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Benthic sediment composition and nutrient cycling in an Intermittently Closed and Open Lake Lagoon

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ABSTRACT

Surfical sediments within Corunna Lake, a moderate size Intermittently Closed and Open Lake Lagoon (ICOLL), were examined for solid phase nutrient concentrations (TN, TP, TOC,) and solute exchange rates between the sediment and water column (O_2, NO_3–N, NH_4–N, FRP, and N_2). The surfical sediments in Corunna Lake contained high concentrations of TN (5 mg/g dry mass), total phosphorus (0.6 mg/g dry mass), and TOC (~5% dry mass). The carbon stable isotope ratio ($\delta^{13}C$) and TOC:TN ratios ($\delta^{13}C$ ~ −24, TOC:TN ~ 11–14) demonstrated that the composition of the organic matter in the sediment was a mixture derived primarily of degraded planktonic matter. The close association between TP and Fe concentrations highlighted the potential role Fe plays in mediating Filterable Reactive Phosphorus (FRP) concentrations in the water column of Corunna Lake. *In situ* benthic chamber incubations were used to measure benthic fluxes. Solute exchange rates between the sediment and water column in Corunna Lake were similar to other reported studies (O_2 = −469 to −1765 µmol m^{-2} h^{-1}, NH_4–N = 0.1–63 µmol m^{-2} h^{-1}, NO_2/NO_3–N = 0 µmol m^{-2} h^{-1}, FRP = −4–1.6 µmol m^{-2} $h^{-1}$and N_2 = 12–356 µmol m^{-2} h^{-1}). As more carbon was deposited and mineralized the efficiency of the bacterial population to denitrify nitrogen in the sediment decreases. The linkage between land use and benthic biogeochemistry was also explored. A dairy farm exists in the middle catchment of Corunna Lake, and the receiving bay sediment consistently demonstrated the highest oxygen consumption rates in winter and spring (−1408 µmol m^{-2} h^{-1} in winter, −1691 µmol m^{-2} h^{-1} in spring) and lowest denitrification efficiencies during summer (~3%). Nitrate/nitrite fluxes were not observed during any of the chamber incubations, with the concentrations of nitrate/nitrite being below detection limits (<10 µg/L). Seasonal changes influenced the rates of solute exchange between the sediment and water column. Critical measures of solute exchange for NH_4–N and biogenic N_2 indicated that seasonal temperature changes play a significant role in mediating the reaction rates of sedimentary based biogeochemical processes. Measurable FRP fluxes were small but greater in the benthic sediments which received higher carbon inputs. Sediments have a high capacity to adsorb P which is released as sediment oxygen demand increases as a result of increases in labile carbon loads.

1. Introduction

Catchment exports of organic matter and *in situ* autotrophic production are major sources of organic material deposited to sediments of aquatic ecosystems. Altered land use regimes change the quantity and composition of organic matter exported to aquatic systems (Young et al., 1996; Harris, 1999). The composition of organic matter in sediment is of primary importance for establishing the sources of organic matter (Peterson and Fry, 1987; Middelburg and Nieuwenhuize, 1998). The highly refractory nature of native Australian vegetation supplies relatively inert organic matter to aquatic

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systems (Esslemont et al., 2007), which is only slowly remineralisation by bacterial populations in sediments. When catchments are cleared of native vegetation, grasslands are often established. Grassland organic matter is highly labile, and has a large biological oxygen demand (Esslemont et al., 2007). Most importantly, conversion from native vegetation to farm production grassland fundamentally changes the nutrient biogeochemistry and hydrological character of the landscape leading to more rapid runoff events and higher nutrient loads (Young et al., 1996). Increased nutrient loads can lead to higher rates of algal production and labile organic matter delivery to the surfical sediments. Under these conditions, high mineralisation rates can occur, changing biogeochemical cycling to reactions that favor the release of large quantities of inorganic nutrients into the water column (Berelson, 1998).

Streams and rivers provide rapid conduits for anthropogenic nutrients to estuarine and coastal marine environments (McMahon and Walker, 1998; Smith et al., 1999). Once the suspended matter enters the marine environment, flocculation induces deposition at inflow locations, often causing localised enrichment in sediments and reduced water quality (Boynton et al., 1996; O'Donohue and Dennison, 1997; Nicholson and Longmore, 1999; Heggie, 1999; Palmer et al., 2002).

