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Analysis of a Blatant Reef Flat Degradation in La Réunion Island (l'Etang-Salé Fringing Reef)

PASCALE CUET[1] AND ODILE NAIM[2]

Abstract. Using a synthetised map of biobuilders' vitality, the incoming nutrient-enriched freshwater impact on benthic communities was assessed. A coral community survey was achieved in one rainy season. Reef water salinity and dissolved inorganic nutrient content were analysed during a rainy and a dry season. A high degree of coral mortality (90–100%) was found on the outer reef flat, where the dead substrate was covered up to 80% by boring sponges. According to hydrology and biological indicators, degradation may be attributed to an accumulation of organic matter, issued presumably from sugar cane refinery waste water. Inner Scleractinians are submitted to nutrient-enriched (mainly N) submarine groundwater discharge, but coral degradation (turf-coral concurrence) was only found along the inner edge of the reef flat, which further receives P coming from the necrotized area of the reef flat.

Introduction

Due to their proximity of the land, fringing reefs are susceptible to anthropogenic influence resulting from land use changes and industrial development. Today, little effort has been made to assess the impact of human disturbance on the coral reef communities, compared to the worldwide reefal degradation (Fishelson 1973; Banner 1974; Mergner 1981; Smith et al 1981; Pastorok and Bilyard 1985; Maragos et al 1985; Tomascik and Sander 1987; Jackson et al 1989; Brown et al 1990; Bell 1991, Done 1991). In this study, carried out on a small fringing reef subject to human influence (l'Etang-Salé, Réunion island), we propose to analyse potential sources of reef disturbance, distribution of benthic communities and type of coral degradation which may mirror the availability of essential nutrients and the pollutants distribution.

Site and Methods

The fringing reefs of the volcanic island of La Réunion (21°7'-19°40' south and 55°13'-61°13' east, western Indian Ocean; Fig. 1) were widely described by Montaggioni and Faure (1980). Rainy season (summer) is from November to April and dry season (winter) from May to October. The prevailing winds and waves in the region are from the south-east in winter. The tidal range is from 0.90 m (springs) to 0.10 m (neaps).

The reef flat covers 70% of the l'Etang-Salé reef area; it stands out at very low tides. The narrow back-reef zone called "Bassin Pirogue" provides a sheltered anchorage for the fishing boats, especially in its south-east part where the depth reaches 1.50 m. In 1983, a channel (4–6 m wide, 0.5–1 m deep) was opened up through the reef flat to facilitate fishermen to get out of the reef through the northern pass (Fig. 2). Localised freshwater springs are found in the southern part of the reef. Currents generated by the oceanic swell are especially strong on the southern reef flat. Water that flows across the reef crest enters the narrow and shallow back-reef zone, and creates strong longshore currents which rapidly exit the back-reef water through the northern pass *via* the artificial channel (Fig.2).

Mapping of dominant benthic communities was conducted during low tides (1986–87) using aerial

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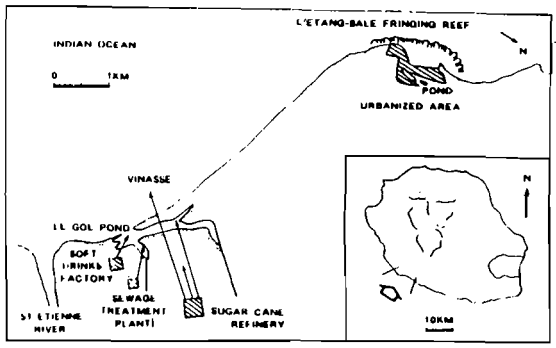


Fig. 1. Location map of l'Etang-Salé fringing reef and major point-source discharges of sewage south of the reef (from SIGH-SOGETI unpubl.).

colour photographs. Samples from surface reef water and freshwater springs were taken in January and February 1986 (rainy season), and from September to November 1986 (dry season). Salinity was determined using a Beckman salinometer. Ammonium analyses were performed within one hour. Unfiltered samples were either kept cooled at 4°C (reactive silicate) or frozen ($NO_3^- + NO_2^-$ and PO_4^{3-}) for later analyses. Analyses were conducted using standard manual methods (Aminot 1983). In addition, mean salinity on the reef flat (1991–92) was obtained from surface samples taken at regular intervals between high and low tide in April, July and December 1991, and February 1992.

Results and Discussion

Physiography of the reef

A zonation scheme (geomorphology and associated biota) is presented in Figures 2 to 7.

