TOLERANCE OF CORALS TO NUTRIENTS AND RELATED WATER QUALITY CHARACTERISTICS

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SUMMARY

The nature of eutrophication in aquatic areas is reviewed and the principle physicochemical and biological factors involved identified. In broad terms' the effects of nutrient enrichment in coral systems are similar to those in other aquatic areas with some specific unique features which apply to coral systems. Utilising the limited information available on local waters and coral systems elsewhere a preliminary set of tolerance levels in ambient waters have been developed.

INTRODUCTION

The addition of nutrients and associated substances to freshwater areas has been the subject of intensive investigations over the last 50 years. In Australia, Wood (1975) carried out an overall evaluation of the nature and extent of nutrient enrichment, often referred to as eutrophication, in Australian inland waters. Marine and estuarine areas in Australia and overseas are also subject to nutrient enrichment but have not been as intensively investigated as inland and freshwater bodies. However in many cases these 'water bodies have been seriously affected. For example in Australia many of the estuaries along the 'east coast are adversely affected and overseas the continental shelf off the north east coast of the United States, the Baltic Sea and the Black Sea are seriously enriched with nutrients.

With coral ecosystems only a limited range of data is available. However the value of this data can be extended by utilising the basic principles established on the nature of nutrient enrichment in inland waters. In this paper we will examine the principal features resulting from nutrient enrichment, collate the existing information available on the interactions with corals and finally suggest some tolerance levels for the relationship between nutrients and related water quality characteristics and corals.

DISCHARGES CAUSING NUTRIENT ENRICHMENT

A variety of discharges to aquatic areas result in nutrient enrichment, together with associated water quality problems. These discharges can be categorized broadly as

1. sewage discharges
2. water run-off
3. industrial discharges

Most information is available on sewage discharges since this type of discharge is more consistent in composition than water run-off and industrial discharges. These latter two tend to vary in nature with the different situations involved but often have a lot of similarities to sewage discharges. Table 1, from Arthington et al (1982), illustrates the water quality characteristics of wastewater from secondary sewage treatment plants.

Table 1 - Typical Composition of Secondarily-Treated Sewage Effluent'

Component	Concentration (mg/1) reported for plants throughout various countries	Concentration (mg/1) for plants in south-east Queensland
Suspended solids	20	18 - 23
BOD	12	12 -21
Dissolved oxygen	7.1	
Temperature	15"	
Chloride	62	56 - 85
pH	7.5	7.5 - 7.8
Total nitrogen forms	18 - 28	0.3 - 37
Total phosphorus forms	3.5 - 9.0	5.1 - 7.6
cu		0.029 - 0.040
Cd		0.003 - 0.007
Cr	0.05	
Hg	0.0013	0.0003 - 0.0007
Zn		0.17 - 0.90

* It should be noted that there can be substantial variations from these values depending on such factors as loading on the plant, type of plant, wastewaters received and so on.

From. considerations of the literature on water quality effects on aquatic ecosystems it can be suggested that suspended solids, BOD, chloride, total nitrogen forms and total phosphorus forms are' the most likely substances likely to adversely affect water quality and corals. Except in special circumstances these same parameters would be expected to be important in industrial discharges and water run-off. Chloride is different to the other parameters, here in that the salinity or chloride content, of a discharge may adversely alter the salinity in a coral reef area.

GENERAL BIOLOGICAL EFFECTS OF NUTRIENT ENRICHMENT

As nutrients are added to an aquatic area over time a gradual "ageing" of the body can be expected as illustrated in Figure 1. While this is more typical of freshwater lakes a somewhat similar process can be expected in coral reef lagoons and similar semi-enclosed areas. The classes oligotraphic, mesotrophic and eutrophic have been developed from freshwater lakes and have a related set 'of physicochemical and biological characteristics (Connell and Miller, 1984). However these terms are often used to describe oceanic and estuarine waters as well. In these situations different criteria would be expected to be applicable but the exact nature of those has not been' developed at present.

