14. BENTHIC NUTRIENT FLUXES

Fluxes of dissolved inorganic nutrients (NH_4, NO_2+NO_3, PO_4) from the benthos to the water column were estimated from the benthic nutrient release rates reported by Alongi (1989, 1990) and Capone et al. (1992). Given that relatively few measurements of benthic metabolism and nutrient release have been measured in GBR shelf waters, the available measurements, none of which were made within the defined boxes, have been extrapolated carefully. Alongi measured inorganic nutrient release rates from sediments collected at a number of sites along a cross-shelf line just south of the Tully box and within the adjoining Rockingham Bay. For the budget herein, near-shore (0-20 m water depth) nutrient excretion fluxes are calculated from the mean of excretion rates measured at two stations located off the mouth of the Murray River. These sites were deemed to be the most representative of inner shelf environments in the central GBR. Mid-shelf (20-30 m water depth) benthic excretion fluxes are estimated from means of rates measured at two sites located in the GBR lagoon immediately seaward of Hinchinbrook Island. Outer shelf rates are taken from the means of excretion rates measured at two stations located between Otter Reef and Britomart Reef. Where possible, excretion rates are partitioned into time-averaged seasonal rates for the winter (April - September) and summer (October - March) periods (Table 30). No benthic metabolism and benthic nutrient release rates are currently available for sites in the Cairns box. It is unclear to what extent the Capone et al. (1992) measurements of NH_4 fluxes can be applied to inter-reefal sediments. The Alongi (1989) excretion rates are therefore used for both the Cairns and Tully boxes with the proviso that the Cairns box estimates are based upon data which may not be wholly representative of benthic conditions within this box.

Table 30. Daily benthic nutrient excretion rates used to estimate benthic nutrient recycling. Negative rates indicate net uptake by the benthos. Rates are derived from Alongi (1989 and 1990).

Depth	Ammonia		Nitrate+Nitrite		Phosphorus		Silicate	
Range	µmol m^{-2} day^{-1}		µmol m^{-2} day^{-1}		µmol m^{-2} day^{-1}		µmol m^{-2} day^{-1}	
	W	S	W	S	W	S	W	S
0 to 10 m	775	352	198	19	40	60	3420	3305
10 to 20 m	775	352	198	19	40	60	3420	3305
20 to 30 m	1212	1212	24	24	111	111	3435	3435
30 to 100 m	414	414	-36	-36	71	71	3378	3378

Estimates of annual benthic fluxes of inorganic nutrients to the water column are given in Table 31. No estimates are currently available for dissolved organic nutrient fluxes between the water column and benthos. Concentrations of DON and DOP in GBR shelf sediment porewaters are not greatly elevated (D. Alongi, pers. comm); therefore, it is likely that fluxes of DON and DOP from shelf sediments to the water column are not large. Where seasonal comparisons were possible within depth bands, the means of winter nitrogen excretion fluxes tended to be higher (2- to >10-fold) than summer excretion fluxes. This likely reflects greater denitrification activity in shelf sediments during the summer, though no direct denitrification measurements have been made to confirm this. This is in contrast to the situation in temperate systems where benthic nutrient N (and P) release fluxes generally increase with temperature (e.g. Nixon, 1981). Summer benthic phosphate excretion fluxes were higher in the summer than in the winter. There was little difference, however, between winter and summer silicate (Si) release fluxes.

Table 31. Estimated annual shelf-scale benthic nutrient fluxes for the Cairns and Tully boxes.

Depth Range	Area	Winter		Summer		Total Annual	% Total
		Release Rate	days	Release Rate	days	Flux	
	km^2	$\mu mol\ m^{-2}\ day^{-1}$		$\mu mol\ m^{-2}\ day^{-1}$		kmol	
Cairns box							
Ammonium							
0-10	377	775	153	352	212	72836	6.1
11 to 20	636	775	153	352	212	122875	10.3
21 to 30	856	1212	153	1212	212	378677	31.8
31-100	4068	414	153	414	212	614715	51.7
				Total		**1189103**	
Nitrate+Nitrite							
0-10	377	40	153	19	212	3826	-10.7
11 to 20	636	40	153	19	212	6454	-18.1
21 to 30	856	24	153	24	212	7499	-21.0
31-100	4068	-36	153	-36	212	-53454	149.8
				Total		**-35675**	
Phosphate							
0-10	377	40	153	60	212	7103	4.5
11 to 20	636	40	153	60	212	11982	7.5
21 to 30	856	111	153	111	212	34681	21.8
31-100	4068	71	153	71	212	105422	66.2
				Total		**159188**	
Tully box							
Ammonia							
0-10	310	775	153	352	212	59892	3.7
11 to 20	535	775	153	352	212	103361	6.5
21 to 30	1306	1212	153	1212	212	577748	36.1
31-100	5675	414	153	414	212	857549	53.6
				Total		**1598551**	
Nitrate+Nitrite							
0-10	310	40	153	19	212	3146	-5.8
11 to 20	535	40	153	19	212	5429	-10.0
21 to 30	1306	24	153	24	212	11441	-21.0
31-100	5675	-36	153	-36	212	-74570	136.7
				Total		**-54554**	
Phosphate							
0-10	310	40	153	60	212	5840	2.7
11 to 20	535	40	153	60	212	10079	4.7
21 to 30	1306	111	153	111	212	52913	24.5
31-100	5675	71	153	71	212	147068	68.1
				Total		**215900**	

Not surprisingly, when estimated benthic nutrient fluxes are weighed by shelf areas, the bulk of the shelf-scale benthic fluxes again occur on the outer shelf (water depth > 30 m). The highest area-specific rates, however, were measured on the mid-shelf. The relatively scant data available suggests that outer shelf sediments are a net sink for nitrate (negative excretion rates), while inshore sediments are a net source. It should be noted, however, that the net loss of inorganic nitrogen from the water column due to benthic nitrate uptake is less than 5 percent of net ammonium release from the benthos.