The outer compact reef flat. About 100m wide, the northern and southern parts of the outer reef flat are alive and prolific (sites **A** and **D**), while the central part (sites **B**, **C**, **F**, **G**) (250 m wide) is mostly necrotized. At site **A**, the biological communities are characterized by the abundance of encrusting hydrocorals (*Millepora tenera*), encrusting scleractinian corals (*Pocillopora, Montipora, Porites, Pavona, Platygyra* and other Faviidae) (75% coral coverage) and Alcyonarians (20% coverage). As a consequence of intensive wave action, deposits are reduced to small and thin sandy pockets, trapped in depressions. Densities of the sea urchin *Echinometra mathaei* are up to 30 ind./m^2, accompanied by *Stromopneustes variolaris, Diadema savignyi* and *Echinothrix calamaris.* At sites **B** and **C**, corals are still diversified (*Pocillopora, Montipora, Porites, Synarea, Pavona*), but small colonies (ϕ = 10 cm) cover only 10% of the necrotized reef flat. At site **B**, very dense populations of *E. mathaei* (> 50 ind./m^2) induce an intense lapiazation of the bioconstruction. A gradient of coral recovering is observed from site **C** to site **D** (10 to 75% coral coverage), but at site **D** the coral communities remain less abundant and diversified than at site **A**; at site **D**, 15% of the reef flat is necrotized; *E. mathaei* is also fairly abundant.

The inner compact reef flat (sites **E**, **F**, **G**). This part of the compact reef flat is constituted with *Porites lutea* mini-atolls (ϕ = 0.20–0.50 m), still connected to the solid substrate. From north (site **E**) to south (site **G**), the colonies become more and more necrotized. At site **E**, corals cover 80% of the substratum, 40% of them are dead and colonized by a sponge, *Cliona inconstans. S. variolaris* is abundant. At site **F**, the mini-atolls become coalescing (90% of the substratum) and present convoluted growth pattern and secondary rim development. Algal turfs invade this substratum and therefore, only 10% of *Porites* rims are still alive. At site **G**, a broad flat pavement, mainly composed with *Porites* mini-atolls surfaces that reveal few or no living polyps, is highly colonized by *C. inconstans* (80% of the substratum). No sea urchins are observed at both sites (**F** and **G**).

The coral strips zone. At site **H**, *Pavona* macrocolonies erect transverse strips, roughly perpendicular to the reef front; these strips alternate with relatively deep channels (1.50 m) where healthy *P. lutea* colonies can enlarge (ϕ = 1–1.20 m).

The scattered coral colonies zone. Fringing the internal part of the reef flat (sites **I**, **J**, **K**, **L**), scattered *P. lutea* micro-atolls (ϕ = 0.5–1.20 m) constitute a very particular facies. At the opposite of the mini-atolls lying at sites **E** to **G**, these broad micro-atolls lie loosely on sand. The concave nature of the tops of these massive corals is attacked by boring, grazing and encrusting organisms (coralline algae, sea urchins mostly *E. mathaei*, worms, sipunculids and bivalves). Most of these massive colonies margins are damaged by spots of mixed assemblages of algal turfs (particularly abundant at site **I**), or are coated with a thin layer of a soft Corallimorpharia *Rhodactis rhodostoma* (particularly at site **K**). Corals that occupyied the southern innermost built zone (site **M**) are small (ϕ = 0.20–0.40 m) and sparse. These branching and foliaceous Scleractinian colonies, dominated by *Pavona* and *Psammocora*, do not seem to suffer any mortality. Along the southern basaltic outcrops (site **N**), a community of *Acropora* (50% coral coverage in a sandy area) is characterized by a high vitality.

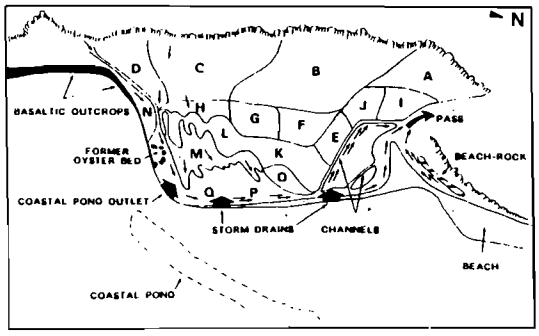


Fig. 2. Localization of the studied sites and hydrology on l'Etang-salé reef.

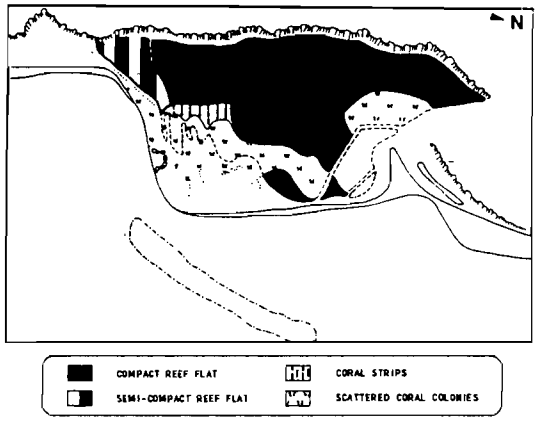


Fig. 3. Geomorphology.

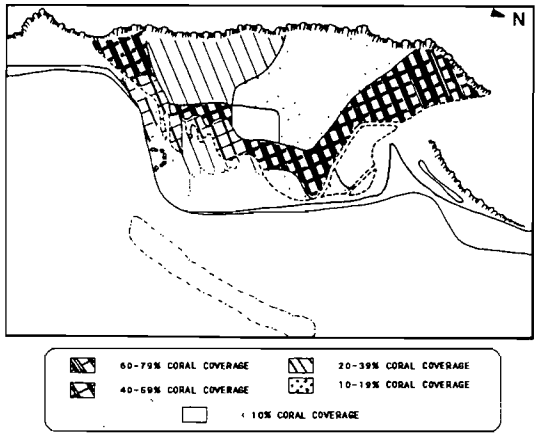


Fig. 4. Percentage of coral coverage.

