbon (dissolved organic carbon (DOC) and bioavailable dissolved organic carbon (BDOC)) (e.g. Fierer and Schimel, 2002; Wilson et al., 2011) from a bench surface will reflect background inundation frequency and bench soil properties.

In many Australian lowland rivers, particularly those of the Murray–Darling Basin (MDB) in south-eastern Australia, water resource development has reduced the frequency of low to moderate flows levels, often isolating the floodplain from more frequently connected channels and anabranches (Page et al., 2005). Consequently, many of these rivers are now in a precarious state of ecological health (Davies et al., 2010) with flow restoration in the low to moderate flow band recognised as vital for restoring connectivity between different levels within the channel at frequent time intervals (Westhorpe and Mitrovic, 2012). Flow rules and irrigation pumping thresholds have been established across rivers in the northern MDB in an attempt to reverse declining ecosystem health by increasing the frequency and variability of flows (Davies et al., 2010). Increasing connectivity between low level in-channel benches and anabranches during low to moderate flow levels is seen as one option for restoring ecosystem health to these rivers. To achieve this, flow rules are used to either set flow thresholds for irrigator access during natural flow events, or restrict the water available during reservoir spills or when high flows enter the river from unregulated tributaries (Westhorpe et al., 2008b).

Here we aimed to (i) describe the inundation frequency and soil properties of a range of in-channel surfaces in a section of the lowland Gwydir River, Murray–Darling Basin, Australia, (ii) quantify the release of mobile C and nutrients from each surface on inundation and (iii) use modelled flow data to estimate the change, if any, of nutrient release from these surfaces under different flow regulation scenarios (with flows extraction rules, without flow extraction rules and natural flows). This information can then be used to model the impact of different flow scenarios on the productivity of this section of river as one tool in restoring the systems declining ecosystem health. On a gradient from the less frequently inundated floodplain to the frequently inundated channel bed we predicted soil organic carbon content and the release of nitrate (NO_x), ammonium (NH_4^+) and soluble reactive phosphorus (SRP) would decrease; however, due to the relatively young age of the deposited soil and leaf litter inputs deeper in the channel we predicted a higher proportion of the available carbon in frequently inundated areas would be bioavailable carbon.

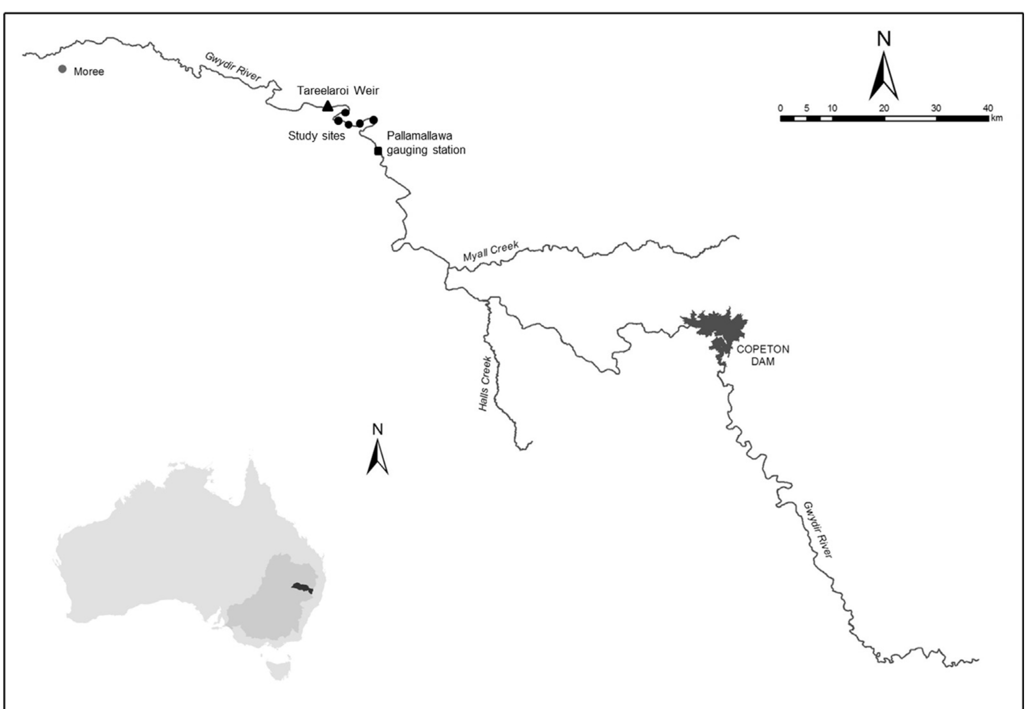

Fig. 1. Map of the Gwydir River in northern New South Wales, Australia, showing the study sites (black circles), Pallawallawa gauging station (black square), Copeton dam and Tareelaroi weir.