

*Chapter 7*  
General  
Discussion and  
Conclusions

## **7.1. Water quality and coral health at Porto Seguro reefs**

Coral reefs can be subjected to a wide range of stressors acting at different temporal and spatial scales. Kinsey (1988) categorised these as acute stresses (e.g. violent storms, freshwater inundation, outbreak of crown-of-thorns starfish - COTS) and chronic stresses (e.g. regular sediment input, sewage and nutrients, or the effects of tourism). He also noted that reefs recover quite rapidly from acute stress when it is the only predominant influence. Chronic stresses however, have an intense and prolonged impact by destabilising the community structure on the reef, and may also inhibit coral recovery after destructive events (Kinsey, 1988).

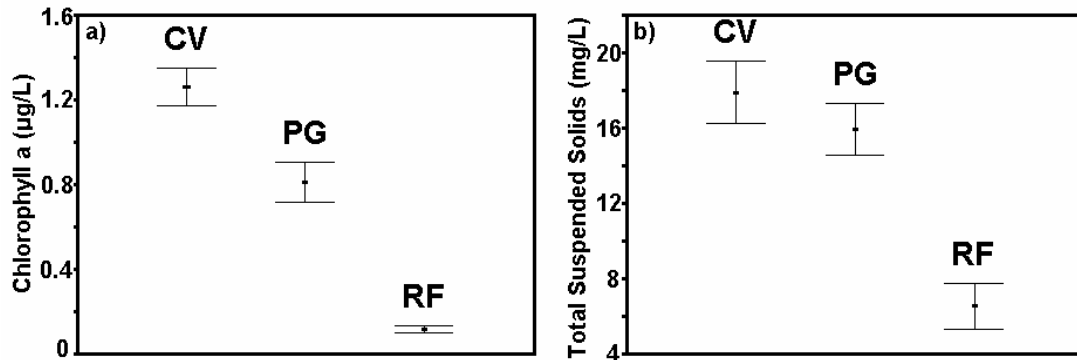
As the Brazilian coast is not affected by hurricanes, nor has infestations of COTS, the reefs are largely spared natural acute stresses that have key influences on Caribbean and Indo-Pacific reefs (Maida & Ferreira, 1997). Although the sea level variations during the last 8000 years has played an important role in defining reef structure and morphology (see chapters 1 and 2), all major stresses to the Brazilian reefs are related to human activities. These include sedimentation caused by up-stream land practises and extensive logging of Brazil's Atlantic coastal forest (Werner et al., 2000), overfishing (Rocha, 1997), tourism related activities (Leão, 1996) and nutrification (Costa et al., 2000).

### **7.1.1. Nutrification patterns and benthic community structure**

Although a large number of variables were determined during the current study, the lack of long-term data for comparisons preclude definitive statements on whether the actual state of the benthic community is being affected by nutrient inputs. Moreover, limitations of the dataset need to be appreciated when making inferences about the nutrient dynamics of the study reefs. Nevertheless, the results have demonstrated some clear patterns which can be linked with the benthic community structure, even though clearly correlation is not necessary causation.