0 300m

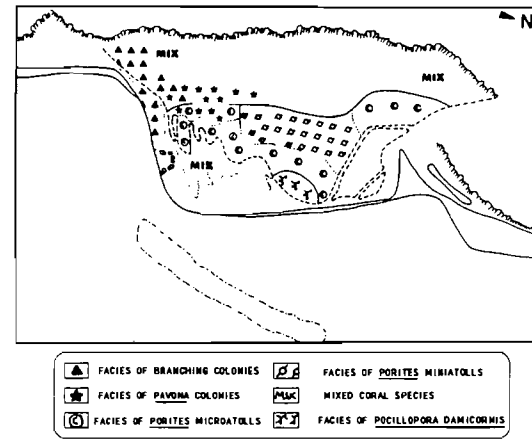


Fig. 5. Principal coral communities.

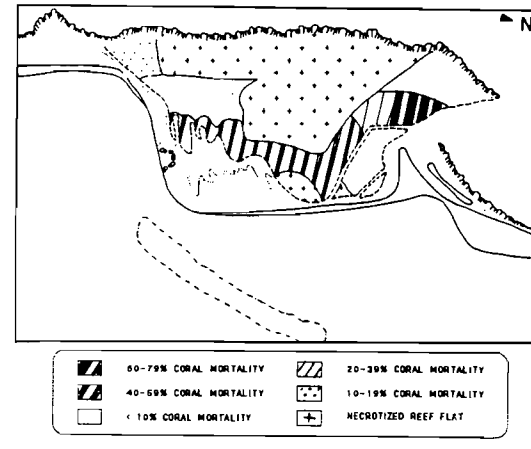


Fig. 6. Percentage of coral mortality.

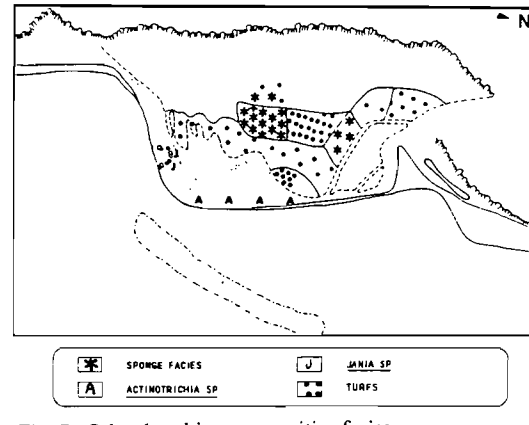


Fig. 7. Other benthic communities facies.

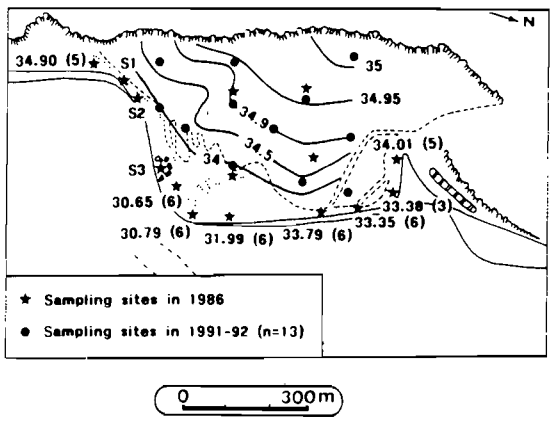


Fig. 8. Mean surface salinity (‰) isopleths on the reef flat from April 1991 to February 1992.
S1, S2, S3: spring mouths sampled in 1986.
Mean 1986 salinities (‰) in the back-reef zone are indicated (n in brackets).

The coastal compact reef flat. At site **O**, a shred of the compact reef flat is almost completely necrotized. In its northern part exposed to strong currents, along the artificial channel, the substratum is totally overlaid by calcareous red algae: sparse small colonies (ϕ = 10 cm) of *Pocillopora damicornis* colonize 10% of the substratum. In its southern part, *Pavona* is dominant (small colonies, ϕ = 10 cm), but the coral patches are surrounded by a thick algal turf (40% coverage) and fleshy algal thallus (*Boergenesia forsbesii*). Close to the channel, sea urchins are abundant (*E. mathaei* dominating, with *D. savignyi* and *S. variolaris*) while *Tripneustes gratilla* is abundant into the turfs.

The back reef zone. Site-attached benthic communities are sparse in this area. In front of the former oyster bed, the sandy area is colonized by *Jania* and *Ulva*. Along the beach (sites **P** and **Q**), *Actinotrichia* of about 10 cm thick, constitutes a carpet rich in Invertebrates.

