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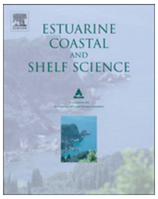

Spatial and temporal changes in estuarine water quality during a post-flood hypoxic event

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ABSTRACT

A major fish kill occurred in the Richmond River estuary in January 2008 due to oxygen depletion following extensive overbank flooding. This paper examines spatial and temporal changes in the chemistry of main channel waters, thereby identifying the primary sources of deoxygenating water. Over 40 km of the mid- to lower estuary main channel was deoxygenated within seven days of the flood peak. Hypoxia was confined to downstream of the confluences with mid-estuary backswamp basins and occurred during the later phase of the flood recession. Water chemistry at key locations in the estuary indicated elevated concentrations of redox sensitive species associated with acid sulfate soils (ASS) during the hypoxic period. Peak concentrations of Fe^{2+} up to 18.2 μmol L^{-1}, dissolved Mn up to 4.3 μmol L^{-1}, chemical oxygen demand (COD) up to 2052 μmol L^{-1}, dissolved organic carbon (DOC) up to 960 μmol L^{-1} and elemental S^0 up to 4.7 μmol L^{-1} were found in the backswamp discharge confluences and mid-estuary main channel locations. The geochemical signature of main channel floodwaters identifies anaerobic decomposition of floodplain vegetation in ASS backswamps as a primary process leading to generation of hypoxic waters. The transport of these hypoxic floodwaters to the estuary has been accelerated and prolonged by extensive floodplain drainage, thereby enhancing the magnitude and duration of estuarine deoxygenation.

1. Introduction

Interactions between rivers and floodplains due to flooding can cause major changes to surface water quality (Junk et al., 1989; Wilson et al., 1999). Riverine deoxygenation events occur episodically following floods as a result of dissolved oxygen consumption on floodplains in Australia (Johnston et al., 2003b; Howitt et al., 2007) and globally (Hamilton et al., 1997). This occurs mainly via decomposition of labile organic material and is a natural component of floodplain carbon cycling. However, anthropogenic alterations to floodplain hydrology and vegetation due to the construction of drains and other flood mitigation works have significantly shifted the timing and magnitude of deoxygenation events (Johnston et al., 2003b). In particular, this has resulted in more severe events which adversely impact on both surface and shallow groundwater quality in these environments (Lin et al., 2004).

Many of the Holocene coastal floodplains of eastern Australia contain large backswamp basins characterised by a distinct levee-toe-backswamp morphology (Walker, 1972). Originally, these backswamp basins were semi-permanent wetlands and natural storage basins for floodwaters (Tulau, 1999), substantially occluded from the main channel by the morphology of extensive natural levee systems. However, following European settlement of the floodplains and expansion of agriculture in the late 19th century (Tulau, 1999), there has been extensive modification of the floodplain surface hydrology via the construction of drainage systems (Johnston et al., 2003c). Drains dissect the natural levee system and have substantially increased the hydrological connectivity between backswamp basins and the main estuarine channel. This has decreased the period of inundation following flooding and greatly increased the movement of water from the floodplain backswamps to the main river channels (White et al., 1997).

The coastal floodplains of eastern Australia are also frequently underlain by extensive areas of acid sulfate soils (ASS) and sulfidic estuarine sediments. These soils commonly occur close to the surface in backswamp basins (Walker, 1972). Enhanced drainage of these areas has resulted in the surface accumulation of metastable Fe minerals such as schwertmannite (Sullivan and Bush, 2004). This provides a significant source of reactive Fe and other trace metals which can be subjected to reductive dissolution and mobilisation

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during flooding (Sammut et al., 1996; Johnston et al., 2003b; Burton et al., 2008). The formation and accumulation of monosulfidic sediments (ie. benthic sediments that are enriched in FeS) also commonly occurs in ASS drains (Bush et al., 2004a; Burton et al., 2006a,b). This material can exert a high oxygen demand when mobilised into the water column following flood events (Sullivan et al., 2002; Bush et al., 2004b). Drainage from these areas is a major threat to water quality, ecosystem health and fisheries productivity due to the discharge of waters with very low levels of dissolved oxygen and high levels of acidity, nutrients and metals (Johnston et al., 2003c).

Changes to the vegetation on the floodplains have altered the rate and nature of biogeochemical processes that occur as a result of surface water–floodplain interactions (Johnston et al., 2003b, 2005). Extensive drainage systems have resulted in drier conditions, thereby encouraging downslope ecotone migration and altering vegetation assemblages (Johnston et al., 2003a). This process has increased the prevalence and abundance of flood intolerant grass species which are a source of labile carbon (Eyre et al., 2006). When inundated, vegetation provides a source of decaying organic material which consumes oxygen from the overlying waters and produces water with a high oxygen demand. Decomposition of floodplain vegetation in ASS backswamp basins can lead to the formation "blackwater" approximately six to ten days after the flood peak, which is typically anoxic and exhibits high COD and dissolved Fe concentrations (Johnston et al., 2003b). Under reduced conditions, Mn (IV), Fe (III) and SO_4^{2-} are important alternative electron acceptors in the decomposition of organic matter. Therefore, the presence of their respiration products (ie. Mn^{2+}, Fe^{2+} and H_2S) are key geochemical indicators of anaerobic decomposition processes.