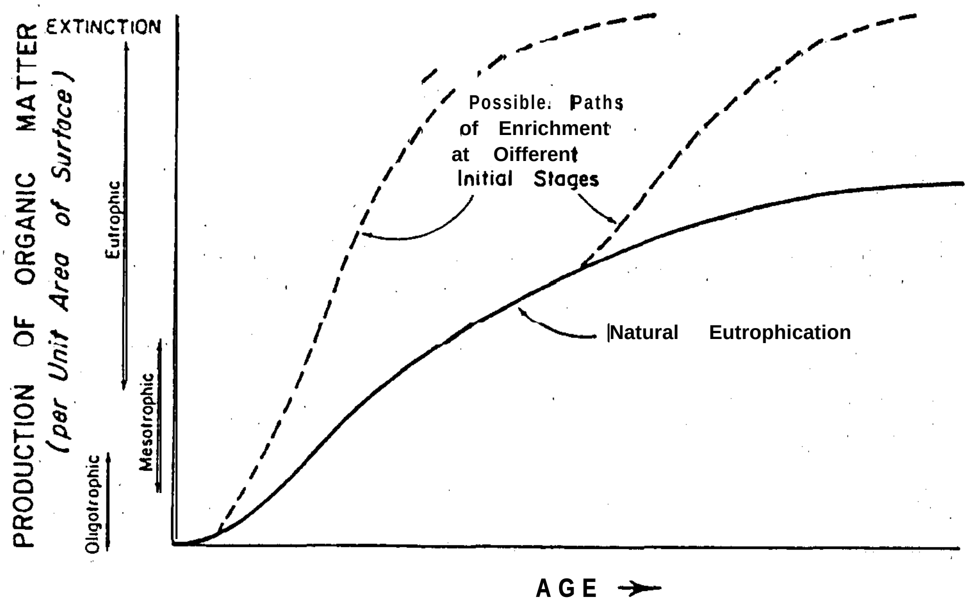

Figure. 1 . Hypothetical curve of the course of eutrophication in a water body. The broken lines show the possible course of accelerated eutrophication when enrichment from pollution occurs.

Table 2. Measure of eutrophication in a water body

1. Nutrient and associated ion concentrations in the water.
2. Total dissolved solids (specific conductance).
3. Dissolved oxygen status.
4. Standing crop (biomass).
5. Primary production.
6. Production/biomass ratio.
7. Transparency of the water.
8. Species diversity and types present.
9. Lake morphometry.
10. Sediment core analysis.
11. Algal bioassays.

Some of the characteristics used to measure eutrophication in aquatic areas are shown in Table 2 (Connell 1981). Many of these are applicable to coral reef systems. Some of the biological and physicochemical changes resulting from nutrient enrichment are shown in Table 3. It should be kept in mind that many of these features often exhibit seasonal patterns of variation which must be considered in making evaluations.

Table 3. Some biological and physicochemical changes which would be expected to result from nutrient enrichment of an aquatic area

Characteristic	Low Enrichment	High Enrichment
Total biomass	low	high
Number of species	high	low
Turbidity	low	high
Bottom sediments	coarse	fine
Primary production	low	high
Chlorophyll-a	low	high
Nutrient salts	low	high

EFFECTS OF WASTE.WATER DISCHARGE IN CORAL REEF ECOSYSTEMS

The 'harmful, effects of sewage are related to the capacity of the receiving waters to accept,; dilute and disperse the effluent: To some extent, its noxious. quality depends on the degree and extent of prior treatment, but treatment can give rise to sewage' sludge, which presents disposal problems of its own. Possibly the most well-known study on the effect of sewage on a'coral reef community is that of Kaneohe Bay, Hawaii. It is a partially enclosed embayment, 12.7 km long and 4.3 km broad, with an ocean frontage of 8.8 km on the north-eastern side of the island of Oahu. One portion of the bay was once known as the Coral Gardens, and before 1939, surrounding watersheds were dominated by rural and agricultural use. Since that time, however, the surrounding population has increased over tenfold, and sewage discharges into the bay increased, culminating in the construction of large sewage outfalls in the south-east sector of the bay in 1963 (Smith, 1977; Maragos, 1985; Banner; 1974). By 1977, the total sewage effluent volume totalled over 20 000 m^3 day^{-1}, with 95% being discharged into the southern section of the bay.'