Potential sources of disturbance

Potential sources of pollution onto the l'Etang-Salé reef include domestic sewage, groundwater discharge, storm drains effluent and industrial wastes. In 1986, sewage from the small city of l'Etang-Salé Les Bains (1,121 inhabitants) was still dumped on the land through suckwell systems and septic tanks, leaking from these into the groundwater. Groundwater nutrient enrichment may also occur through the addition of fertilizers on the watershed. Storm water comes from the main road which runs across l'Etang-Salé Les Bains, and from a coastal pond which discharge onto the reef during heavy rains (Fig. 2). In 1986, industrial wastes, mainly from a sugar cane refinery (equivalent to 275,000–425,000 inhabitants 100 days a year; D.D.A.S.S. unpubl.), were thrown up south of the reef either in the Gol pond, or directly at sea (Fig. 1). Organic wastes may be subsequently carried northward along the coast by nearshore currents (D.D.E. unpubl.), as confirmed by the presence of water jacinths (*Eichhornia crassipes*) issued from the Gol pond on the l'Etang-Salé reef flat.

Further disturbance comes from silting-up which is likely due to sand extractions south to the reef and to beach erosion following the construction of the walls surrounding the houses built on the beach (Masson unpubl.). Storm drains also tip out terrigeneous materials in great amounts onto the reef (Faure 1982).

Submarine groundwater discharge

Salinity decreases to 8.0‰ during the rainy season and 9.5‰ during the dry one in the spring mouths (Fig. 8). According to dominant currents (Fig. 2), "freshwater" from these submarine springs mixes with superficial oceanic water (35.2‰; Gamberoni et al 1984) from the reef front while flowing north along the beach; this results in a salinity gradient on the eastern shore. However, further groundwater discharge occurs along the beach, as shown by the secondary salinity minimum observed on shore in the northern cove of the reef. Because of dominant currents, only inner coral communities (in particular sites **K, L, M, N**) are notably affected by freshwater discharge. In the south-western part of the reef, the shape of the salinity isopleths is probably related to a strong outgoing current observed during southeasterly trade winds.

Further evidence of submarine groundwater discharge into the back-reef zone comes from the strong negative linear relationship observed between **reactive silicate** content and salinity of the reef water samples (Fig. 9a and 9b). A seasonal variation in the groundwater silicate content probably occurs, as the ordinal intercept ($\pm$ standard error) obtained from the regression shown on Fig. 9a (rainy season) is clearly lower (495 $\pm$ 17 μM) than the value obtained from the dry season samples (696 $\pm$ 13 μM; Fig. 9b). The dry season value agrees with freshwater measurements made in the vicinity of the reef (698 μM on average during September 1986; Grunberger 1989), but adding the three samples from the S3 spring mouth results in some curvilinearity in the dilution curve (Fig. 9b). Such a change in gradient resulting in two lines of differing slope was attributed by Mackay and Leatherland

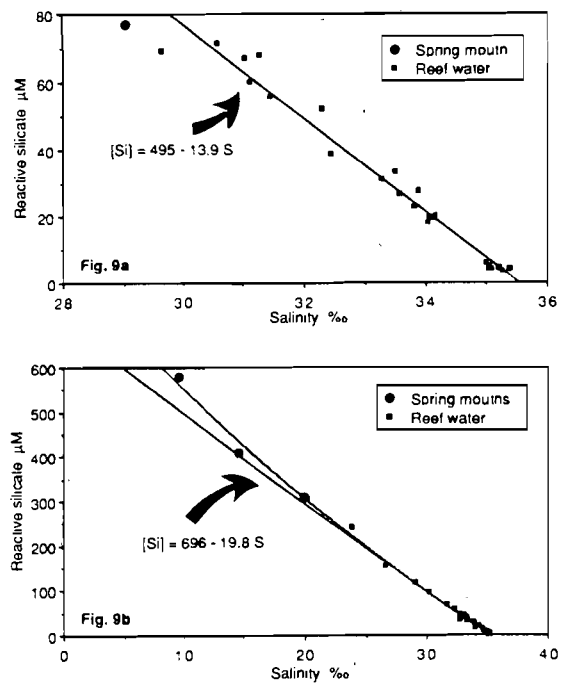


Fig. 9. Salinity vs. reactive silicate mixing diagrams. (a) rainy season. (b) dry season. Regression lines: reef water samples only.

(1976) to the inflow of two distinct silicate point sources. Alternatives are possible such as a variation with time (D'Elia et al 1981) in the groundwater silicate concentration. Benthic nutrient sinks or sources are unlikely to be significant in the case of silicate (Smith et al 1984; Ullman and Sandstrom 1987). Behaviour of silicate during estuarine mixing may be non-conservative (Liss 1976), but non-biological removal of dissolved silicon mainly occurs during the early stages of mixing (0–5‰).