### Spatial patterns

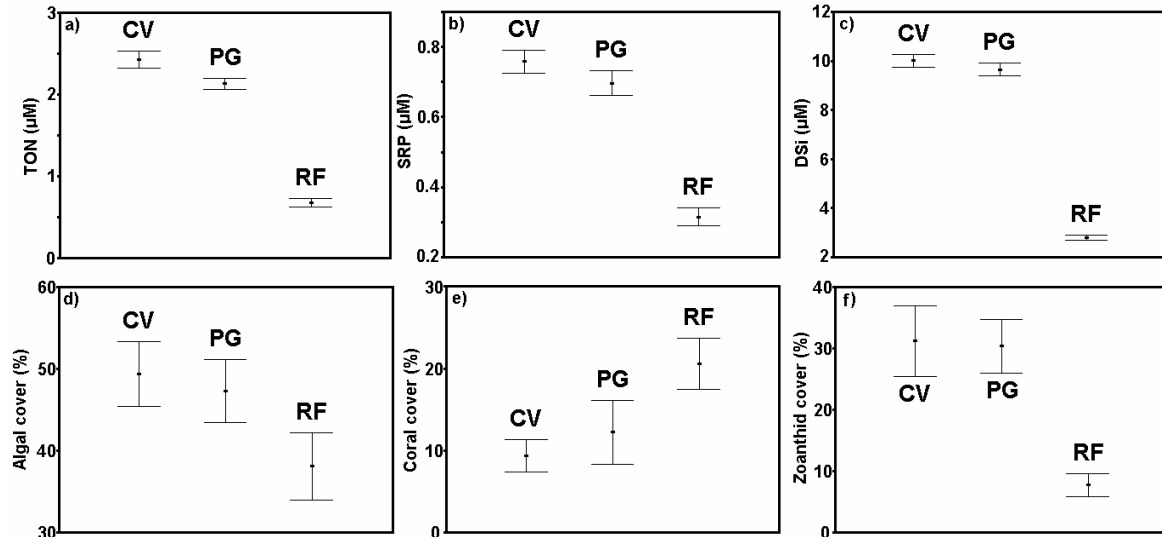
All measured parameters (chapters 4, 5 and 6) have demonstrated two patterns of spatial variation with different scales. The first pattern was a clear inshore-offshore gradient, with the offshore reef presenting four times less chlorophyll *a* concentrations and three times less suspended material than the nearshore reefs (Fig. 7.1).



**Figure 7.1.** Spatial variation of chlorophyll *a* and TSS concentrations measured at the water column in the study area. Bars represent mean and 95% confidence intervals.

All the physico-chemical parameters, except dissolved oxygen, demonstrated such a gradient. Higher temperatures in the nearshore reefs were expected, and are likely to be related with surface run-off, groundwater seepage, river discharge and the heating of shallow coastal waters. This hypothesis is strengthened by seasonal variations, with a decrease in temperature during the rainy season. A similar pattern was observed for salinity, which is also a good indicator of terrestrial contribution (Cuet et al., 1988). The data indicates considerable dilution nearshore, providing further evidence of significant terrestrial sources of freshwater.

Nutrient concentrations also decrease with increasing distance from the shore, reflecting terrestrial and nearshore sources of nutrients, both natural (rivers, mangroves and grass-bed detritus) and anthropogenic (wastewater seepage and agricultural run-off). The inshore-offshore gradient in nutrient concentration was negatively correlated with coral cover (Fig. 7.2). Such a correlation suggests that an adverse effect of nutrients may be occurring, especially because this gradient was positively correlated with percent cover of both algae and zoanthids (Table 7.1).



**Figure 7.2.** Spatial variation of nutrient concentration measured at the water column (a-c) and the major groups of benthic organisms (d-f). Algal cover includes fleshy, turf and coralline algae. Coral cover includes stony corals and hydrocorals. Bars represent mean and 95% confidence intervals.

**Table 7.1.** Pearson's product-moment correlation between measured parameters in the study area

	Chl a	TON	SRP	DSi	Algae	Coral
TON	0.801					
SRP	0.735	0.971				
DSi	0.806	0.980	0.950			
Algae	0.280	0.458	0.521	0.389		
Coral	-0.313	-0.450	-0.477	-0.389	-0.594	
Zoanthid	0.586	0.555	0.562	0.607	0.174	0.176

Many field and laboratory experiments have also reported detrimental effects of nutrients on corals (Banner, 1974; Smith et al., 1981; Walker & Ormond, 1982; Tomascik & Sander, 1985; Muscatine et al., 1989; D'Elia & Wiebe, 1990; Dubinsky et al., 1990; Stambler et al., 1991; Hughes, 1994; Sebens, 1994; Hoegh-Guldberg et al., 1997b; Steven & Broadbent, 1997; Ward & Harrison, 1997; Lapointe et al., 1997; Koop et al., 2001). At the same time, a number of studies have also shown that algae and fast growing filter feeders (mainly zoanthids and sponges) have their development enhanced in elevated nutrient conditions (Buss & Jackson, 1981; Goreau, 1992; Hallock et al., 1993; McCook, 1999; Holmes, 2000; Richter et al., 2001).

The second spatial pattern was a small-scale inshore-offshore gradient observed, in the nearshore reefs, from the reef flat to the 30m location (for seawater parameters), or from the flat to the slopes (for the benthos). This gradient also reflects the varying degree of terrestrial influence observed but may include some specific characteristics of each reef such as differing levels of urbanization (use of septic tanks) and the degree of use by tourists (the stepping over the flat is higher in Coroa Vermelha - pers. obs.).

