2.2.12 The ecology and biogeochemistry of sandy sediments in the warm temperate coastal waters of Western Australia

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Executive Summary

Benthic microalgae (BMA) are a major source of primary production in shallow coastal waters and play an important role in the cycling of organic matter. The biomass and functioning of the communities of BMA and associated organisms can be affected by wave and current disturbance. This thesis tested a conceptual model that proposed that 1: the biomass of BMA was inversely proportional to the level of disturbance by waves and currents and 2: the increased BMA biomass would increase the capacity for uptake of inorganic nutrients. A suite of pigment and lipid biomarkers and other sediment properties were used to characterise the sediment organic matter and communities of BMA and other microbes. Fluxes of oxygen, N_2 fixation, denitrification and inorganic nutrients were measured in ex-situ incubations to document how these processes respond to changes in the physical and chemical environment.

The effect of depth was measured at 1.5m, 4m, 8m and 14m along triplicate transects.

The 1.5m sediments were markedly different from the other depths; there was frequent wave disturbance and BMA biomass was around 50% of the other depths. The bacterial fraction of the community was significantly less than the other depths. Inorganic nutrients were released in the light and taken up in the dark; around half of the dark uptake at 1.5m could be attributed to diatoms. The net fluxes of inorganic nutrients were not significantly different to the other depths. The deeper depths were strongly autotrophic, biomass was around 88 $mg.m^{-2}$ chlorophyll a and net primary production (NPP) was 2.4 mmol O_2. $m^{-2}.h^{-1}$.

The extensive shallow coastal waters of Western Australia (WA) are oligotrophic, warm (16° to 24°C) and subject to a seasonal pattern of greatest swell activity in winter and mainly smaller, wind-generated waves in summer. There is also a wide spectrum of exposure to swells along the coastline which varies from being open to the Indian Ocean to fringed by reefs and islands. A survey was made of sediments at paired sites, exposed and sheltered by sea walls, at 3 times of year. NPP ranged from -0.39 to 2.51 mmol $O_2.m^{-2}.h^{-1}$. Shelter resulted in increased biomass and elevated rates of NPP and community respiration (CR); though there were no consistent differences in the fluxes of inorganic nutrients. CR increased between cool and warm times of the year by around 100%. N_2 fixation was an order of magnitude smaller than DIN (NH_4+NO_x) fluxes and could only be detected in warm months. Denitrification was of a similar magnitude to N_2 fixation, measurable on all 3 occasions and 6 locations.

Experiments were conducted to examine the effects of shelter and of nutrient enrichment of the water column. After ten days, BMA biomass had increased by around 30% due to shelter, but enrichment had no additional effect. Bacteria and microheterotrophs also increased as a fraction of the community in response to shelter and to enrichment. Sheltered plots had elevated photosynthesis: respiration (P:R) ratios, enrichment resulted in larger ratios. Neither shelter nor the decrease in the N:P ratio stimulated N_2 fixation; there were no significant changes in fluxes of inorganic nutrients.

The resuspension of sediments by waves was simulated by raking. There was a loss of biomass in response to raking, and an increase in the ratio of heterotroph to autotroph biomarkers, suggesting that bacteria were more susceptible to removal and damage by resuspension than were BMA. Raking did not result in any significant changes in the sediment-water exchanges of inorganic nutrients.

Only the first part of the proposed conceptual model proved to be correct in these sediments. Disturbance by waves was responsible for removing biomass; but changes in BMA biomass resulted in little or no significant change to sediment-water exchanges of inorganic nutrients. The balance between autotrophic and heterotrophic components of the microbial biomass changed with disturbance, optimising the use of resources in these oligotrophic waters.

