

Nutrient recycling and benthic activity in a shallow coastal lagoon in Western Australia

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A collaborative study of benthic activity in Wilson Inlet (southwest WA; Fig. 5) has found that nitrogen released as ammonium contributes to high NH_4^+ fluxes, which are considerably reduced by microphytobenthos (MPB, small bottom-dwelling algae) in summer and autumn. The benthic fluxes of NH_4^+ are higher than the catchment fluxes, and can be sustained only by rapid recycling of nitrogen from the sea-floor.

The study contributed to an assessment of the capacity of Wilson Inlet, a recreational reserve, to accommodate nutrient and sediment discharge from the catchment, and local point sources of discharge (such as sewerage treatment plants).

Study site

Wilson Inlet is a coastal lagoon ~14 km long by 4 km wide with an average depth of 1.7 m. It comprises a distinct marine-sand delta opening into a central basin up to 4.5 m deep underlain by organic-rich mud (up to 9% organic carbon). Coarse, probably fluviodeltaic sand is accumulating at the estuary perimeter and river entrances.

The Inlet has a highly seasonal run-off, reflecting the Mediterranean-type climate (hot dry summers, cool wet

winters): most rainfall occurs in winter, virtually none in summer. It is isolated from the sea by a sand bar for ~7 months a year (usually January–August), but is tidal while open to the sea. Tides in the Inlet (<10 cm) are considerably more attenuated than marine tides (1.2 m), and sea-level changes due to atmospheric effects commonly exert a greater influence on sea-water exchange than astronomic tides (Lukatelich et al. 1987: *Estuarine, Coastal and Shelf Science*, 24, 141–165). Accordingly, marine water entering the Inlet settles to form a generally shallow (<0.5-m-thick) layer of bottom water.

Nutrient (N and P) and chlorophyll-a concentrations in the Inlet are generally low. Even so, the bulk of the bottom of the Inlet lies within the photic zone in summer, which has favoured the proliferation of a large MPB community.

Materials and methods

Using benthic chambers and techniques described in Berelson et al. 1996 (AGSO Record 1996/17), we measured benthic fluxes in situ at four sites (6, 12, 18 and 30; Fig. 5) in the mud facies in spring (November 1997), summer (February 1999), autumn (May 1998) and winter–early spring when run-off is still occurring (September 1998). The Inlet was

isolated from the sea and the water column well mixed during the autumn survey, and stratified during the other surveys.

Most parameters were measured in chambers that isolated ~7 L of water above the bottom sediment. Two transparent chambers and two opaque chambers were deployed at each site with a central data logger that recorded the concentration of dissolved oxygen and temperature in each chamber and in ambient bottom water.

Dissolved oxygen within the chamber was measured every 5 min by a pulsed electrode. Five 100-mL samples withdrawn from the chambers during a 6-hour deployment were immediately filtered and analysed in an onshore laboratory. Two chambers equipped with conductivity–temperature–depth probes automatically collected samples for analysis at pre-programmed intervals in additional deployments.

Nitrite ($\text{NO}_2\text{-N}$), nitrate ($\text{NO}_3\text{-N}$), ammonia ($\text{NH}_4^+\text{-N}$), orthophosphate ($\text{PO}_4\text{-P}$), and silicate ($\text{SiO}_4\text{-Si}$) concentrations in the samples were measured colorimetrically. Alkalinity was determined by Gran titration, and total CO_2 (TCO_2) calculated from alkalinity and pH. The chamber volume was determined from the dilution of a known volume of an inert tracer (NaCl , NaBr or CsCl) injected at the start of each deployment. Nutrient and metabolite fluxes were calculated from the linear regression of metabolite concentration against time — typically the first 4.5 hours of each deployment.

Results

Winter and spring

Oxygen uptake and TCO_2 production (reflecting net respiration) were apparent in both the transparent and opaque chambers during the winter and spring surveys (Fig. 6). The similarity of the fluxes in the clear and transparent chambers indicated that no benthic photosynthesis occurred.