Just after the Second World War, the most abundant coral species were reported to be Porites compressa and Mon'tipora verrucosa. Other corals of lesser importance included Pocillopora damicornis, Fungia scutaria, Cyphastrea ocellina, Leptastrea bottae, Pavona varians, and the ahermatypic Tubastrea aurea. Most, if not all, of the above genera are represented in the waters of the Great Barrier Reef. Available information, for Kaneohe Bay suggests that the most conspicuous effects of the sewage were in, terms of increased biomass and productivity, together with altered community structure (Smith, 1981). The sewage discharge was reported not to have markedly affected the pH, dissolved oxygen, or BOD in the bay away from the immediate areas of discharge. The most obvious changes to the once-living reef areas were the Toss of almost all living corals from the south-east sector of the bay, and the replacement of living corals by the alga Dictyosphaeria cavernosa in the central section. The' benthic fauna of the south-east section of the bay saw a dominance of filter and detrital feeders such as sponges, sea cucumbers, oysters and clams depending upon suspended organic material in the water. In addition, the bottom sediments were fine and black, with indications of anaerobic decomposition taking place near the surface. The reef flats had massive growths of algae, such

as Acanthophora, Graciliara and Hydroclathrus (but no D. cavernosa). In many' places, the old dead heads of Porites compressa were still present, though covered with fine sediment, together with sponges and sea cucumbers. Some coelenterate corals (e.g. Porites compressa) had been found extremely susceptible to increased phosphate concentrations so it is probable that the detergent phosphates in sewage effluent played an important role in reducing coral populations.

Sporadic outbreaks of phytoplankton concentrations known as "red tides" also became a feature of the bay. Average standing phytoplankton crops, as measured by chlorophyll a concentrations, increased by a factor of 1.56 in the south-east section, the site of the sewage outfalls, 0.38 in the middle bay, and 0.07 in the northern sector.

In 1977, 95% of the sewage that had previously been discharged into the poorly flushed south-east sector (residence time of the order of weeks (Maragos, 1985)), was diverted to an ocean outfall. This event presented investigators with the opportunity to confirm that the coral mortality evident was due primarily to the effects of sewage., and observe the recovery of the marine ecosystem. Recent surveys have revealed a remarkable recovery of corals, especially Porites compressa and Montipora verrucosa . In contrast, the alga Dictyosphaeria declined greatly, with decreases in deeper water appearing to be larger than decreases in shallow water. With sewage diversion, the biomass of both plankton and benthos decreased rapidly, although benthic biological composition has not yet returned to pre-sewage conditions, partly because some key organisms are relatively long-lived and partly because the bay substratum has been perturbed by sewage input, and acts as a reservoir of nutrients and organic detritus (Smith, 1981).

Localized pollution of coral reef areas at Aqaba on the Red Sea, as a result of sewage discharge and spillage of phosphate dust during loading of phosphate mineral onto ships, has also been reported (Walker, 1982). Effects were studied by comparison of an area nearby a sewage outfall with a control area some distance away. The region around the outfall had reduced water visibility, increased algal cover (mainly Ulva lactua and Enteromorpha clathrata), a corresponding increase in small, grazing

gastropod mollusca and the sea-hare Aphysia, and a decrease in coral diversity., Stylophora pistillata, was found to be 'the only remaining coral species. In the control area of: reef flat, approximately 50% of the surface was covered with living coral colonies. These were mainly Favia spp., Favites spp., Pocillopora danae, Seriatopora hystrix and some' Stylophora pistillata. There was only a limited algal, presence observed. Table 4'provides a summary of a comparison between the sewage - influenced and control area.