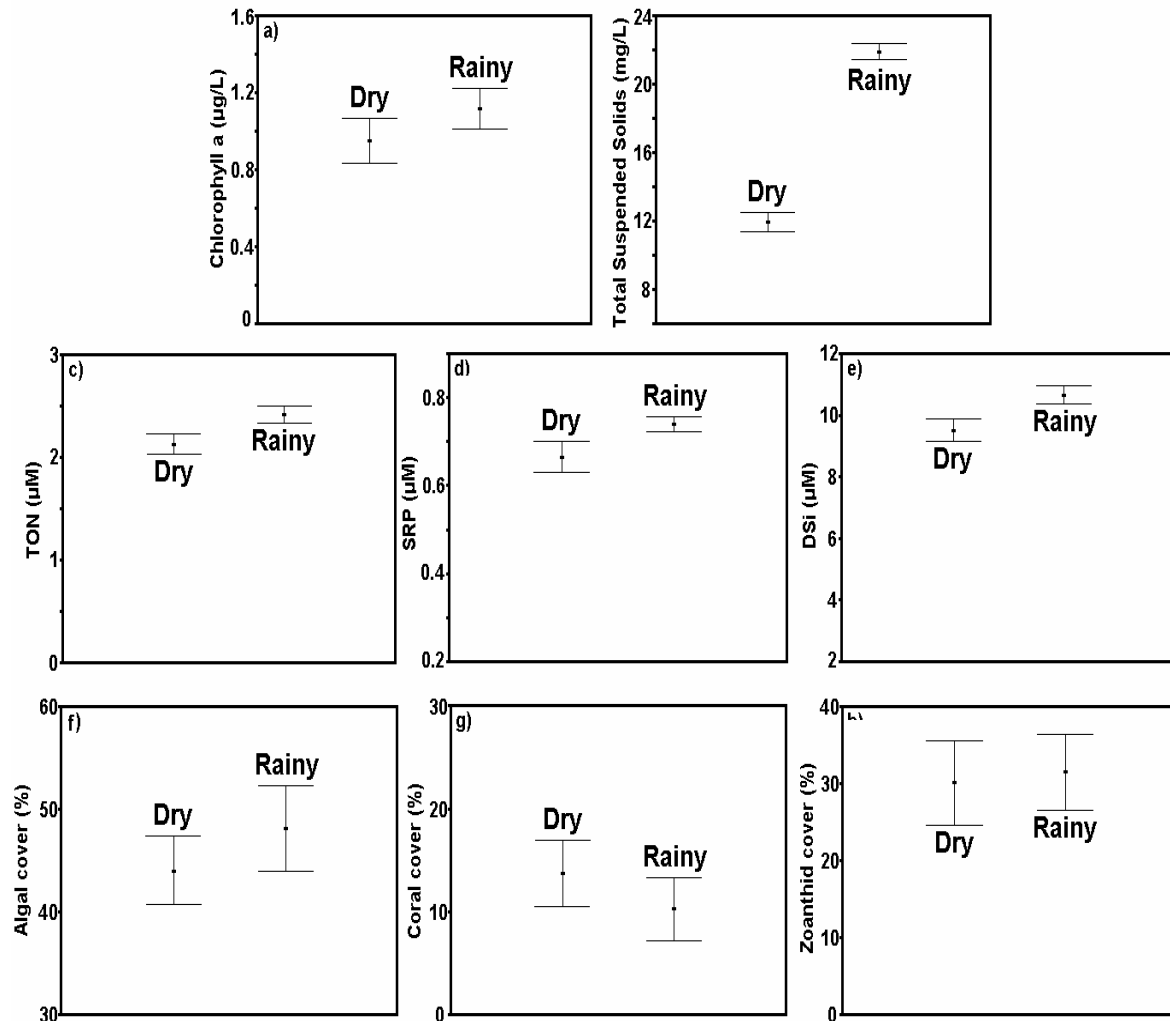
Similarly, the variation of topography, the amount of sand and vegetation and many other characteristics make these reefs distinct from each other, while sharing the same physical setting. This may explain the differences that, although small, were observed between the nearshore reefs. Coroa Vermelha showed the most elevated nutrient concentrations, probably due to untreated sewage and wastewater contributions from the nearby urban area. Lower levels of nutrients in Ponta Grande reflect, in general, the lack of a continuous, permanent source, in addition to biological and chemical removal processes.