Nutrient inputs through submarine groundwater discharge

During the dry season, groundwater discharge produces a significant enrichment of **dissolved inorganic nitrogen** (DIN = $NO_3^- + NO_2^- + NH_4^+$) to the back-reef zone (mainly as NO_3^-), as shown (Fig. 10a) by the linear relationship observed between DIN content and salinity of the reef water samples (D'Elia et al 1981; Lewis 1987). During the same period, groundwater NO_3^- content (0–1.6 mM) varies greatly in the vicinity of l'Etang-Salé reef (Grunberger 1989). However, DIN concentration of freshwater discharging onto the reef may be roughly estimated as the ordinal intercept value obtained from the regression shown on Fig. 10a (D'Elia et al

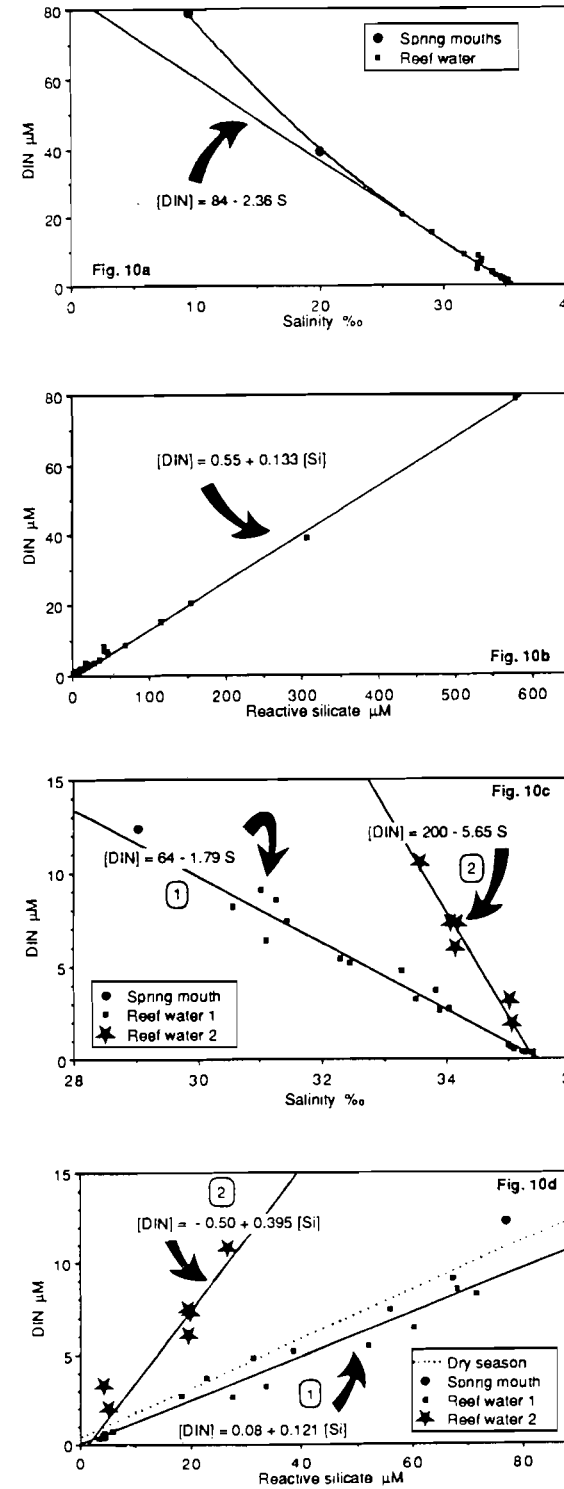
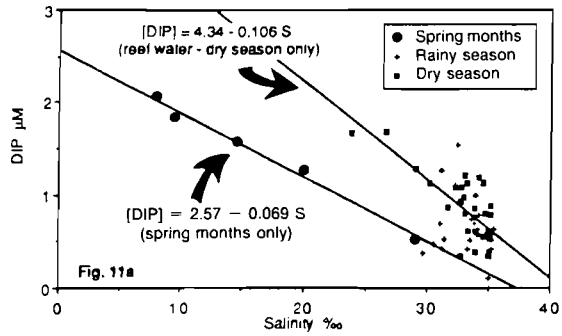


Fig. 10. Salinity (a and c) or reactive silicate (b and d) vs. dissolved inorganic nitrogen (DIN) mixing diagrams. (a) and (b) dry season. (c) and (d) rainy season. Regression lines: reef water samples only, except on Fig. 10b.



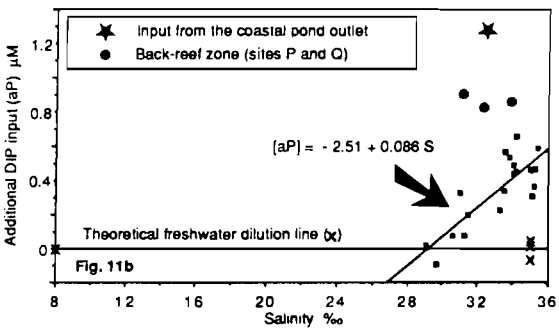


Fig. 11 a. Salinity vs. dissolved inorganic phosphorus (DIP) mixing diagram. "Rainy season" and "dry season": reef water samples only. The regression line obtained from the samples taken in the spring mouths is called "theoretical dilution line" in the text.