Table 4 - Levels of increase of related parameters from the sewage-influenced area compared to those from the control area, Gulf of Aquaba (a)

Factor	Level in sewage-influenced area / Level in control area
Rate of coral death	4.7
Density of sea urchins	3.1
Algal biomass	2.2
% Suspended sediment	4.3
Phosphate concentration	3.3

(a) From Walker and Ormond, 1982

Investigations in an adjacent area of the Red Sea by Fishelson (1973); affected by oil spills and phosphate dust spillages,, 'resulting in eutrophication of shallow lagoon waters of the coral region, revealed much the same trends. Between 1966 and 1972, the average number of total living coral colonies along a series of 10 m transects fell, from 541 to 195. Fishelson also found that the bush-like micropolypal branching forms, such as species of the genera Acropora, Stylophora and Seriatopora, are much more sensitive to severe ecological conditions than the brain-like macropolypal' species, such as those from 'the genera Platygyra, Favia,, Favites and Lobophyllia.

Nutrient content is a significantfactor in the response of corals to seawater containing variable dilutions of treated sewage. In experiments involving a

treatment plant utilizing raw sewage from metropolitan Miami, Florida, effluents were produced over a wide range of qualities using primary (filtered raw sewage), secondary (activated sludge) and tertiary (alum precipitated) treatments. Corals and other reef biota were maintained in an array of 350 l seawater tanks, and exposed to a continuous flow of effluents at each of the treatment steps, with and without chlorination, at dilutions with seawater of 1:30, 1:100 and 1:300. Preliminary results using the reef corals Montastrea cavernosa, Montastrea annularis and Dichocoenia stokesii as test specimens indicated that nutrient loading had the most pronounced effect on reef corals. Certain treatments and effluent concentrations greatly enhanced the growth of algae at the expense of coral. Coral morbidity and, mortality under those experimental conditions were thought not to be directly related to effluent toxicity, but the result of competition with algae for space, and especially light (Marszalek, 1981(a)).

Table 5. Summary of physicochemical and biological effects of sewage wastewater on coral systems

Characteristic	Change with increasing enrichment
biomass	increase
primary production	increase
coral numbers	decrease with Porites compressa among the most sensitive; numbers effective zero, in extreme situations
chlorophyll-a	large increase
filter and detritus feeders	large increase
benthic algae	large increase
sediments	medium size low in organic matter to fine and high in organic matter
sediment redox potential	high, with high dissolved oxygen in the interstital water, to patches with low oxygen arid some anaerobic areas
water characteristics	pH, DO, BOD, little affected
turbidity	increase
occurrence of blooms	large increase

Overall, the immediate effect of sewage input into coral reef systems would appear to be 'enhanced, nutrient levels and sedimentation rates. Subsequent effects include increased, primary, production and possibly decreased oxygen levels; , Because of' narrow environmenta. 'tolerances and immobility, corals are generally the most sensitive organisms in coral reef ecosystems to pollution including sewage. Table 5 presents, a summary of the physicochemical and biological effects of nutrient enrichment on coral systems.

WATER QUALITY ASPECTS OF NUTRIENT ENRICHMENT

Investigations concerning response of nutrient levels to sewage diversion in Kaneohe Bay ,are useful in assessing effects on reef systems. Pre- and post-diversion levels for various forms of nitrogen and phosphorous are in Table 6. Results show decreases in nitrate plus nitrite, phosphorous and ammonium concentrations, but an increase in dissolved organic nitrogen.

Table 6 - Pre- and post-sewage diversion nutrient levels In Kaneohe Bay (μg at l^{-1})[(a)]

Sector		North-west	Central	South-east	Ocean
Dissolved inorganic nitrogen					
Nitrate and nitrite	Pre	0.53	0.33	0.38	0.14
	Post	0.66	0.27	0.27	
Ammonium	Pre	0.57	0.60	0.77	0.47
	Post	0.43	0.38	0.51	
Dissolved organic nitrogen	Pre	4.4	4.50	5.4	4.5
	Post	5.1	5.7	6.2	
Particulate nitrogen	Pre	2.04	2.28	4.04	0.44
	Post	1.55	1.81	2.86	
Total nitrogen	Pre	7.5	7.7	10.6	5.6
	Post	7.7	8.2	9.8	
Dissolved inorganic phosphorous	Pre	0.23	0.26	0.48	0.13
	Post	0.11	0.09	0.15	
Dissolved organic phosphorous	Pre	0.27	0.30	0.33	0.30
	Post	0.15	0.19	0.24	
Particulate phosphorous	Pre	0.08	0.09	0.20	0.01
	Post	0.05	0.06	0.13	
Total phosphorous	Pre	0.58	0.65	1.01	0.44
	Post	0.31	0.34	0.52	

(a) From Smith et al., 1981

Past-diversion dissolved organic nitrogen levels are only slightly elevated over quoted oceanic' values, while the reverse is' true for dissolved organic phosphorous levels. On the basis of Table 6, it would seem that total phosphorous and nitrogen levels about twice background levels can cause phytoplankton growth and coral death. Levels, greater than this result in massive coral mortality (Smith, et al 1981).