At Recife de Fora, the same small-scale spatial variation was observed. A clear difference was visible between landward and seaward sides of the reef. Such differences are related primarily, although not exclusively, to variations in wave energy, with landward areas being more protected from the wave action generated by the dominant E-SE and NE winds. Only occasional S-SE winds, connected to the passage of cold fronts during the winter (June to August) can disrupt the calmness of the landward reef.

### **Seasonal patterns**

Until recently, seasonal variability in the function of coral reefs has been overlooked because of the general perception that tropical communities lack season-to-season variability. Johannes et al. (1983) were the first to report that dissolved inorganic nitrogen (DIN) concentrations on coral reefs varied with season. They also reported that the uptake of nutrients by the benthic community was concentration-dependent.

On the study area, the effect of season is variable, being significant for some parameters and not for others (Fig. 7.3). Suspended solids, for instance, is one variable heavily influenced by season. Conversely, the physico-chemical parameters (temperature, salinity, pH) are generally independent of seasonal effects, with diel and tidal variations being frequently more important (see Chapter 4).



**Figure 7.3.** Seasonal variation of parameters measured at the water column (a-e) and the major groups of benthic organisms (f-h) on nearshore reefs only. Bars represent mean and 95% confidence intervals.

There are also some variables in which the effect of season is mixed, being apparent for one reef and not for other(s). A good example of such is the distribution of chlorophyll *a* in the nearshore reefs. A strong seasonal variation was observed in Ponta Grande, but not for Coroa Vermelha.

The seawater nutrient distribution was also significantly affected by season. The observed higher nutrient concentration during the rainy season suggests that rainfall promote an increasing load of nutrients from terrigenous sources (run-off and groundwater seepage). This hypothesis is supported by a marked increase in nutrient concentrations near the sediment during the rainy season, notably for TON. This seasonal pattern suggests that submarine groundwater discharge (SGD) rather than regeneration from the sediment, may be the cause of the elevated nutrient concentrations in the bottom layer. Such pattern is in agreement with some recent studies focusing in the SGD affecting nearshore, and eventually offshore, communities (e.g. Lapointe & Clark, 1992; Lapointe et al., 1994).

The data also suggest that the effect of the SGD is not restricted to the nearshore reefs, and may be an important factor controlling the differences between landward and seaward sides of the offshore reef. This hypothesis is supported by increasing knowledge of the hydrology of coastal aquifers. Since the sixties (Kohout, 1960) it is accepted that the zone of diffusion (or mixing) may be as much as 14 km seaward of the coast, thus allowing groundwater discharge to have an impact well offshore. Moore (1999) referred to this subsurface region of mixing between meteoric water and seawater in coastal aquifers as "subterranean estuaries", suggesting that the mixing of these waters in the subsurface creates an active chemical environment. In addition to these natural chemical processes, wastewater disposal in the urban area of Coroa Vermelha adds yet another source of water to the subsurface environment.

Although the direction of the groundwater flow is assumed to oscillate as the fluctuating tides create a differential head between sea level and the water table, a previous study of groundwater discharge in other parts of the Bahian coast has shown that this may not always be the case, and a unidirectional flow may be established (Costa et al., 2000). Such a permanent supply of nutrients via groundwater seepage may pose an ecological problem, leading to algal blooms and the deterioration of the water quality.

Significant flows of groundwater nutrients to nearshore reefs were also reported by Marsh (1977) in Guam, Johannes (1980) in Western Australia, Bienfang (1980) in Hawaii, D'Elia et al. (1981) and Lapointe (1997) in Jamaica, Lewis (1985) in Barbados, Jickells et al. (1989) in Bermuda, Naim (1993) in Reunion Island, Lapointe & Matzie (1996) in Florida Keys and Vacelet et al. (1998) in Comoro Archipelago.