Changes in the sediment microbial community and nutrient cycling along a depth gradient in oligotrophic warm temperate waters

The microbial communities of coastal sandy sediments are often highly productive, sometimes containing more biomass than the water column. The composition of benthic microalgae (BMA) and bacteria in sediment communities become less autotrophic with water depth. As depth increases, the 2 gradients of decreasing levels of light and hydrodynamic energy have opposing effects on autotrophic biomass and sediment ecology. Many studies of sediment biogeochemistry and ecology have been conducted in eutrophic cool temperate conditions. In clear, warm temperate waters, the depth-related gradients of energy operate over very different spatial scales.

Three replicate transects were sampled at 4 depths down a subtidal sandbank in Cockburn Sound, Western Australia (WA); at its shallowest, 1.5m, then 4m, 8m and on the flat at its base at 14m. Sediment cores were collected for ex-situ incubations to measure fluorescence, fluxes of oxygen and inorganic nutrients, N_2 fixation and denitrification. Sediments were analysed for granulometry, pigments, fatty acids, neutral lipids, and organic C and total N. The sediments could be classified into 2 functional zones based on depth: 1.5~<4, and ≥4m. At 1.5m there was a chl *a* concentration of 42.3mg.m^{-2}, wave disturbance was the dominant influence on the sediment biota, and on nutrient processing. The 1.5m sediments were net heterotrophic, with bacterial activity apparently fuelled by BMA photosynthates; there were effluxes of inorganic nutrients in the light and uptake in the dark. The ratio of bacterial: BMA biomass increased with depth, but the P:R ratio was around 2 for all the other depths. The 2 intermediate depths had greater amounts of BMA biomass, 88.4 mg.m^{-2} and 87.6 mg.m^{-2} respectively and greater primary productivity of up to 2.38 mmol O_2. m^{-2}.h^{-1}. The BMA at 4m and 8m also supported a conspicuously large biomass of herbivores (sand dollars). The 14m sites were on a depositional flat at the base of the bank, where chl *a* concentration was slightly lower at 74.7 mg.m^{-2}, and sediments were still net autotrophic, though the greatest bacterial biomass was recorded at this depth.

Fluxes of inorganic nutrients were dominated by NH_4, with a large uptake at 4m (539µmol.m^{-2}.d^{-1}, se 207 n=6) and efflux at 8m (1044µmol.m^{-2}.d^{-1}, se 753 n=6). Around half of the uptake in the dark could be attributed to diatoms. There was no N_2 fixation detected, and denitrification was only measured twice, at one site at 8m and at 14m; rates were less than 0.1µmol N_2.m^{-2}.h^{-1}.

The BMA community was dominated by diatoms at all depths, with around 10% cyanophytes and chlorophytes. The strong PAR climate and clear waters resulted in an important contribution by BMA to primary production beyond 14m. The discontinuity in most parameters at 1.5m suggested that wave disturbance of these sediments resulted in a dramatic shift in their ecology; biogeochemical modelling should not assume linear gradients of biomass and nutrient cycling in these shallow coastal sediments. Compared with areas with shallow euphotic zones, the sediments of Cockburn Sound showed shifts in community composition and ecology over large distances and depth ranges. Wave disturbance in the shallows significantly controlled biomass; there were high levels of biomass and productivity at deeper depths due to organic matter accumulation.

Benthic microalgae in subtidal sandy sediments: effects of seasons and exposure to ocean swells on microbial communities and nutrient cycling