Summer and autumn

During the summer and autumn surveys, a net positive flux of oxygen into the water in both transparent chambers, notably in the shallower sites, contrasts with the decrease in (uptake of) oxygen and liberation of ammonia in both opaque

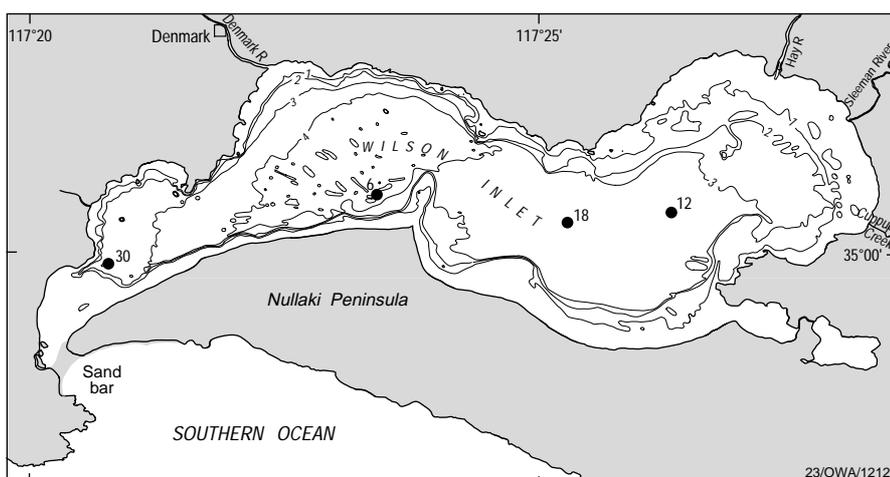


Fig. 5. Wilson Inlet study area. Bathymetric contours are annotated in metres.

chambers (Fig. 7), and probably reflects MPB photosynthesis. The positive flux of oxygen in the transparent chambers was accompanied by an uptake of ammonia, presumably by the MPB.

Discussion

The seasonal variation in oxygen flux (Fig. 8) is pronounced for the transparent chambers, in which the MPB were photosynthesising during summer and autumn. In contrast, respiration in the opaque chambers showed little variation between the surveys.

TCO₂ fluxes (Fig. 8) show a similar seasonal pattern, but are ~30 per cent higher than the O₂ fluxes. The higher TCO₂ fluxes may reflect either (a) carbonate dissolution within the sediments releasing CO₂, or (b) suboxic and anoxic reduction of organic carbon (e.g., sulphate reduction) which does not consume O₂.

Nitrogen is released from the bottom mud mainly (95%) as ammonia. The ammonia, phosphate, and (high) silicate (17Si:106C) fluxes correlate well with the TCO₂ flux, suggesting that diatoms are a notable component of the labile organic carbon being consumed in the sediments (Brzezinski 1985: Journal of Phycology, 21, 347–357).

The ammonia fluxes vary between opaque and transparent chambers, but show some seasonal variation (Fig. 8). They were highest in the opaque chambers between late winter and summer, probably as a result of the increased input of organic debris to the sediments. Ammonia fluxes in the transparent chambers were similar to those measured in the opaque chambers in winter and autumn, but were near zero in summer. Little uptake of dissolved inorganic nitrogen (DIN) from the water column was measured during these seasons, despite moderately high rates of MPB photosynthesis. Assuming a typical marine composition of plankton or Redfield stoichiometry (Hillebrand & Sommer 1999: Limnology and Oceanography, 44(2), 440–446) for the MPB, we estimated that N uptake from the water column was less than 1 per cent of the potential uptake predicted from the TCO₂ flux.

The phosphate fluxes, consistently near zero, show no clear seasonal variation in either the transparent or opaque chambers (Fig. 8). The chamber data indicate that the sediments are an effective trap for PO₄-P generated within them for the prevailing conditions. Higher concentrations of PO₄-P have been recorded when the Inlet was stratified and

dissolved oxygen in the bottom water was low (Water and Rivers Commission 1999: Water Resources Technical Series, WRT 14).

We provisionally estimated the annual fluxes of nutrients from sediments (Table 1) by averaging the fluxes measured in the opaque and transparent chambers and multiplying them by the area of the Inlet. The annual respiration flux of NH₄⁺-N from sediments greatly exceeds the input of all forms of N from the catchment. Clearly, such a large flux of NH₄⁺-N from the sediments to the water column must be balanced by a return flux, to maintain a long-term equilibrium in the system. By comparison, PO₄-P fluxes are small, but still of a similar order of magnitude to the catchment inputs.