This strong relationship between high precipitation and high coastal productivity rates suggests that land drainage and groundwater seepage are important factors in nutrient enrichment in the study area. Furthermore, the corresponding low salinities with high silicate levels is an indicator that the freshwater is either river or groundwater derived (and not simply precipitation), which is in accordance with findings from Cuet et al. (1988) and Bell (1992).

Another useful proxy for assessing the impacts of nitrification gradients in the study area is the distribution of chlorophyll *a* (Fig. 7.1a). The spatial variation of chlorophyll *a* was found to be strongly correlated with nutrients (TON:  $r = 0.801$ ,  $p < 0.001$ , SRP:  $r = 0.735$ ,  $p < 0.001$ , DSi:  $r = 0.806$ ,  $p < 0.001$ ). This result is in agreement with reports from the literature, which show that nutrient-stressed coral-reef communities are firstly dominated by turf algae and then by increased numbers of planktonic producers (Smith et al., 1981; Twilley et al., 1985; D'Elia, 1986).

The seasonal increase in surface runoff and groundwater discharge has a clear effect in the nitrification of coastal areas, as measured by either nutrient or chlorophyll *a* concentrations. Such pattern is also reflected in the biota, by means of a positive correlation with increased algae and zoanthid cover and a negative correlation with coral cover (Fig. 7.4).

These results also shown that the statistical significance of the correlation between nutrients and algae cover is not as strong as that between nutrients and chlorophyll, suggesting that fleshy and turf algae in the nearshore reefs may be nutrient replete, i.e. they are not nutrient limited. Nutrient repletion of macroalgae has been previously reported (Koop et al., 2001).