Fig. 11 b. Salinity vs. "additional DIP input" (aP) (rainy season only). For each of the samples, [aP] is obtained from

$$[aP] = [DIP]m - [DIP]th,$$

where [DIP]m is the measured DIP content; [DIP]th represents the potential input of PO_4^{3-} through the submarine springs, as calculated (using the sample salinity S) from the empirical conservative mixing line given by

$$[DIP]th = a + bS.$$

The conservative mixing line ([aP] = 0) is calculated from 3 samples showing a typical oceanic PO_4^{3-} content, and from the spring mouth sample showing the lowest salinity.

1981). This value (84 ± 3 µM) agrees with NO_3^- measurements reported for freshwater believed to be naturally N-enriched (Marsh 1977; D'Elia et al 1981). In St-Gilles La Saline (Réunion island), where we believe that freshwater nitrogen is mainly anthropogenically derived (Cuet 1989), mean groundwater NO_3^- content is notably higher (289 ± 74 µM during 1985–86). In Barbados, nitrate values as high as 779 µM were considered to be due to the heavy use of nitrogen fertilizers and to pollution accompanying urban development (Lewis 1985). As shown for reactive silicate, adding the samples from the S3 spring mouth results in curvilinearity (Fig 10a). Nitrate behaviour is conservative during estuarine mixing (Liss 1976). Neither benthic nutrient sinks nor sources can explain this change in gradient, as all data points fall on a straight line on the silicate vs. DIN mixing diagram (Fig. 10b). This suggests that a single water body discharges onto l'Etang-Salé reef, whose spatial variations (or time variations) in nitrogen and silicate content may be mainly controlled by hydrogeological factors such as evaporation (70–104 mm.y–1 at l'Etang-Salé; Grunberger 1989). During the rainy season, the salinity vs. DIN mixing diagram shows two distinct lines (Fig. 10c). The samples belonging to the regression 1 (ordinal intercept value: 64 ± 3 µM) and the single sample taken in a spring mouth virtually fall on the same line as during the dry season on the silicate vs. DIN mixing diagram (Fig. 10d), further supporting the assumption that variations in freshwater characteristics are mainly controlled by dilution and evaporation.

The DIN content of the six data points which fall substantially above the dilution line 1 (Fig. 10c) is significantly related to salinity (Spearman rank order correlation; $P = 0.005$). Most of these samples were taken five days after a cyclonic event, suggesting that groundwater DIN-enrichment occured in the vicinity of the reef through soil leaching by rainwater. Sources of DIN-enrichment may include NH_4^+ derived from terrestrial nitrogen fixing organisms and plant litter decomposers, domestic sewage and fertilizers (D'Elia et al 1981). Rainfall itself, although low in NO_3^- in La Réunion (Grunberger 1989), might significantly contribute to it.

No seasonal variation is detected in the groundwater PO_4^{3-} content, as all the samples taken in the spring mouths fall on a straight line on the salinity vs. PO_4^{3-} mixing diagram (Fig. 11a). Obviously, PO_4^{3-} does not have the opportunity to reach sorption equilibrium with the suspended solids and sediments, resulting in an unusual conservative behaviour (Mackay and Leatherland 1976). Thus, groundwater PO_4^{3-} content is presumably close to the ordinal intercept value obtained from the theoretical dilution line (2.57 ± 0.08 µM). This value is slightly lower than the mean groundwater PO_4^{3-} content (3.87 ± 0.36 µM) measured in St-Gilles La Saline (Cuet 1989). The groundwater PO_4^{3-} content was found to be distinctly lower (0.2 µM) in unpolluted areas (D'Elia et al 1981), while higher values (up to 27 µM) were attributed to an anthropogenic P-enrichment of freshwater (Marsh 1977; Lewis 1985). In the vicinity of l'Etang-Salé reef, Grunberger (1989) found higher values (13 µM on average) than ours. Such an apparent decrease in P (and N) content between the coastal water wells and the groundwater seepages was explained by nitrate

and phosphate reduction in the sediment (Lewis 1985).

Although they produce a limited enrichment of PO_4^{3-} to the back-reef zone, the submarine springs are obviously not the only source of PO_4^{3-} to the reef, as most of the reef water samples fall substantially above the theoretical dilution line (Fig. 11a). Yet the PO_4^{3-} content of the reef water samples is significantly related to salinity during the dry season (Spearman correlation; P = 0.001; Fig. 11a). The PO_4^{3-} maximum found in the back-reef zone corresponds to an intermediate salinity, suggesting that an additional input of PO_4^{3-} is occurring there through mixing of interstitial water into the water column (Knox et al 1981), or that freshwater discharging along the beach was further P-enriched in the vicinity of the reef. The *Actinotrichia* population (sites **P** and **Q**) might take advantage of the P thus supplied.