Direct measurements of the NH₄⁺-N flux show that sediments are a net source of nutrients throughout the year, despite the moderately high rates of MPB photosynthesis in summer. Whereas median rates of MPB photosynthesis in summer were 20 mmol O₂m⁻² day⁻¹, the median

NH₄⁺-N uptake from the water column was only 0.1 mmol m⁻² day⁻¹. This is much less than the estimated requirement of 3 mmol N m⁻² day⁻¹ (calculated for a stoichiometry of 106O:16N:1P). Concentrations of DIN in the water column at the start of the summer deployments were generally low. Accordingly, the MPB apparently derived N for photosynthesis from an alternative source — perhaps the pore water just below the sediment–water interface.

The MPB clearly modified the flux of N across the sediment–water interface in summer. The role they play in controlling water quality in shallow coastal waters has been documented at only a few sites, and appears to vary. For example, water clarity and MPB productivity are highest in winter in Indian River–Rehoboth Bay, two coastal lagoons on the east coast of the US (Cercio & Seitzinger 1997: Estuaries, 20(1), 231–248). Ecosystem modelling indicated that the MPB had a major influence on nutrient cycling of nitrogen and phosphorus. In winter, when

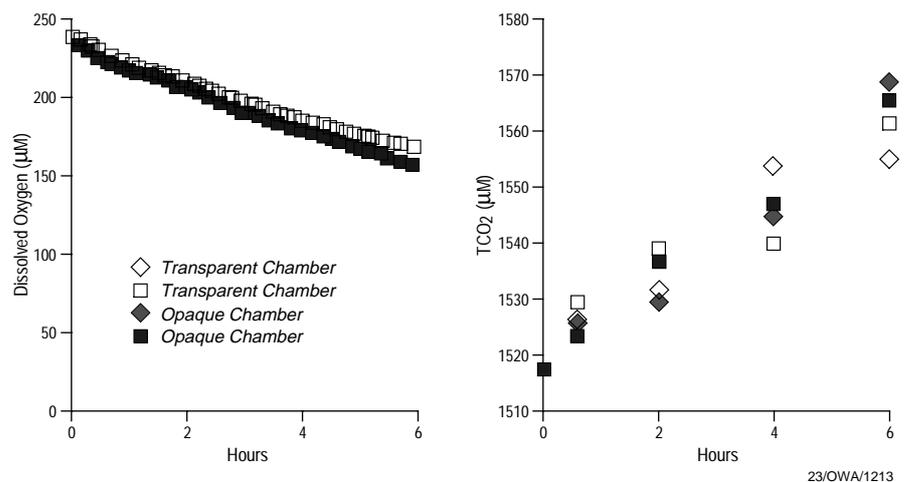


Fig. 6. Variations in dissolved O₂ and TCO₂ concentrations during a 6-hour benthic chamber deployment in November 1997. The diminishing O₂ concentration correlates with MPB respiration in each chamber, and shows no differences between the oxygen fluxes in the clear and opaque chambers.

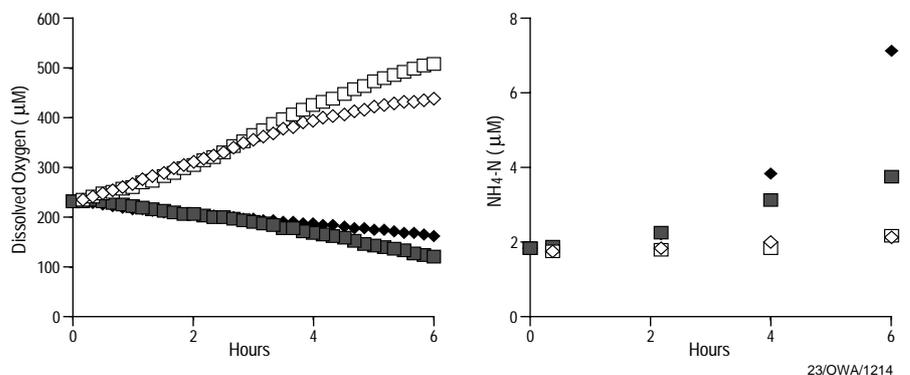


Fig. 7. Changes in dissolved O₂ and ammonia concentrations during a 6-hour benthic chamber deployment in May 1998. The increasing O₂ concentration in the transparent chambers correlates with net MPB photosynthesis.