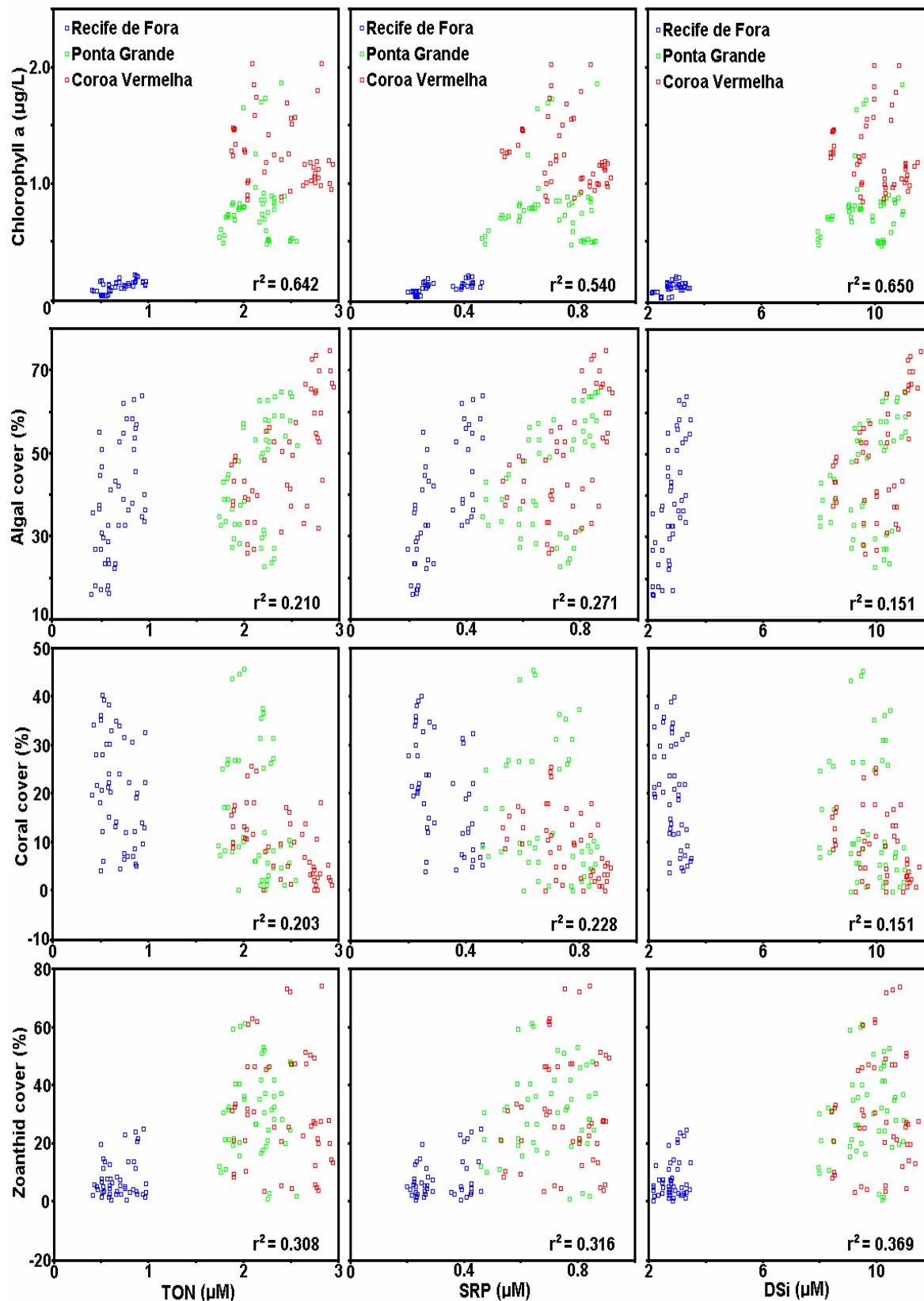


Figure 7.4. Pearson's product-moment correlations between nutrients and chlorophyll *a*, algal, coral and zoanthid cover in the study area.

At the offshore reef, this pattern is explained by the within-reef spatial variation (reef flat x seaward x landward). The results of correlation analysis (Table 7.2) suggests that algae on the offshore reef may be P-limited (TON:  $r = 0.519$ , SRP:  $r = 0.686$ ), especially during the dry season. This means that 47% of the variation in algal cover between habitats on the offshore reef is explained by variations in SRP, whilst only 27% of such variation in algal cover is explained by variations in TON concentrations (Fig. 7.5).

**Table 7.2.** Pearson's product-moment correlation between measured parameters in the offshore reef

	<b>Chl a</b>	<b>TON</b>	<b>SRP</b>	<b>DSi</b>	<b>Algae</b>	<b>Coral</b>
<b>TON</b>	0.648					
<b>SRP</b>	0.644	0.931				
<b>DSi</b>	0.513	0.828	0.885			
<b>Algae</b>	0.581	0.519	0.686	0.671		
<b>Coral</b>	-0.488	-0.370	-0.533	-0.463	-0.455	
<b>Zoanthid</b>	0.213	0.202	0.264	0.254	0.641	0.020

Figure 7.5 also shows no significant correlation between nutrient concentration and zoanthid cover, suggesting that the distribution of these organisms on the offshore reef is being controlled by other physical and biological factors, such as wave energy (Karlson, 1983) and intra- and interspecific competition for space (Tanner, 1997).