A study of the phytoplankton community and water column chemistry in the bay, before and after sewage diversion, has shown that changes in total nutrient concentrations in the water cannot be accurately predicted without taking into account water-benthos interactions. The return towards oligotrophy of the system is relatively slow because of nutrient cycling between the sediments, benthic organisms and the overlying water.

The principal stresses on a reef community as a result of sewage discharges appear to result from elevated concentrations of plankton in the water. Thus various measures of plankton concentration such as chlorophyll a or adenosine triphosphate (ATP) levels may be more relevant towards judging the ecological impact of sewage than are inorganic nutrient concentrations.

In areas of the Red Sea near Aqaba where coral mortality due to the effects of sewage and phosphate pollution have been recorded, and phosphate levels (0.96 µg at 1^{-1}) were found to be over three times greater than in control levels (0.26 µg at 1^{-1}). Increases of nutrient concentrations, particularly phosphate, in this case by a factor of 3 over background levels, result in severe coral mortality (Walker, 1982).

Thus it can be suggested that nutrient enrichment of coral reef communities produces a variety of direct and indirect effects. At lower nutrient levels, say up to twice background levels, primary production of benthic algae is. enhanced.

Extremely high nutrient inputs causing levels three or more times normal. exert additional stress on reef-building organisms by promoting sedimentation and toxicity. High nutrient loading enhances planktonic primary production and leads to increased sedimentation of organic material.

The process of sedimentation also constitutes a significant stress on coral reef ecosystems. Sediment can arise from sources such as terrestrial runoff', dredging and sewage; Suspended solids in receiving waters for sewage' discharges originate 'from three sources: particles contained in, 'effluents, particulate organic matter produced by nutrient enrichment, and natural seston. The relative importance of these depends on wastewater treatment levels. This paper will not address this aspect, since it will be covered in other papers.

TOLERANCE OF CORALS TO NUTRIENT ENRICHMENT AND RELATED WATER QUALITY CHARACTERISTICS

Based on the work described previously it seems likely that nutrient levels (particularly total phosphorous) elevated to two or three times the normal ambient levels can cause increased primary production and biomass in both phytoplankton and benthic algal populations, affecting coral nutrition, growth and, ultimately, survival. Enhancement of nutrient levels by sewage discharges by a factor of 3 or more would appear to constitute a significant anthropogenic stress on coral reef communities. Therefore, enhanced nurient (nitrogen and phosphorous) concentrations can be used as an indication of detrimental effects of discharge, and as a preliminary estimate, levels should not exceed three times the normal (pre-discharge) levels.

Domestic sewage waste usually contains degradable organic materials derived from faecal and food wastes which require dissolved oxygen for efficient biological degradation. Receiving waters can therefore be severely depleted in oxygen, causing mortality to many sessile marine organims. Biochemical oxygen demand (BOD) is a commonly used criterion of effluent quality, and also suggests itself as a parameter which may be useful in assessing tolerances to sewage effluent. Although, in some instances, increasing BOD levels can be correlated with increasing stress symptoms on coral reef communities often there is no relationship. For example, studies in Kaneohe Bay showed that sewage discharge had not markedly affected dissolved oxygen or BOD outside the immediate areas of discharge, yet there was significant coral mortality away from the outfall (Banner, 1974).