In January 2008, an extensive fish kill occurred in the Richmond River estuary in eastern Australia due to a flood-induced deoxygenation event. Over 200 000 dead fish and other aquatic organisms including prawns, eels and mud crabs weighing more than 30 tonnes were collected in a survey over 14 days following the flood peak. This event resulted in the closure of the Richmond River estuary to commercial and recreational fishing for approximately two months following the flood peak. A similar event occurred in February 2001, where poor water quality following flooding caused a major fish kill along a 20 km reach of the river (Walsh et al., 2004; Eyre et al., 2006). Smaller flood events have also resulted in depressed oxygen concentrations (Eyre, 1997; Eyre and Twigg, 1997). Previous studies of such events have lacked the spatial and temporal resolution to resolve the relative importance of the role of allochthonous material input from the upper catchment compared to the inputs from mid-estuary floodplain drainage. Therefore, the sources and timing of poor water quality and their effect on the main river channel water chemistry is not clear.

This study examines the geochemistry of waters in the Richmond River following a large flood event. We aim to a) identify the spatial sources of water with a high oxygen demand entering the main channel, b) identify the relative importance of key water quality degrading processes and c) assess the spatial and temporal dimensions of water quality decline and recovery in the main channel.

2. Methods

2.1. Site description

The Richmond River estuary is located in the sub-tropical region of eastern Australia and discharges to the Pacific Ocean at Ballina (153°33′34.61″E, 28°52′16.84″S; Fig. 1). Rainfall is summer dominated (January–April), with mean annual rainfall ranging from 1739 mm at Ballina to 1343 mm at Lismore (BOM, 2009). Mean maximum temperature at Ballina is 28.1 °C.

The Richmond River is a mature barrier estuary with a catchment area of ca. 6900 km^2 and a mean annual discharge of 1 920 000 ML (Tulau, 1999). The Wilsons River, a major tributary, joins the Richmond at Coraki (Fig. 1a). Tidal influence extends approximately 120 km upstream of the Richmond River mouth along the Wilsons River due to the transmission of the tidal signal. There is an attenuation of the influence of marine water with

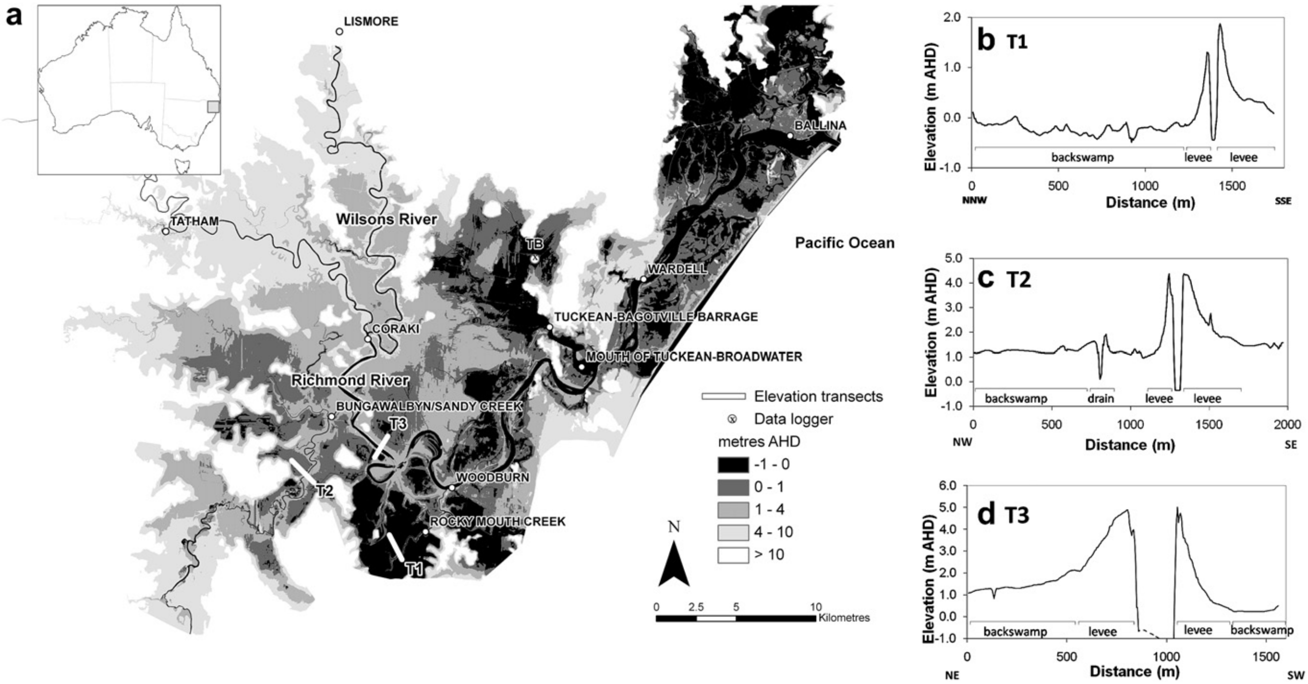

Fig. 1. (a) The Richmond River estuary and floodplain. Elevation classes are derived from a digital elevation model; AHD is Australian Height Datum where 0 m ≈ mean sea level; and cross-sectional elevation profiles illustrating pronounced natural levee-backswamp morphology at (b) T1; (c) T2; and (d) T3.