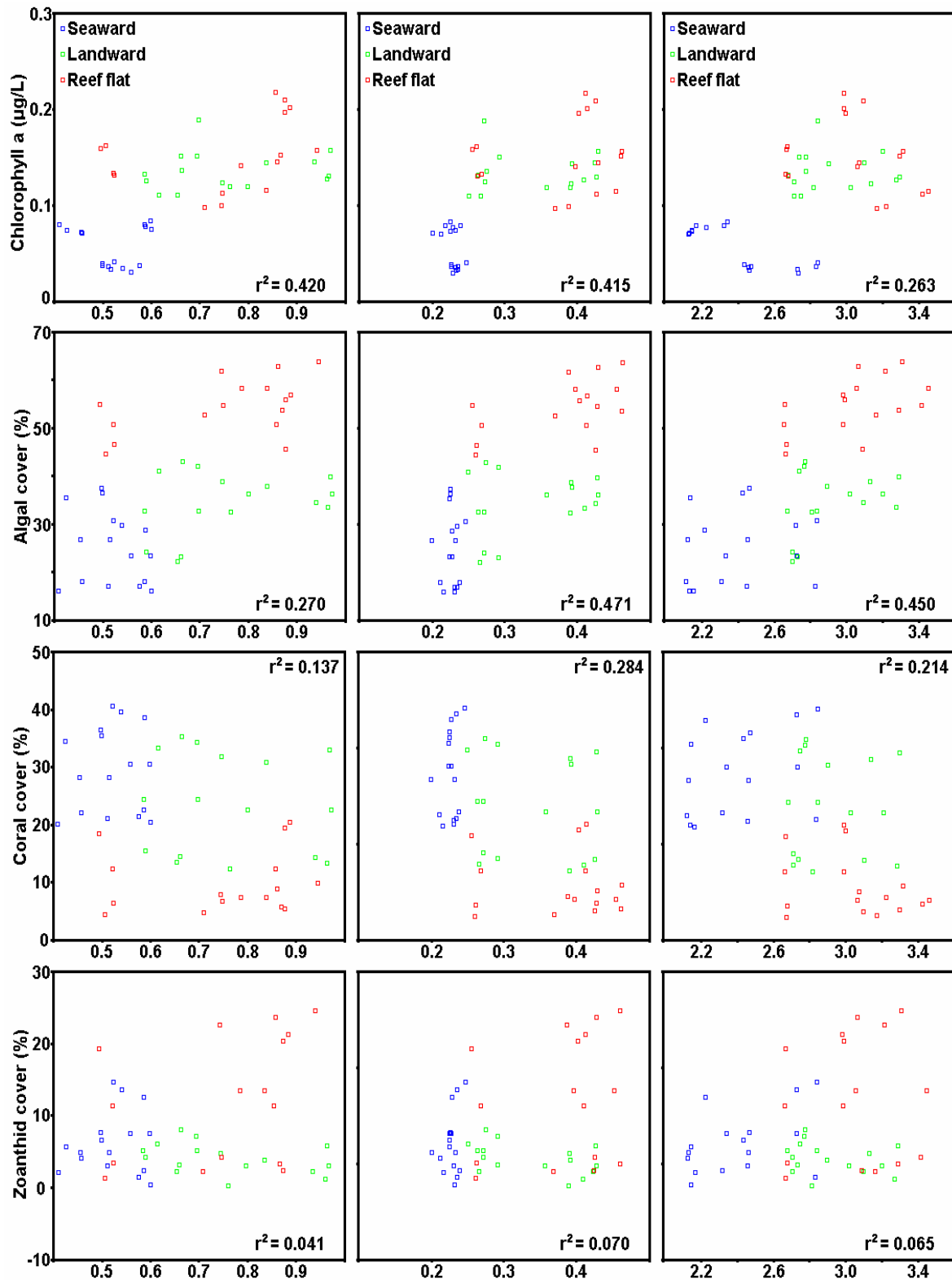


Figure 7.5. Pearson's product-moment correlations between nutrients and chlorophyll *a*, algal, coral and zoanthid cover in the offshore reef.

### **Factors controlling the benthic community distribution**

Although nutrients may play an important role in defining the community structure at the study reefs, there may be other factors controlling the abundance and relative distribution of different groups of benthic organisms. The contribution of each of these benthic groups varied considerably not only between offshore and nearshore reefs, but also between windward and leeward sides of the offshore reef. This within-reef variation is consistent with the literature, which, since the thirties, have shown that corals and frondose macroalgae are more developed in the calmer waters landward of the algal ridge and on deeper areas of the seaward reef wall (Round, 1981).

Apart from zoanthids, which constitute the group which distribution is most clearly related to variations in nutrient concentrations, the distribution patterns of the remaining reef organisms, and ultimately the whole reef structure itself, appear to be the result of a complex interplay between a variety of physical (light, sedimentation, wave regime, topography) and chemical (nutrient inhibition and enhancement) factors. Also important are inter- and intra-specific competition and interactions (herbivory, recruitment, exclusion, competition for space and light).

Different levels of associations between these factors may generate the marked variation in the spatial distribution of species observed in the studied area (both between nearshore and offshore reefs and within specific habitats, i.e., reef flat and reef slopes). For instance, the abundance of macroalgae, especially turf algae, presents a positive correlation with physical stress from waves ( $r = 0.439$ ,  $p < 0.001$ ), but a negative correlation ( $r = -0.205$ ,  $p = 0.043$ ) with depth (i.e. low light availability).

On coastal reefs, macroalgal abundance was inversely related to zoanthid abundance, and thus directly related to the amount of available space for settlement. On the offshore reef, however, the inverse was observed and algal cover increased with both zoanthid abundance and the consequent reduction in available space.