Area-specific particulate nitrogen and phosphorus deposition fluxes (Table 29) in the Cairns and Tully boxes consistently exceeded measured benthic release fluxes (Table 31) for these two elements. Seasonally averaged benthic nitrogen release fluxes were on the order of 1 mmol m^{-2} day^{-1}, while the majority of nitrogen deposition fluxes fell between 2.5 and 20 mmol m^{-2} day^{-1}. Maximal benthic nitrogen release fluxes were 2.5 mmol m^{-2} day^{-1} (Alongi, 1989). A similar discrepancy was also observed between measured phosphorus deposition fluxes and benthic phosphorus release fluxes. Most gross phosphorus deposition rates fell between 0.2 and 1 mmol m^{-2} day^{-1}, while time-averaged phosphorus release rates from the benthos ranged between 0.04 and 0.11 mmol m^{-2} day^{-1}.

The discrepancies between nitrogen and phosphorus deposition fluxes and measured benthic remineralization rates clearly indicates that the shelf benthos is a sink for carbon, nitrogen and phosphorus. Of these three elements, only phosphorus would likely accumulate over long periods in the sediment. The mean weight percent of carbon, nitrogen and phosphorus in sedimenting material from the Tully box moored traps (1.5, 0.8 and 0.07 % D.W.) are considerably higher than the organic carbon (0.2-0.4 % D.W.), N (0.02-0.12 % D.W.) and phosphorus (0.02 - 0.05 % D.W.) content of bulk shelf sediments collected away from the inshore zone (Alongi, 1989). The phosphorus composition of bulk sediment is closest to that of sedimenting material. Organic carbon and nitrogen can be converted to either gaseous or dissolved organic forms by aerobic and anaerobic metabolic processes (respiration, denitrification). Phosphorus, on the other hand, is readily adsorbed to particulate matter and converted to insoluble mineral phases (e.g. apatites) in carbonate sediments (Entsch, 1983; Froelich, 1988).

At present, there are no independent estimates available for either relative or absolute sediment and organic nutrient resuspension fluxes on the GBR shelf. It is quite clear that resuspension due to wind waves occurs on a regular basis in nearshore waters (< ca. 20 m; e.g. Oviatt and Nixon, 1975; Roman and Tenore, 1978) as almost all traps deployed in depths < 25 m collected significant quantities of terrigenous mud. Varying amounts of fine-grained carbonate muds were collected in traps deployed on the mid- and outer-shelf (depths 30-55 m). It is unclear, however, whether this outer-shelf inorganic material was resuspended from the inter-reefal benthos, or was transported laterally from reefs. Resuspension of mid- and outer-continental shelf sediments and organic matter has been documented in temperate shelf systems (e.g. Falkowski et al., 1983; Fanning et al., 1982). Resuspension is particularly pronounced during storm events (Fanning et al., 1982). The observed discrepancy between measured sedimentation fluxes and benthic nutrient release rates clearly points to the need to quantify rates and variability in resuspension and particle cycling processes in shelf waters.

Annual estimates of shelf-scale benthic nutrient releases estimated from Alongi's measured nutrient fluxes are given in Table 31. Ammonium is the principal form of inorganic nitrogen released from the sediments, with annual inputs to the water column of 1.2 and 1.6 x 10^3 Mmol from Cairns and Tully box sediments, respectively. Although the area-specific fluxes are highest on the inner shelf and in the GBR lagoon, over half of the total benthic flux came from the larger area of the outer shelf. Oxidized nitrogen ($NO_x = NO_2 + NO_3$) releases from shelf sediments are relatively small in comparison and restricted to the inner shelf. The outer shelf is a net sink for oxidized forms of nitrogen, with a net NO_x uptake equalling 5 percent of the NH_4 release flux.

The cross-shelf pattern of phosphate release from sediments differed from nitrogen. The highest area-specific release rates were measured on the middle and outer shelf (Alongi, 1989). Accordingly, over two-thirds of the estimated annual PO_4 release from shelf sediments is calculated to come from the calcareous outer lagoon and inter-reefal sediments located at depths greater than 30 m. The total estimated annual benthic PO_4 release fluxes for the Cairns and Tully boxes are estimated to be 1.6 and 2.2 x 10^5 kmol, respectively. The time- and area-

weighted benthic N/P ratios release for the Cairns and Tully boxes are 7.25 and 7.15 (atoms), considerably lower than the Redfield ratio for healthy phytoplankton. This low ratio would contribute to the apparent nitrogen-limited state of shelf phytoplankton populations by maintenance of water column DIN/DIP ratios conducive to nitrogen limitation.