Additional nutrient inputs and nutrient export

During the rainy season, **DIN** content of undilute seawater (0.27 μM) is roughly determined as the intersect of the two mixing lines shown on Fig. 10c. The dry season value (0.94 μM) is obtained from the regression shown on Fig. 10b, assuming a seawater silicate content equal to 3 μM in winter (Anonyme 1986). DIN content of unpolluted superficial oceanic waters around Réunion island is not higher than 0.2 μM throughout the year (Leroy and Barbaroux 1980; Anonyme 1986). In agreement with observations of inorganic N export from coral reefs (Webb et al. 1975), the data, although unconfirmed, suggest that groundwater discharge is not the only source of N-enrichment to the reef. Algal turfs (Fig. 7) provide an optimal area for N_2 fixation and subsequent export (Wilkinson and Sammarco 1983). Although loss of fixed N may increase through denitrification as a result of the temperature increase, the DIN production rate is expected to be higher in summer (Hatcher and Frith 1985). However, DIN export is most significant in late winter on the l'Etang-Salé reef. At this time of year, an extra source of N was proposed to be ammonification of detrital macrophytes (Crossland et al 1984; Hatcher and Frith 1985), but macroalgae are missing on the l'Etang-Salé reef flat. In summer, net uptake of nutrients is likely to occur (Johannes et al. 1983) in the area of the back-reef zone colonized by *Actinotrichia* (sites **P** and **Q**). However, water renewal rate is probably not usually low enough in the back-reef zone to allow DIN concentrations to decrease in the water column (Hatcher 1985). Besides, N2 fixation is probably limited on coral reefs that are polluted with sewage or enhanced terrestrial runoff (Wiebe 1985). An alternative is possible, as DIN-enrichment is observed throughout the reef during the working period of the sugar cane refinery (August-December). Nitrogen thrown up at sea (540 kg TKN daily; D.D.A.S.S. unpubl.) is likely to be carried as far as the reef by nearshore currents (D.D.E. unpubl.), either as DIN or organic nitrogen. Mineralization of organic matter filtered from the sea water by sponges might contribute to the DIN-enrichment observed on the reef flat (Corredor et al. 1988).

During the dry season, the mean PO_4^{3-} content of undilute oceanic waters is obtained from the dilution line corresponding to reef water samples (Fig. 11a), assuming an oceanic water salinity of 35.2‰. This value (0.62 μM) is distinctly higher than the typical winter oceanic value (0.2–0.3 μM; Leroy and Barbaroux 1980). The lowest PO_4^{3-} concentrations (0.34 μM) are shown by a few samples taken on the healthy southern reef flat (sites **N** and **M**), suggesting that the P-enrichment of oceanic waters is occurring on the central reef flat (sites **B, C, F**; no samples taken in site **G**). This phenomenon is most obvious during the rainy season: most of the data points fall on a straight line on Fig. 11b (Spearman correlation; $P = 0.001$), where the additional input of PO_4^{3-} (calculated from Knox et al 1981) was plotted against salinity. Estimated P-enrichment of oceanic waters (about 0.52 μM) is twice as high as during the dry season (about 0.28 μM). Typical summer oceanic values (0.1 μM; Leroy and Barbaroux 1980) are found only on the healthy southern reef flat. Because of slow uptake of P, patchiness in P concentration over reef flats may be a result of spatial and temporal variabilities of P excretion from the benthos: high concentrations of P will occur where or when horizontal diffusion and advection of water are low and excretion of P is high (Atkinson and Smith 1987). As l'Etang-Salé central reef flat is almost wholly necrotized and miss a significant algal cover, assimilation may not balance anymore outward PO_4^{3-} diffusion through the reef framework (Andrews and Müller 1983) and PO_4^{3-} excretion from benthic invertebrates (Vink and Atkinson 1985), resulting in a net release of P. Water turnover time is likely to be of consequence (Hatcher 1985), as water renewal rate is low enough on the central reef flat, especially during calm summer periods, to allow PO_4^{3-} concentrations to increase in the water column. Bioerosion is likely to be enhanced (sites **B** and **G**), allowing P from the intersticial spaces to spread into the water. Even P trapped within the crystalline lattice of the carbon-

ates could be released by organisms that dissolve the carbonates (Entsch et al 1983).