The benthic microalgae (BMA) in subtidal sediments play an important role in nutrient cycling in coastal waters. Physical disturbance of the sediments by waves and currents reduces BMA biomass. On the West Australian coast, sediments are subject to a range of hydrodynamic conditions, due to a coastline that can be open or fringed by reefs and islands. There is also a strong temporal difference between frequent disturbance of sediments by large waves in winter and more stable conditions in summer. This study examines the effects of high and low levels of hydrodynamic energy on the sediment ecology at 3 times of year: August and December 2002 and March 2003. A suite of pigment and lipid biomarkers and other sediment properties were used to characterise sediment communities. A range of different fluxes: oxygen, N_2 fixation, denitrification and inorganic nutrients, were measured in ex-situ incubations. Sediment organic matter was mainly composed of benthic microalgae and bacteria, though relative proportions varied. Diatoms remained the dominant algae in all locations and at all times of year. Chlorophyll a (chl *a*) concentrations in the top 0.5cm of the sediment surface ranged from 5.43 (se 0.61, n=4) to 20.25 (se 15.76 n=4) $mg.m^{-2}$. The BMA contained between 2.4 to 14.5 times the chlorophyll a (chl *a*) of water column phytoplankton per square m. Chl *a* concentrations were always less at exposed sites than at the paired sheltered sites; the reduction was proportional to levels of hydrodynamic energy and ranged from 96% to 14%. Net primary production (NPP) ranged from -0.39 (se 0.27, n=4) to 2.51 (se 0.40, n=4) $mmol.m^{-2}.h^{-1}$, its magnitude was greater at sheltered than at exposed sites. Rates of NPP were comparable to sandy sediments elsewhere in the world, and fixed C contributed 175mg $C.m^{-2}.d^{-1}$ to the ecosystem. Despite this level of productivity, net (24 hour) nutrient fluxes between the sediments and water column were small, the largest inorganic nutrient flux was an uptake of 1.45 (se 1.22) mmol dissolved inorganic nitrogen (DIN).$m^{-2}.d^{-1}$.

Denitrification and N_2 fixation were minor fluxes of N, around 2 orders of magnitude less than DIN. No N_2 fixation was detected in August, which was the coolest sampling period. Sediments were usually a sink for DIN, a source for Si, the direction of P fluxes varied at different times of year. Different conditions of hydrodynamics, temperature and light resulted in large variations in the sediment metabolism and biomass, and the ratio of heterotrophs to BMA, particularly between winter and spring. The resulting fluxes of nutrients across the sediment-water interface changed relatively little. Across a range of conditions, the sediment community acted to minimise the loss of nutrients to the water column. Mainly via increases in the standing stock of BMA, the sheltering of subtidal sediments of coastal Western Australia increases the sequestering of nutrients into BMA and increases the supply of resources available to the food web.

The effects of shelter and enrichment on the ecology of subtidal carbonate sediments in the warm temperate waters of Cockburn Sound, Western Australia

Sheltered sediments often have greater biomass of benthic microalgae (BMA) than those that are exposed to waves and currents. Nutrient enrichment of the water column can also increase biomass in the sediments; and if the enrichment results in N limitation, then N_2 fixation can be expected to increase. Increased water column stability and enrichment are conditions likely to co-exist in sheltered coastal waters, or in prolonged periods of calm waters. The coastline of Western Australia borders the Indian Ocean, and a series of islands, rocky reefs and subtidal sand bars provide sediments with variable degrees of shelter from swells. Summer in these waters is characterised by extended periods with small swells. An experiment was designed to test whether the sediments in oligotrophic waters of Western Australia would respond to decreased physical disturbance by increasing biomass, changing community composition; and whether decreasing the N:P ratio of the water column would stimulate N_2 fixation. Enclosures with 500 micron plankton mesh tops were used to examine the effects of shelter and enrichment on subtidal (7m deep) sediments in Cockburn Sound, Western Australia over a ten day period. Control plots were just marked with stakes (C), treated plots were either only enclosed (E), or enclosed and enriched with slow release N+P fertiliser (E+E). Concentrations of fatty acids, neutral lipids and pigments in the sediment were measured, and intact sediment cores were incubated to measure fluxes of oxygen, inorganic nutrients and N_2 fixation, at the start and end of the experiment. In-situ concentrations of inorganic nutrients were elevated in all enclosures, with greatest concentrations and the lowest N:P ratio, 4.46 (se 1.69), in the E+E treatments. Shelter resulted in a 30% increase in the biomass of BMA, and there was no evidence of an effect of enrichment on biomass. There was an increase in diatoms as a fraction of the BMA community, but only a very small increase of cyanophytes; the shift in the N:P ratio did not increase N_2 fixation over the 10 day period. The remaining biomass, bacteria and other heterotrophs, also increased in response to enrichment and shelter. Levels of net primary production (NPP) were high for oligotrophic sediments, up to 3.67mmol.m^{-2}.h^{-1} and community respiration (CR) ranged up to 3.06 mmolO_2.m^{-2}.h^{-1}. There was a correlation between NPP and the water column nutrient concentration; but accounting for CR, gross primary production increased by similar amounts in both enclosure treatments. Lipid biomarkers suggested that macrofaunal grazers that were excluded from the enclosures, such as sand dollars, were replaced by microheterotrophs. There were small changes in hourly rates of sediment-water fluxes of PO_4 and Si in response to shelter, but there was no net difference over 24 hours. Reducing bottom stress on these sediments caused an accumulation of labile organic carbon and little change to inorganic nutrient cycling. Sheltered sediments are likely to have an increased capacity for supporting grazers, including invertebrates and fish. With increased hydrodynamic energy, resuspension of previously sheltered sediments would be likely to result in a significant increase in water column biomass.

