Benthic metabolism and nutrient dynamics across the sediment-water interface - Assessing the effects of catchment development and depth on benthic ecosystem functioning in estuaries of Southern Australia.

Jaimie Dwayne Potts
Sydney, New South Wales
Bachelor of Science, University of Sydney 1994
Graduate Diploma of Science, University of Sydney 2001

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Environmental Chemistry Laboratory, Institute for Applied Ecology,
University of Canberra,
Bruce ACT 2601 Australia

Abstract:

Understanding the causes of estuarine eutrophication requires knowledge of benthic biogeochemical processes and the factors influencing them. Currently there is limited information on benthic biogeochemical processes in shallow, wave-dominated estuarine lakes and lagoons of south-eastern Australia. The first objective of this dissertation was to understand how metabolic processes such as benthic community respiration (BCR), benthic primary productivity (GPP), trophic state, and sediment-water nutrient fluxes respond and interact to increased catchment development and nutrient loading in small, shallow intermittently closed and open lakes and lagoons (ICOLLs) along and the Otway Coast of Victoria and the Northern Illawarra Coast of NSW.

In the shallow, light replete lagoons along the Otway Coast, benthic respiration and primary productivity were low compared to temperate estuaries worldwide. BCR and GPP were tightly coupled and increased linearly with increasing catchment development. The daily balance of these processes (trophic state) rendered the sediments net autotrophic and the sediments were a net sink/low source of inorganic nitrogen and phosphorus with respect to the water column due to the assimilative demands of the photosynthetically active benthic microalgae situated on the sediment-water interface. The sediments were also predominantly a net sink for N_2 indicating that N-fixation exceeded denitrification suggesting that the nitrogen demand of the sediment complex could not be met from supplies in the water column.

Similarly, BCR rates in the Northern Illawarra ICOLLs generally increased with increasing catchment development and N-loading and this relationship was further supported when rates were integrated and compared across a larger set of published N-loading and benthic metabolism data for NSW estuaries. BCR rates in the Northern Illawarra ICOLLs were considerably higher than BCR rates measured in the Otway coast ICOLLs and this was attributed to the Northern Illawarra ICOLLs having higher rainfall, warmer water temperatures, greater levels of catchment development and greater retention of organic matter and nutrients due to the ICOLLs being predominantly closed to the sea. The most developed Northern Illawarra ICOLLs (i.e. Towradgi and Tramway) had high BCR rates (-2499 to -3769 O_2-μmol.m^{-2}.h^{-1})

compared to temperate estuaries worldwide and they were significantly greater than BCR rates measured in larger estuaries of NSW that are permanently open to the sea (i.e. Wallis Lake, Parramatta River, Lane Cove River, Botany Bay).

Like trends found for the Otway coast ICOLLs, benthic primary productivity (GPP) rates in the Northern Illawarra coast ICOLLs generally increased with increasing catchment development and nutrient loading. The exception to this occurred in Towradgi lagoon which was very turbid during summer and the benthic microalgal production was light limited. Excluding Towradgi lagoon in summer, BCR and GPP rates generally under light replete conditions across the Northern Illawarra coast ICOLLs increased linearly when BCR rates were less than -2000 O_2-µmol.m^{-2}.h^{-1}. However, GPP rates then approached to a maximum as BCR rates increased and exceeded -2500 to -3000 O_2-µmol.m^{-2}.h^{-1}. This result suggested that there were factors other than light limiting BMA productivity (i.e. H_2S toxicity, carbon limitation, self-shading) as organic matter and nutrient loading to the ICOLLs increased. This result had important implications on the benthic trophic state as the sediments shifted from autotrophy to heterotrophy as BCR rates became large (i.e. > -2500 O_2-µmol.m^{-2}.h^{-1}) and the sediments concomitantly shifted from a low source/sink to a significant (large) source of inorganic nutrients to the water column.

The other objective was to understand how metabolic processes such as benthic community respiration (BCR), benthic primary productivity (GPP), trophic state and sediment-water nutrient fluxes vary and interrelate across a depth gradient in two bays (Coomba and Pipers Bays) in a large coastal lake (Wallis Lake). This study also investigated how these metabolic processes relate to seasonally variable factors such as water quality (e.g. temperature, turbidity), light climate and sediment properties such as carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotope ratios, benthic pigments (e.g. chlorophyll-a) and organic carbon and nitrogen content.

