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Soil fertility in a large dryland floodplain: Patterns, processes and the implications of water resource development

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Abstract

1. Primary production on semiarid floodplains supports a diverse local and regional fauna. Reduced flooding from water resource development (WRD) may affect floodplain production by decreasing water and nutrient supply.
2. We investigated the effects of reduced wetting on soil fertility by performing a regional soil survey across a gradient of flood frequency. Soil nitrogen (N), phosphorus (P) and carbon (C) were recorded over a soil-wetting event where heavy rainfall and flooding coincided.
3. Soil nutrient concentrations indicate N limits plant growth and P does not.
4. No spatial patterns in soil P were detected across the floodplain, suggesting that the principal mechanism controlling P fertility is the concentration of P in floodplain source material, and that flood mediated import and export of P are minor processes.
5. Soil N concentrations rose following rainfall and flooding and the greatest increased occurred in flooded areas. Flood deposition of N accounted for only 9% of the boost in soil N in flooded areas, and N concentrations continued to rise when the floods and rains ceased. Elevated soil N levels do not appear to persist because at the start of a growth cycle, when soils were dry, soil N did not vary significantly with flood frequency. This suggests most of the boost in soil N was due to N-fixation, with the subsequent loss of N likely to have resulted from in situ processes such as denitrification.
6. Agricultural export of nutrients appears to not be a significant process in the context of the high phosphorus fertility of floodplain source material and the apparently high rates of in situ processing of nitrogen.
7. *Synthesis and applications*. Our data suggest that floodplain soil fertility is controlled by mechanisms other than flood frequency or agricultural export, meaning that WRD is unlikely to affect soil fertility; however, the biological implications of the brief pulse in soil N associated with wetting need further investigation.

Keywords: Soil nitrogen; Soil phosphorus; Flood frequency; River regulation; Grazing; Pastoralism

1. Introduction

Floodplains are regarded as highly productive ecosystems (Brinson et al., 1981; Mitsch and Gosselink, 1993). In arid and semi-arid regions floodplain primary production has far-reaching effects on consumers, influencing the abundance and diversity of local and regional fauna (Morton, 1990; Stafford-Smith and Morton, 1990; Morton et al., 1995; Kingsford, 2000; Lemly et al., 2000). This high productivity is influenced by periodic inundation, so changes to the frequency and duration of flooding, such as those resulting from water resource development–WRD–(Thoms, 2003) have the potential to affect the productivity of floodplains.

Moisture is the main factor usually limiting plant growth in arid and semi-arid areas (Harrington et al., 1984). Floods augment soil moisture above that gained from relatively infrequent heavy rainfall events and this is certain to be the

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primary reason why elevated productivity is found on arid and semi-arid floodplains in comparison to surrounding areas (Sims et al., 1999). However, floodwater also creates a metabolic stress that may reduce production in waterlogged areas (Jackson and Drew, 1984). Productivity may also be affected by nutrient fluxes in floods. Studies of temperate humid floodplains have shown they are relatively fertile (Van Oorschot et al., 1997, 1998; Spink et al., 1998), although examples exist of floodplains deficient in both nitrogen (N) (Van Oorschot et al., 1997, 1998) and phosphorus (P) (Doren et al., 1997). Limited sampling (e.g., Gunn, 1974) suggests Australian semiarid floodplains are more fertile than surrounding areas, which are renowned for having very poor soil fertility (Morton, 1990). However, little is known of the role of floods in maintaining fertility and it is likely to incorporate multiple, interacting processes operating at a range of spatial and temporal scales. Furthermore, spatial and temporal patterns in soil fertility and productivity may also be affected by other factors such as agricultural exports and in situ soil processes.

The objective of this paper is to determine the effect of flooding on soil fertility. To do this, we examine spatial patterns in soil N, P and carbon (C) across the floodplain. The multiplicity of factors affecting fertility means that the patterns observed will often not reveal the exact processes that cause them to arise, but we use the data and a literature review to generate hypotheses for the dominant processes affecting soil fertility on the floodplain and, by extension, the effects on fertility of changes in flood frequency. A better understanding of the effects of flooding on soil fertility and floodplain productivity should improve our capacity to manage our water resources for better ecological outcomes within the constraints imposed by a desired level of water resource development.