Scratching the surface: resuspension of subtidal sediments in Western Australia, effects on sediment ecology and nutrient cycling

The biomass of benthic microalgae (BMA) is reduced by the disturbance of sediments by waves, causing resuspension and cell damage. BMA can modify sediment-water fluxes of oxygen and nutrients in a number of ways. In a conceptual model of the sediments in Cockburn Sound, it was proposed that physical disturbance decreased BMA biomass and reduced the sediment uptake of inorganic nutrients. To investigate the effects of physical disturbance on the sediment community, a resuspension event was simulated by raking subtidal sediments. Concentrations of sediment pigments, fatty acids, neutral lipids, organic carbon and nitrogen were used to characterise the sediment community before and after the disturbance. Fluxes of oxygen, inorganic nutrients, denitrification and N_2 fixing capacity were measured by intact core incubations. The sediment community was dominated by BMA and there were strong correlations between the biomass of BMA and bacteria. Following the disturbance, concentrations of degradation products were similar to those found following a winter storm in nearby sediments. Raking resulted in a 41.5% reduction in chlorophyll a (chl *a*) concentration; lost by removal of, and damage to, BMA. Diatoms remained dominant, but a decrease in the fucoxanthin: chl *a* ratio, and in sediment sterol ratios suggested a possible change at the species level. The ratio of bacteria to BMA was decreased in raked relative to control plots, suggesting that bacteria were more susceptible to removal or damage. Net primary production (NPP) differed significantly from the start to the end of the experiment for unraked controls, but changed little in control plots. Rates of N_2 fixation were around 2 orders of magnitude less than DIN fluxes, and were reduced by raking. Raking resulted in greater uptake of Si relative to controls, most likely due to a reduction in sediment reserves. NH_4 uptake, the majority DIN flux by an order of magnitude, did not change. The resuspension associated with raking suspended sufficient chl *a* to raise the concentration of the 7m deep water column by 2.44µg.L^{-1} (171%), or 148µg.L^{-1} organic carbon. The study demonstrated that resuspension events were important in increasing water column productivity. Resuspension decreased benthic biomass, and controlled sediment microbial community composition in these coastal subtidal sediments in south west Australia. Apart from increasing the uptake of Si, a result contrary to the original proposition, resuspension did not significantly alter sediment-water fluxes of inorganic nutrients.

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Conferences/workshop attended

2005 Oral paper given at American Society of Limnology and Oceanography summer meeting

2004 Oral paper given at Australian Marine Sciences Association annual meeting

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2003 Presented paper at Phycological Society of America Annual Meeting

2002 Attended "Sediment biogeochemistry workshop" at Southern Cross University

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