Impact of disturbances on benthic communities

The reef flat. L'Etang-Salé benthic communities are not very diversified, except on the outer reef flat (sites **A** and **D**). We observe a total necrosis of the central reef flat (sites **B, C, E, F, G**). The high coral mortality observed cannot be due to a significant sea level shift, otherwise all the corals from sites **A** and **D** would have been killed while exposed at low tide. The shape of the mean salinity isopleths (Fig. 8) suggests that oceanic influence is maximal at site **B** (and **C** to a lesser extent). Besides, geomorphology suggests that water is ponded at low tide at sites **F** and **G** in broad shallow pools: in such pools, small thin micro-atolls can grow and coalesce to fill the pool with a flat coral pavement (Scoffin and Stoddart 1978); sites **F** and **G** match with it. Both sites are secondarily colonized by algal turfs. At site **G**, a bioeroder sponge (*Cliona inconstans*) invades almost all the substratum. Rose and Risk (1985) recorded a marked increase in the biomass of *Cliona delitrix* infesting a coral substrate on a fringing reef affected by the discharge of untreated fecal sewage. They suggest that the increase in bacteria biomass in reef waters is linked to an increase in sponge biomass at the polluted site. In order to assess the response of *C. inconstans* growth at site **G** to an eventual organic and bacterial loading of reef waters, we must consider the normal dietary habits exhibited by sponges in unpolluted reef waters: Reiswig (1971, 1975) demonstrated for sponges the dietary importance of non-discrete unresolvable particulate organic matter and bacteria. Decomposition of drift detritus is essentially a microbially-mediated process (Alongi 1988). The large biomass of *C. inconstans* at site **G** is then interpreted as a direct relationship with the amount of organic matter (Wilkinson and Cheshire 1988) which may derive with the steady current from southern industrial wastes. During low tides, organic matter is likely trapped at site **G** which may constitute a zone of maximum retention of organic pollutants. The absence of sponges on the outer sites **B** and **C** might be interpreted by the action of predators that find shelter in the slopes (Wilkinson 1987).

On the reef flat, algal biomass and macro-algal abundance are low. Experiments on microcosms showed that particulate organic loading shifts communities toward net heterotrophy (Smith et al 1981). Moreover, a review by Ogden and Lobel (1978) indicated that herbivory reduces algal biomass and shifts community dominance from macroalgae to turf. Sea-urchins are very abundant (>50 ind./m^2) on the outer sites (**A, B, D**). At sites **A** and **D**, coral coverage is high ($>75\%$) while at site **B** very low (10%). Assuming that there was a widespread death of coral colonies at site **B**, sea-urchins probably caused the desintegration of dead standing coral skeletons. Particulate organic loading and buildup of benthic heterotrophs favor eventually $CaCO_3$ erosion (Smith et al 1981).

The zone of scattered colonies. The inner micro-atolls of *Porites* (sites **I, J, K, L**) present degradation signs, while along the southern basaltic outcrops (site **N**), a community of *Acropora* presents a high vitality. Scleractinians from the southern innermost built zone (site **M**) do not either suffer of any mortality. Sites **M** and **N** are obviously subjected to a notable N-enrichment through freshwater inputs (up to 8.6 μM DIN at site **M**), while parallel P-enrichment remains limited. The vitality of the more fragile branching corals suggests that such a nutrient enrichment is not sufficient to cause coral degradation. The micro-atolls of *Porites*, damaged by turfs, are not only submitted to N-enriched groundwater discharge, but also to P export from the central reef flat, particularly in summer. This season was observed to be the keystone period in the strategy of coral overgrowed with turfs and algae on an eutrophised reef flat in la Réunion Island (Naim 1993). Atkinson (1987) suggested that increases in P concentration would raise the growth rate of algae that can retain or fix sufficient amounts of N, and this P concentration might regulate the species composition of the autotrophs. Thus, it is tempting to state that turfs are favoured by P export from the necrotized area of the reef flat. Moreover, silting-up of the back-reef zone occurs through beach erosion and increase in sand deposits due to the opening up of the artificial channel (Masson unpubl.). Run-off drainage systems are also contributing likely to the degradation of the inner built zone, through discharge of micro-pollutants issued from the urbanized watershed and terrigeneous materials. In this area, a branching coral community disappeared between 1981 and 1987 and the sites **I** to **L** were widely impoverished (Faure, comm. pers.). It confirms that micro-atolls of *Porites* would constitute a very specialized population which can survive in the more fluctuating environment of the near-shore zone.

The back reef zone. In this area, sea-urchins are lacking. N-enrichment through the submarine springs stimulates the growth of *Ulva* and *Jania* in front of the former oyster bed. Along the eastern shoreline (beach) it looks like that N- and P-en-

riched freshwater inputs favour the growth of a dense population of *Actinotrichia.*

Conclusion

The disturbance of the l'Etang-Salé fringing reef results in (1) concurrence between coral polyps, turfs and Corallimorpharia, and mortality of sessile reef organisms (2) invasion of coalesced coral colonies by biological competitors (sponges). In the first case, the local reef structure and topography may not be altered significantly. Thus, if environmental conditions become favourable, reef recovery is possible *via* newly settled coral and other invertebrate larvae. In return, at sites where coral colonies are coalesced and the substratum invaded with competitors, reef recovery would be highly problematic.

The present analysis may have implications for conservation management. Controlling further mortality requires, in practice, the minimization of deleterious anthropogenic inputs. The maintenance of a good reef environment leads to dominate (1) the direct pollution inputs (*via* sewage, storm and rain drains issued from an urbanized area) (2) the modification of the reef structure and environment (channels opening the reef flat, concrete structures on the coast, both altering the dynamics of the beach) (3) the far off pollutions which can, by their chronicity and their rule, modify the development and even the perennity of a whole reef. Hydrodynamic variations must inevitably complicate this scheme. The interaction of wind, tidal and shelf currents with coral reef geomorphology can create zones that can have high (or little) susceptibility to pollutant retention. Therefore, hydrography study appears to be one key aspect for reef management.

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