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NUTRIENT LOADING TO THE GREAT BARRIER REEF REGION

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INTRODUCTION

Fundamental to effective water quality management is an understanding of the relationships existing between biotic and abiotic components of the aquatic environment. Such an understanding constitutes the basis for informed environmental management. The major components of the management process can be identified as follows:

1. Identify beneficial uses of the water body to be protected (includes ecosystem preservation).

2. Determine tolerance thresholds for physical, chemical and biological variables which are compatible with the protection of defined uses.

3. Set physical, chemical and biological criteria consistent with the maintenance of the desired condition.

4. Initiate management practices to control inputs of substances such that desired water quality criteria are maintained. Management can be achieved by:

   - diffuse source pollution control,

   - setting point source effluent quality standards.

Within the context of coral reef water quality management, the most important component of the management process is the determination of tolerance thresholds for physical, chemical and biological variables which are compatible with the preservation of the integrity of the reef ecosystem. Information as to the capacity of the reef system to tolerate changes in ambient water quality and the response of the system to such changes is thus required for effective water quality management.

Nutrients, principally nitrogen and phosphorus, are of particular significance with respect to water quality management, firstly because of their fundamental role in the functioning of biotic systems, and secondly, because concentrations and nutrient loads are susceptible to anthropogenic manipulation. Excessive nutrient input can result in severe degradation of the reef resource. In order to manage nutrient loading to reef waters such that the integrity of the reef system is maintained it is clearly necessary to understand the role of nutrients in ecosystem functioning and the relationships between concentration and biotic response. With this information tolerance thresholds can be deduced and nutrient loading from anthropogenic sources regulated accordingly. The biological significance of nutrient loading is, however, highly dependent on a number of factors, including nutrient mass, areal loading characteristics, the temporal distribution of loading, and the nutrient species. Consequently, in order to evaluate the significance of anthropogenic loading relative to natural loading in ecosystem function, information as to quantities, areal and temporal loading characteristics sinks, and the pathways of biological assimilation is required for each. Some aspects of th loading characteristics of respective sources will be discussed in this paper.

Nutrient Pools, Sources and Sinks

The major pools of biologically 'available' nutrients in the Great Barrier Reef region include:

- Water column
- Sediments (exchangable fraction)
- Biota
- Atmosphere (N only)

The absolute magnitudes of the different pools and the relative partitioning of nutrient masses between pools are unknown.

Nutrients are continually cycled within and between pools, and are also added to and lost fr the available nutrient pool. Nutrient sources and sinks include:

Sources:
- Mainland runoff
- Continental island runoff
- Atmospheric fallout
- Regeneration from sediments
- Continental shelf upwelling and oceanic intrusion
- Currents
- Point source discharges (sewage and industrial effluents)

Sinks:
- Sediments
- Biota
- Atmosphere (denitrification)

Nutrient inputs from the respective sources exhibit considerable variability with respect to the magnitude of input and the temporal and spatial distribution of input.

Temporal variations in loading may be considered in terms of short, medium and long term time scales. Factors responsible for variations in loading include:

Short term:
- Tides
- Wind (sediment resuspension; induced currents)

Medium term:
- Seasonal rainfall
- Seasonal runoff events
- Periodic oceanic intrusions
- Temperature induced variations in sedimentary remineralization
- Current changes

Long term:
- Climatic cycles
- Anomolous climatic events

Variations in loading in space may be attributable to the:

- Location of rivers
- Location of shelf water intrusions
- Location of nutrient rich sediments
- Flow paths of currents
- Location of point-source discharges

The quantitative significance and the biological significance of nutrient inputs from the different sources clearly vary both in time and in space. Any assessment of the significance of nutrients derived from anthropogenic sources must be made relative to natural loading characteristics applicable to the particular locality.