1.1. Background and study area

The study was conducted along two rivers of Lower Balonne River floodplain, the Culgoa River and Briarie Creek (Fig. 1). Channels of the 87300 km^2 (QWRC, 1986) Condamine–Balonne River catchment rise in the humid eastern and semi-arid central subtropics of Queensland, Australia. Channels join and drain west or south and until just above Dirranbandi, Queensland (elevation 170 m, Fig. 1), where the channel of the Condamine–Balonne River splits into several smaller distributary or anabranching channels, developing into a large alluvial fan complex known as the Lower Balonne floodplain. Here the climate is semiarid, with pan evaporation (1900 mm/year) well in excess of precipitation (average 400–450 mm/year) (Kalma, 1974; Mottell Pty Ltd, 1996: Table 1). Around 60% of the rain falls in summer, but annual rainfall is extremely variable. In droughts, several years may pass between effective rainfall events (where rainfall exceeds evaporation for a period of about 10 days; Mottell Pty Ltd, 1996). Temperatures range from a mean monthly maximum of 35 °C in summer to a mean monthly minimum of 4 °C in winter.

River discharge is highly variable with coefficients of variation for annual flows within the Lower Balonne region ranging from 103 in the Culgoa to 200 in the Briarie (Thoms, 2003). Flows originate mainly from rainfall in the east of the catchment and less commonly from areas to the north or rainfall within the study region. Flows inundate the floodplain once every 1.5 years on average (Sims and Thoms, 2002). The Culgoa River is the largest river in the Lower Balonne Region, conveying about 35% of the Condamine–Balonne's median annual flow (1995 ML) at St. George (Thoms, 2003). Floodwaters are unconfined and mainly shallow. River–floodplain exchanges occur at many points and in large floods overland flows from different rivers are mixed. The water entering Briarie Creek originates from overland and intermittently channelised flood flow that coalesces into a continuous channel on the station Kelso (Fig. 1). Briarie Creek carries 5% of the Condamine–Balonne River discharge at Kelso. Flow naturally decreases about 30% by the New South Wales border from floodplain absorption. Flows in all rivers of the Lower Balonne region are highly turbid (average ~300 NTU; Kenway, 1993) indicating a considerable suspended load (cf. Riley and Taylor, 1978; Woodyer et al., 1979).

The Lower Balonne catchment is composed mainly of moderately to highly weathered sedimentary rocks, with small areas of basalt in the eastern headwaters (Galloway, 1974; Galloway et al., 1974; Geological Survey of Queensland, 1975). Soils formed from the eastern basalts are P-rich, whereas soils formed from the sedimentary rocks have low to moderate P status (Wild, 1958; Gunn, 1974; Norrish and Rosser, 1983; Williams and Raupach, 1983). Limited sampling (Gunn, 1974; Ogden et al., 2002) suggests that soils on the Lower Balonne floodplain have moderate to high P status and are neutral to strongly alkaline clays and clay loams, with coarser sediments near river channels. A number of geomorphic features may be identified on the floodplain (e.g., Thoms, 2003), but the predominant units are: flat, featureless floodplain (undifferentiated or UDF); floodplain occurring between networks of small distributary channels (inter-distributary floodplain or INT); and floodplain deposited over old channels (buried channel traces or BCT). Distributary channels grade from slight depressions to channels incised a couple of meters into the floodplain. They experience bidirectional flow, conveying water onto the floodplain as floodwaters rise, and back to the rivers as floods recede.

Water abstractions for irrigation have occurred from the Condamine–Balonne River since the construction of weirs in the 1960s and 1970s and have increased in the past two decades as extensive areas of irrigated crops have been developed on the floodplain and nearby terraces (Thoms and Parsons, 2003). In addition to direct abstraction from the river, flood harvesting, where floodwaters are retained in private off-stream dams, is also a common practice in the