The principal stresses on a coral reef community as a direct result of sewage discharge result largely from increased attached algal growth, localized dissolved oxygen depletion and in some cases elevated concentrations of plankton in the water. Where the latter factor is important varous measures of seston concentration may be the most ecologically appropriate and significant indicators of sewage impact, rather than inorganic nutrient levels. Based on investigations in Kaneohe Bay, Hawaii, Laws and Redalje (1979) ranked water quality parameters according to sensitivity toward eutrophication is shown in Table 7. The most sensitive indicator was chlorophyll a concentration, followed

Table 7. Relative sensitivity of water quality parameters as indicators of eutrophication in Kaneohe Bay[a]

Most sensitive:	Chlorophyll a
Sensitive:	Inorganic phosphorous
	Particulate nitrogen
	Adenosine triphosphate
Insensitive:	Secchi disc depth
	Particulate organic carbon
Very insensitive:	Particulate inorganic carbon
	Ammonium
	Inorganic nitrogen
	Nitrate and nitrite

[a] From Laws and Redalje, 1979

by inorganic phosphorous, particulate nitrogen and adenosine triphosphate (ATP) levels

To assess the effects of eutrophication from sewage waste on hermatypic reef-building corals, 14 environmental variables were monitored along a transect of seven locations off the west coast of Barbados. The physicochemical and biological data indicate that an environmental gradient away from the primary

sources exists as a result of eutrophication of coastal waters. Growth rates of Montastrea annularis, a principal reef-builder measured along this' gradient, exhibited high correlation. with a number of water, quality variables. Mean suspended particulate matter and volatile particulate, matter concentrations were the strongest estimators of growth rates, followed by chlorophyll a and BOD. The highest chlorophyll a concentrations occurred at stations off Bridgetown (which is served by activated sludge treatment plants) and tourist resorts, with a gradual decrease away from these sites. Volatile particulate matter concentrations and BOD levels showed a similar trend. However, dissolved oxygen levels were relatively constant, possibly due to efficient flushing and circulation.

Table 8. Regression equations for predicting coral growth rates (Y in cm yr^{-1}) from water quality variables[(a)] using transformed (log $(X + 1)$) data.

Suspended particulate matter (mg l^{-1})	$\log Y = -0.638 \log SPM + 0.760$	$r^2 = 0.79$
Volatile particulate matter (mg l^{-1})	$\log Y = -0.340 \log VPM + 1.670$	$r^2 = 0.79$
Chlorophyll a (mg m^{-3})	$\log Y = -0.863 \log CHL + 0.452$	$r^2 = 0.75$
BOD (mg l^{-1})	$\log Y = -1.368 \log 800 + 0.611$	$r^2 = 0.72$
Sediment organic content (%)	$\log Y = -0.169 \log ORG + 0.367$	$r^2 = 0.63$
Surface illumination (%)	$\log Y = 0.619 \log ILL - 0.701$	$r^2 = 0.56$
Inorganic phosphate	$\log Y = -1.940 \log PO_4 + 0.335$	$r^2 = 0.51$

Ammonium, Nitrate and Nitrite, Temperature, Salinity and Current Velocity all had $r^2 < 0.48$

[(a)] Tomascik and Sander, 1985.

Among the 'inorganic nutrients,. phosphate showed the strongest negative relationship with growth, followed by ammonium and nitrate plus nitrite concentrations. Table 8 presents linear regressions between transformed average

coral growth rates and environment variables, where the raw data is transformed by log (X +1).

The applicability of these equations to other coral reef areas and the sensitivity of coral to the more important of the parameters was assessed. The factor increase in concentration for 90%, 50% and 10% decreases in growth was calculated as in Table 9. Coral is clearly most sensitive to phosphorous and a 90% decrease in growth, probably effective death, is caused by an approximately three fold increase in concentration in accord with previous investigations.