Few quantitative estimates of loading are available, although information as to the temporal and spatial distribution of inputs can be derived from climatic data, oceanographic data, etc, etc. Wolanski et al. (1988) detailed the occurrence of tidally induced localized upwellings of nutrient enriched waters on the upper continental slope of the northern Great Barrier Reef. The subsequent intrusion of the upwelled water to the Barrier Reef Lagoon through passages in the Ribbon Reefs supported productive meadows of the calcareous algal *Halimeda* situated several kilometres inshore of the reefs. It was estimated that suitable spring tides for upwelling may occur on 74 days in a year, and that the total N mass associated with the intrusions was 58 tonnes N year^{-1}. These upwellings are thus of regular occurrence and are o considerable local quantitative and biological significance.

Ullman and Sandstrom (1987) measured N and P fluxes from nearshore sediments of the central Great Barrier Reef Lagoon. Annual nitrate flux from 2000 km^2 of nearshore sediments was estimated as 26.6 - 50.4 x 10^5 tonnes N year^{-1} (as N). The riverine nitrate flux to the same area was estimated as 546 tonnes N year^{-1}.

However, comparison of N fluxes in terms of nitrate-N is not appropriate. Organic-N is the dominant N form in Queensland rivers, whereas nitrate is only a transitory form in the N cycle originating from the mineralization of organic-N. The quantitative significance of riverine flux with respect to the addition of biologically available N to the system in thus more appropriately expressed in terms of total N. A comparison of loads is further complicated by the fact that a significant proportion of the riverine organic-N input could be the N source for sedimentary nitrate-N production, and therefore on the basis of an annual budget considerable 'double counting' could occur. Evaluating the relative quantitative significance of the respective sources is therefore a difficult task. However, irrespective of the relative magnitudes of the inputs, a fundamental distinction between the two sources exists. Riverine flux constitutes the addition of nutrients to the available nutrient pool, whereas sedimentary flux constitutes flux between pools (the sediment and the water column). This distinction is of significance for management purposes as flux between pools does not affect the actual mass of the biologically available nutrient pool, whereas riverine flux does.

A practical example to illustrate the importance of the distinction can be found in the Peel-Harvey estuarine system, W.A. Massive algae blooms associated with P enrichment of the system have occurred in recent years. The immediate source of biologically available P is sedimentary flux. However, the increase in sedimentary flux responsible for elevating P concentrations in the water column is a result of an increase in the mass of the sediment P pool due to elevated riverine flux. Consequently, although an increase in flux between P pools in the immediate cause, the real cause is an increase in the P mass entering the system. Water quality restoration strategies are thus focussed on the actual origin of P in an attempt to limit the mass of the biologically available P pool, rather than attempting to regulate sedimentary flux to the water column.

The regeneration of nutrients from the sediment is clearly of vital importance with respect to ecosystem function. Sedimentary flux undoubtedly occurs over most of the Great Barrier Reef Region, although some spatial variability will occur as a result of differences in sediment type. It is therefore of high quantitative and biological significance over the entire reef region. However, sedimentary flux is dependent on the mass of the available nutrient pool, which is in turn determined, in part, by riverine nutrient flux. Riverine flux is thus a fundamental significance with respect to the nutrient dynamics of the system. Riverine flux is also of significance in that it is subject to anthropogenic influence.

Riverine Nutrient Flux

Nutrients derived from riverine sources are distributed widely in the Great Barrier Reef Lagoon. Wolanski and Jones (1981) and Wolanski and van Seuden (1983) have documented the considerable extent of freshwater influence associated with mainland flood runoff. The distribution of terrigenous sediments in the Cairns region of the Lagoon indicates dispersion across the width of the Lagoon (Wolanski et al., 1986). Consequently, although some attenuation of nutrient load will occur with distance from the source river, riverine flux is of high quantitative significance on a regional scale. However, the temporal distribution of flux is highly seasonal and episodic. As flux is correlated with discharge a high proportion of total annual flux occurs during a relatively small percentage of the time in association with major flood events. The hydrologic regime of rivers draining to the Great Barrier Reef region is such that more than 80% of the annual discharge may occur in less than 15% of the time. The temporal distribution of nutrient flux is therefore similar. Although episodic, the processes of sedimentation and regeneration serve to distribute biologically available nutrients, particularly phosphorus, throughout the year (Cosser, 1988). Consequently, despite irregular nutrient input to the system, the biologically available fraction, once in the nutrient pool, is available throughout the year.