Table 1. Nutrient fluxes for Wilson Inlet

	TCO ₂	O ₂	TN	DIN	NH ₄ ⁺ -N	PO ₄ -P	SiO ₄ -Si
Median benthic flux (mmol m ⁻² day ⁻¹)	26.0	-27.5	-	1.72	1.1	0.002	4.8
Annual benthic flux (t)	-	-	-	422	267	1	2400
Catchment loads (t)	-	-	210	43	11.6	6.1	-

they were active and nutrients were abundant, they transferred N and P from the water column to the sediments. In summer (when they were shaded), sediment diagenesis released these nutrients to the water column, fuelling phytoplankton production. Thus the MPB provided a mechanism for maintaining high nutrient concentrations and phytoplankton production in summer. Removing the MPB from the model reduced both the sediment-water fluxes and phytoplankton production in summer.

In Wilson Inlet, water clarity and MPB activity are lowest in winter, when nutrients are entering the Inlet from the catchment. MPB primary production begins in January, after the spring phytoplankton bloom. Thus, the MPB do not provide a mechanism for the temporary storage of nutrients and release of winter nutrients. Rather, they appear to be most active at times of low nutrient concentration, and probably compete with phytoplankton and other primary producers for nutrients. The absence of MPB in this system in summer would increase the flux of nutrients to the water column and may enhance primary production by phytoplankton. Maintenance of benthic production may therefore be critical to ensuring low levels of phytoplankton and macrophyte production in summer and autumn.

Conclusions

According to benthic fluxes measured in Wilson Inlet between November 1997 and February 1999, sediments are a major source of NH₄⁺-N: the annual flux of ammonia greatly exceeds the annual input of all forms of nitrogen from the catchment. In contrast, fluxes of PO₄-P from the sediments are low, and the sediments appear to be an effective trap for PO₄-P under oxic conditions.

MPB are active in summer and autumn, when the water is clear and nutrient concentrations are low. MPB primary production greatly reduced the measured NH₄⁺-N flux from the sediments during these seasons, and may therefore play an important role in maintaining low levels of primary production in the water column.

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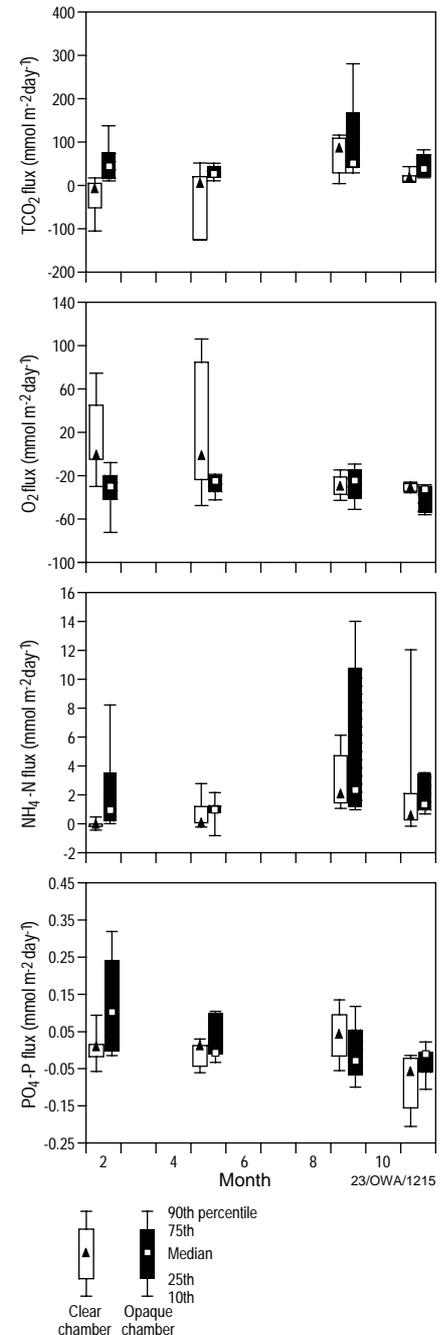


Fig. 8. Seasonal variations in metabolite fluxes from sediments.