In Wallis Lake, BCR rates in the deeper basins (2.5-2.8 m) of both bays were similar across seasons whereas seasonal patterns in the mid-depth (1.5 metres) of Coomba Bay were less clear with a large increase in BCR rates in late summer (February) 2007. The shallow depths (0.5 m) of Coomba Bay exhibited a distinct seasonal pattern with least and greatest GPP occurring in August (winter) and February (summer) respectively. The shallows of Pipers Bay had the least and greatest benthic GPP occurring in November (spring) and February (summer) respectively. Benthic microalgal productivity generally decreased with increasing depth in both bays with greatest rates occurring in the deeper basins in late autumn-late winter. In contrast, greatest benthic GPP rates occurred in spring to late summer in the shallower depths. Seasonal differences in benthic productivity rates in the deeper basins corresponded to factors affecting water column light attenuation such as pelagic chlorophyll-a concentrations and turbidity which were generally greater in the spring-summer than late autumn-late winter period due to stronger wind driven currents and resuspension. Estimates of benthic trophic state showed a distinct pattern across the depth gradient with the shallow (0.5 m) and deeper (2.5 - 2.8 m) basin sites being respectively autotrophic and heterotrophic across seasons. In contrast, the mid-depth (1.5 metres) of Coomba Bay varied seasonally between autotrophy and heterotrophy but was 'balanced' over the year. Averaged across seasons, net daily sediment-water dissolved silicate effluxes in Coomba Bay increased with depth indicating decreasing uptake by photosynthesising BMA (diatoms). In contrast, inorganic nitrogen and phosphorus fluxes across the gradient were low to negligible whereas there was a net efflux of N_2 from the sediment to the water column at all depths.

In Pipers Bay, there were significant differences for sediment-water DSi and N_2 fluxes with a net influx at the shallow depth (0.5 m) and a net efflux in the deeper basin (2.5 m). Sediment-water DIP fluxes were negligible at both 0.5 and 2.5 m depths whereas there was a net efflux of DIN in the deeper basin and negligible fluxes in the shallows. Across the depth gradient in both bays, seasonally averaged estimates of net benthic metabolism (e.g. trophic state) were highly correlated to sediment concentration ratios chlorophyll-a:pheophytin, TOC:chlorophyll-a and TN:chlorophyll-a indicating that these multi-proxies are potentially useful indicators to assess benthic trophic state and determine the depth threshold where the unvegetated benthos transitions from autotrophy to heterotrophy.

In summary, this dissertation demonstrated that increased catchment development and nutrient loading increased both benthic respiration and primary productivity rates linearly in shallow, light replete lagoons of south-eastern Australia, however, benthic primary productivity rates did not continue to increase and approached a maximum when respiration rates were high. This shifted the daily balance of these processes (trophic state) from net autotrophy to net heterotrophy and concomitantly transformed the sediments from being a sink/low source of nutrients to a significant/large source to the water column. The trophic state of the benthos similarly shifted from autotrophy to heterotrophy with increasing depth and the transition depth was influenced by seasonal factors affecting light attenuation through the water column. Similarly, the trophic state across the depth gradient was the major determinant of whether the sediments acted as a sink or source of nutrients to the water column.

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Abbreviations and Units

BCR	Benthic Community Respiration
Chl-*a*	Chlorophyll-*a*
DSi	Dissolved Silicate
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphorus
DON	Dissolved Organic Nitrogen
DOP	Dissolved Organic Phosphorus
DO	Dissolved Oxygen
DSi	Dissolved Silicate
GPP	Gross Primary Production
ICOLL	Intermittently Closed Open Lake and Lagoon
N	Nitrogen
N_2	Di-nitrogen gas
NBM	Net benthic metabolism
NH_4^+	Ammonium
NPP	Net Primary Production
NO_2^-	Nitrite
NO_3^-	Nitrate
NO_x	Nitrite + Nitrate
O_2	Oxygen
OM	Organic matter
P	Phosphorus
PO_4^{3-}	Phosphate
SiO_4^{2-}	Silicate
CO_2	Carbon dioxide
TDN	Total Dissolved Nitrogen
TDP	Total Dissolved Phosphorus
TN	Total Nitrogen
TP	Total Phosphorus

Table of Contents

Table of Figures

Table of Tables