The annual nutrient mass entering the Great Barrier Reef Lagoon from riverine sources cannot be estimated reliably. Cosser (1988) estimated the mean phosphorus input to the Cairns Section of the reef as approximately 9,400 tonnes, with a standard deviation of 4,700 tonnes ? These estimates were for stormflow input and probably represent in the order of 90% of the total annual load. For comparison, the annual phosphorus loading associated with the intrusion of nutrient enriched water in the same region, as described by Wolanski et al. (1988), is calculated as 153.4 tonnes. This estimate is based on a concentration of 0.3 μM PO_4 (9.6 mg P m^{-3}) and flow volumes given by Wolanski et al. (1988). While masses are ~~only~~ approximate, the relative magnitude of the different fluxes is evident. Other major nutrient sources to this region include atmospheric input and northerly flowing currents. The magnitude of these inputs cannot be estimated.

The quantitative and biological significance of riverine nutrient loading is considered to be high, and as such, perturbations to flux characteristics have considerable potential to affect the integrity of the reef system. It can be said with some confidence that riverine loading has increased over the past century as a direct result of European settlement. Numerous studies have proved increased catchment nutrient export as a result of clearing, and higher nutrient flux associated with agricultural landuse is well documented. Nutrient loading has increased, but by how much and at what rate is unknown. Of importance now with respect to future management is what is the current loading, and at what rate is it changing. Change may be considered as a warning sign which precedes resulting biotic manifestations; the ability to detect change is therefore an important management tool. Reliable estimates of current riverine flux are therefore required in order to provide a data base for future comparison.

Point Source Nutrient Inputs

Information relating to point source nutrient loading is relatively easily obtained. Loading per unit area tends to be high in limited areas, and is therefore of very high quantitative and biological significance on a local scale. However, relative to total regional loading, point-source discharges are quantitatively insignificant. Annual loading from a 3000 person discharge is approximately 2.1 tonnes P and 7.9 tonnes N, assuming 240 l person dy^{-1} and P and N concentrations of 8 and 30 mg/L respectively. Relative to estimates given above these values are negligible. However, discharge is continuous and nutrients are immediately available for biological assimilation. Consequently, a local productivity response may occur. Significant changes in the flora and fauna of coral reefs as a result of sewage discharges have been observed in a large number of cases. The potentially high local biological significance of point source nutrient loading means that careful management of discharges is required as considerable potential for degradation of the local reef resource exists.

Conclusions

Nutrient loading to waters of the Great Barrier Reef region in highly variable both in space and in time. This variability has significant ramifications with respect to management of the ambient nutrient regime. The management process, as outlined above, traditionally involves the determination of tolerance thresholds and the subsequent establishment of desirable water quality criteria. In the case of coral reef management, not only are tolerance thresholds quite unknown, but because of the variability in nutrient concentrations, just when and where criteria should apply is open to debate.

It is also apparent that nutrient load does not necessarily equate with ambient concentration. Changes in riverine nutrient flux may increase the mass of the biologically available nutrient pool, but because of the metering effect of sedimentary regeneration changes in ambient concentrations may not occur. However, as a result of the elevation in nutrient mass a productivity response may occur. Consequently, monitoring of concentrations need not necessarily reveal the changing nutrient status of the system, or the manifestations of such changes.