Table 9. Factor increases over ambient for various proportions of growth inhibition with some water quality parameters[a]

Water Quality Parameter	% Growth Decrease		
	90	50	10
suspended particular matter	X 4.23	x 1.94	x 1.13
chlorophyll a	X 4.88	X 2.48	x 1.22
inorganic phosphate concentration	X 2.25	X 1.61	x -1.11

(a) derived from the equations in Table 8

It is arbitrary as to what decrease in growth rate constitutes an unacceptable stress but a 20% decrease is 'sometimes taken as a threshold level. Using this a c a t n f tolerance levels for vaious water quality parameters is set out in Table 10. In deriving these, some knowledge of the appropriate water quality parameters is required. Wolanski (1981) has 'found that total suspended particulate concentration along a cross-shelf transect from Cape Ferguson to Keeper Reef varied from 15 mg l^{-1} inshore to 3 mg l^{-1} at the mid-shelf Keeper Reef, assuming a particulate density of 1.5 g cm^{-3}. These levels were determined in mid-July, however, and it is likely that there is considerable variability during the year, with large increases inshore during the rainy season. The coral communities that exist across the shelf (i.e. outer shelf,

mid-shelf, fringing and inner shelf reefs) are all adapted to existence in environments of differing water qualities. For example, inner shelf reefs would be dominated by species capable of survival in turbid waters and efficient at sediment removal (Done, 1982). Based on this and Wolanski's data, it is suggested that suspended matter concentrations not to be exceeded for any extended-periods on mid-shelf and outer shelf locations be 3 x 1.28 or 3.85 mg l^{-1} (3.85 ppm). It should be noted that these values are based on limited data, and do not take into account natural temporal variation. More appropriate levels might be set by consideration of mean annual suspended solids concentration;

Chlorophyll a 'surface concentrations in local waters seem to be about 0.4 mg m^{-3}, compared to 0.13 mg m^{-3} in the Coral Sea (Andrews, 1982 and 1983; Ikeda, 1979). Again, values vary throughout the year, with a minimum in winter, and generally higher concentrations inshore, (Wolanski, 1981). Assuming a mean level of 0.4 mg m^{-3}, the maximum tolerable long-term concentration would be 1.48 x 0.4 or 0.59 mg m^{-3}. It is stressed however, that local variations of chlorophyll need to be determined before this parameter can be used, and that it may not be appropriate in all cases. There is little information available on background BOD levels in waters surrounding tourist facilities,' since it is a parameter primarily associated with sewage effluent and is often only measured, after discharge has commenced. Based on Barbadian water, the threshold for BOD levels is 1.19 x 0.71 or 0.84 mg l^{-1}. Both chlorophyll a and BOD would appear to be sensitive indications of eutrophication, particularly where receiving waters are partially enclosed, and ciruclation relatively poor.

For inorganic nutrients, average phosphate concentrations in local reef areas appear to be approximately 0.2 µg at l^{-1} (Kinsey, 1979; Andrews, 1983, while NH_4^+ and NO_3^- + NO_2^- concentrations average 0.17 and 0.34 µg at l^{-1} respectively. Tolerance limits then are 0.25, 0.65 and 1.31 µg at l^{-1}. From this data, nitrogen levels are relatively poor indicators of eutrophication, as also found by Laws (1979).

As a caveat, it should be remembered that these calculated tolerance limits are derived using data from one Barbadian coral genus (also present on the Great Barrier Reef), an arbitrary. stress limit, and limited local water quality information. Iniproved limit definition could be obtained by more extensive biological, chemical and physical investigations of local waters.

CONCLUSIONS

The derived long-term tolerance levels in ambient water below which minimal disruption to coral communities should occur are summarized in Table 10. The waste discharges considered are those effluents consisting principally of sewage although the ambient levels are probably applicable irrespective of source. These levels are conservative ones, since synergistic or additive deleterious effects are possible, but difficult to quantitate. It is also difficult to gauge the effects of natural stresses such as turbidity, temperature, salinity, borers and Acanthaster planci to coral ecosystems already stressed by waste discharges.

Table 10. Summary of derived coral maximum tolerance levels in ambient water[a]

Water Quality Characteristic	% increase over ambient levels	Quantitative estimate of tolerance levels
Suspended material	28	3.85 mg l^{-1}
Sedimentation rate		30 mg cm^{-2} day^{-1}
800	19	0.84 mg l^{-1}
Chlorophyll a	48	0.59 mg m^{-3}
PO_4^{3-}	23	0.25 µg at l^{-1}
NH_4^+	285	0.65 µg at l^{-1}
NO_2^- and NO_3^-	285	1.31 µg at l^{-1}

[a] derived on the basis of a tolerance of 20% growth decrease

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