The relationship between benthic geochemical processes and water column nutrient dynamics is well established (Nixon, 1981; Fisher et al., 1982; Berelson et al., 1996). Sediment is the primary site for mineralisation of organic matter in near-shore systems (Jorgensen and Revsbech, 1989; McMahon and Walker, 1998; Heggie et al., 1999). Once allochothonous matter settles onto sediments it is rapidly incorporated via bioturbation (Harris, 1999). Bioturbation creates a complex three-dimensional structure partitioning the organic matter into oxic and anoxic zones (Harris, 1999). Within these zones bacterial processes mineralise the organic matter and inorganic nutrients are released into the pore water and then the water column (Berelson et al., 1996).

Intermittently Closed and Open Lake Lagoon (ICOLL) systems have restricted flushing regimes that make them particularly vulnerable to organic matter and nutrient enrichment (Comin and Valiela, 1993; King and Hodgson, 1995; Boynton et al., 1996; Menendez and Comin, 2000; Newton and Mudge, 2005). Recent studies in coastal ICOLLs have indicated that sediments are the most important sink and source of nitrogen and phosphorus to the water column (Fredericks and Heggie 2000; Palmer et al., 2000; Smith et al., 2001; Palmer et al., 2002), contributing as much as 3–4 times catchment discharges (Fredericks and Heggie 2000). Denitrification rates are commonly high under low organic carbon loads, and decrease under high loads (Heggie et al., 1999). Most sediment in ICOLLs retain phosphorus, which is associated with iron hydrous oxide complexes in the oxic zones (Heggie et al., 1999).

Unlike larger coastal embayments (e.g. Port Phillip Bay, Vic, Australia), the benthic geochemical processes in shallow coastal water bodies (ICOLLs) are markedly influenced by seasonal physio-chemical conditions (Fredericks and Heggie, 2000). ICOLLs often have a shallow water column that promotes large seasonal fluctuations of temperature and oxygen concentration, particularly in bottom waters and can also be influenced by vertical salinity stratification that restricts oxygen penetration (Webster et al., 2001). The inherently shallow waters also create smaller sediment surface area to water volume ratios, making sedimentary based nutrient processes very influential on the net nutrient concentration in the water column.

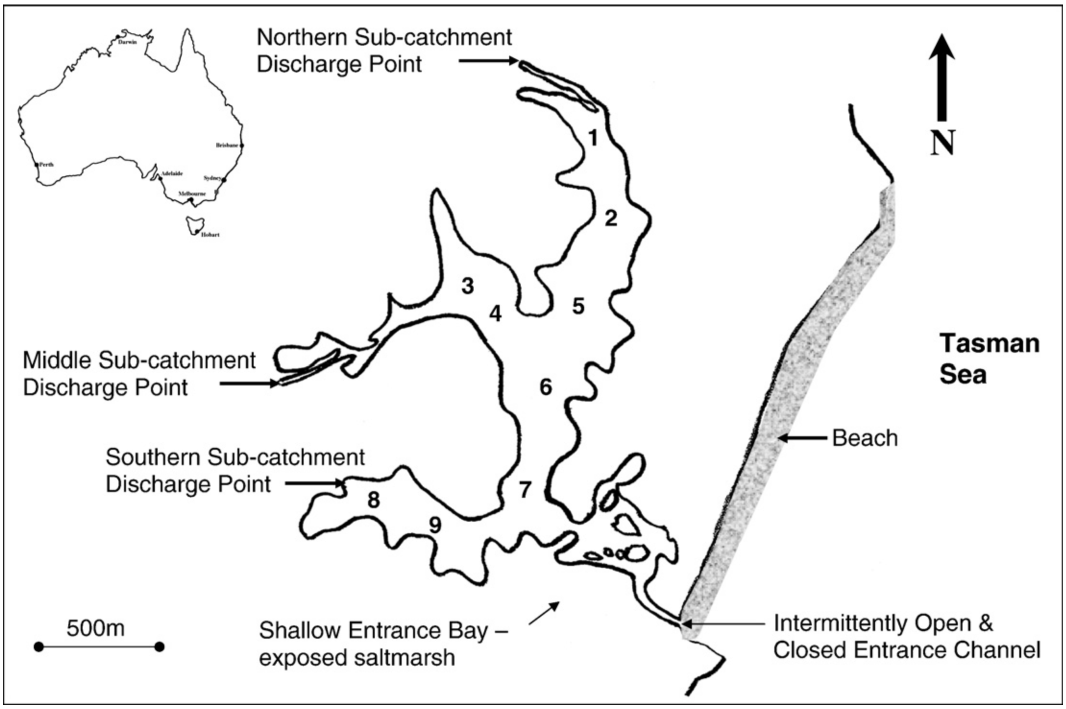

Fig. 1. Study site locations. Sites 1 and 2 (Northern Bay), sites 3 and 4 (Middle Bay), sites 5, 6 and 7 (Central Basin), Sites 8 and 9 (Southern Bay).