While a number of nutrient sources are identifiable, only two are potentially affected by anthropogenic activities to any great extent - point source discharges and riverine flux. The former is of high biological significance, but on a local scale. The environmental impact associated with such discharges is relatively easily managed, and as such small point source discharges are not seen as an immediate threat to the integrity of the Great Barrier Reef. Proper management is, however, required. Conversely, a very real threat exists from riverine flux. Quantitatively, riverine flux is possibly the largest source of nutrients to the Great Barrier Reef region and is of high biological significance throughout the region. Perturbations to flux characteristics may therefore have far reaching consequences on the reef ecosystem. Flux may have already doubled as a result of European settlement, and is very probably still increasing as a result of further clearing and intensification of agricultural practices. This poses a potential threat to the Great Barrier Reef, but we do not know the consequences of increasing riverine flux, or the threshold at which biotic manifestations become evident. These may already be occurring. The Crown of Thorns starfish infestations for instance, while not fully understood, could be a response to increased nutrient availability, and thus increased productivity and fecundity. We may simply be unable to relate the cause to the effect. In the absence of the necessary information for informed management, a conservative approach to the control of nutrient flux would seem appropriate.

References

Cosser, P.R. (1988). Phosphorus loading to the northern Great Barrier Reef from mainland runoff. In, Proceeding of a Workshop on Nutrients in the Great Barrier Reef Region. Ed. C. Baldwin. Great Barrier Reef Marine Park Authority, Townsville.

Wolanski, E., Drew, E., Abel, K.M., and O'Brien, J. (1988). Tidal jets, nutrient upwelling and their influence on the productivity of the alga Halimeda in the Ribbon Reefs, Great Barrier Reef. Estuarine, Coastal and Shelf Science 26, 169-201.

Wolanski, E., and Jones, M. (1981). Physical properties of Great Barrier Reef Lagoon waters near Townsville 1. Effects of Burdekin River floods. Australian Journal of Marine and Freshwater Research 32, 305-319.

Wolanski, E., and Jupp, D.L.B. (1986). Currents and coastal reefs. Oceanus 29 (2), 83-89.

Wolanski, E., and van Senden, D. (1983). Mixing of Burdekin River flood waters in the Great Barrier Reef. Australian Journal of Marine and Freshwater Research 34, 49-63.

Ullman, W.J., and Sandstorm, M.W. (1987). Dissolved nutrient fluxes from nearshore sediments of Bowling Green Bay, Central Great Barrier Reef Lagoon (Australia). Estuarine, Coastal and Shelf Science 24, 289-303.

TOLERANCE OF CORALS TO NUTRIENTS AND OTHER WATER QUALITY FACTORS

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In addition of plant nutrients to freshwater systems may result in entrophication which is associated with increased production of aglae and macrophytes, deterioration of water quality and reduction of resident species diversity. The relationship between water nutrient concentrations and effects on aquatic biota is complex, but has received increasing attention over recent years. Evaluation of such relationships for freshwater areas has resulted in the development of preliminary nutrient tolerances.

There have been few comparable investigations in marine areas and in particular, less in coral reef systems. With tourism increasing worldwide, such areas are likely to be subject to increased discharges of nutrient containing waste waters such as sewage and urban run-off resulting in higher nutrient levels in the ambient water. The value of the limited number of data sets available on the direct and indirect response of corals to this type of stress may be extended by collating and evaluating this information and utilizing some of the basic principles established regarding the effects of nutrient enrichment in freshwater systems.

The aims of this paper are to examine the principle effects resulting from nutrient enrichment in coral reef systems and derive relationships between nutrients and related water quality characteristics, and corals, for corals to this type of stress.

Nutrient enrichment of coral reef ecosystems results in increased primary production and biomass in both phytoplankton and benthic algal populations, affecting coral nutrition, growth and survival. Various water quality parameters have previously been shown to correlate with coral growth rate. Using these relationships, factor increases likely to cause 10, 50 and 90% reduction for corals of the great Barrier Reef have been calculated. Factor increases for 90% reduction are in agreement with those observed in other parts of the world. In addition, maximum tolerance levels for Great Barrier Reef corals based on a 20% reduction in growth rate have been derived. Phosphate levels are a sensitive indicator of nutrient enrichment, along with BOD and suspended particulate matter concentration, while the various measures of nitrogen are relatively insensitive. Improved tolerance definition may be obtained by more extensive biological, chemical and physical investigations of Great Barrier Reef waters.