This pattern suggests that available hard substrate may be the primary limiting factor for algal settlement and growth in the coastal reefs, especially if the potentially low herbivory pressure due to overfishing is considered (N.B. although there is no study regarding herbivory in the area, this assumption is based on field observations and on recent changes in fishery practices, e.g., previously unfished groups of species are now targeted due to the lack of commercial groups).

Differential herbivory between offshore and coastal reefs may also be inferred from the comparison of abundance between the algal functional groups. Turf algae, which along with fleshy algae is the main group targeted by herbivorous fish (Hackney et al., 1989), are more abundant in the coastal reefs, whereas crustose coralline algae, a group that take advantage of herbivory/grazing activity (Hackney et al., 1989), reaches maximum development on the offshore reef. Additionally, the nutrient availability, as described previously, is higher in the coastal reefs, which, if combined with low herbivory, could lead to much higher algal abundance (Aronson & Precht, 2000; Lapointe, 1997, 1999; Miller et al., 1999; Smith et al., 2001). Notwithstanding, at 1m and 3m depths, the algal abundance is lower than on the offshore reefs, where herbivory is supposedly higher (i.e. low fishing pressure due to the MPA), and the nutrient availability is reduced. Such a result reflects the important role of inter-specific competition for space in structuring the benthic community at each depth zone, along with physical and chemical factors.

In the offshore reef, zoanthids occur predominantly in reef flat pools and the whole flat remains underwater most of the time. This combination of factors provides the necessary balance of light and settlement space that allow better development of fleshy and turf algae, which cover, respectively, 22.4% and 28.2% of the flat. In this reef, the status of MPA and less disturbed conditions has supposedly preserved the fish stock, and herbivory is likely to be the dominant force driving the distribution and abundance of reef macroalgae.

In addition, the data suggest that highly variable physical disturbance between seaward and landward reef sides can result in a distinctive algal distribution pattern, intimately related to gradients in exposure, wave energy and water flow regimes. These findings add to the growing recognition that hydrodynamics are of primary importance in coral reef ecosystems (Atkinson, 1988, 1992; Cheroske et al., 2000) and may explain the differences in macroalgal abundance between the low tide emersed reef flat, the high-energy reef wall (seaward) and the sheltered area (landward). Water flow has been shown to regulate the high rates of net primary production and nitrogen fixation in algal turfs (Carpenter et al., 1991; Williams & Carpenter, 1998). Metabolic rates are negatively correlated with boundary layer thickness over the turfs, and the latter is reduced as ambient water flow speeds increase and algal canopy heights decrease (Carpenter & Williams, 1993; Williams & Carpenter, 1998).

Variations in topography (or topographic complexity, as described by Szmant, 1997) may also play an important part in community distribution. The landward slope (low energy habitat) and its steep slope, displays a depth-related community zonation, with 1m, 3m and 5m depths showing high levels of dissimilarity. This may be an effect of small-scale variations in topography at that reef slope, whose influences on community zonation are well documented by Ohlhorst & Liddell (1988). At the shallow slope of the windward reef, characteristic zones were identified but without sharp boundaries, and wave exposure appears to be the main factor regulating zonation. At the 1m and 3m depth zones, water motion effect is even and these two habitats presented similar characteristics. At the 5m depth the influence of water motion is reduced and both landward and seaward slopes presented habitats with high degree of similarity. This depth also experienced the lowest levels of diversity ( $H'$  and  $S$ ), reflecting reduced light availability and increased number of sand patches.

### 7.1.2. Comparisons with other reef areas around the world

The mean chlorophyll *a* concentrations reported for Ponta Grande and Coroa Vermelha reefs are higher than that of other coral reef areas (Florida, Caribbean, Australia). Such concentrations are comparable with values reported for urbanized open embayments (Kaneohe Bay, Hawaii) yet well below values determined for highly eutrophic coastal systems (Chesapeake Bay, East US Coast) - see Table 7.3. On the offshore reef, chlorophyll *a* concentrations are similar to non-bloom situations in the Florida Keys and considerably below reefs from Australia and Caribbean.

**Table 7.3.** A comparison of chlorophyll *a* concentrations ( $\mu\text{g/L}$ ) taken from the literature and from this study.

Location	Average	Comments	Reference
Carter Lake, Nebraska, US	>20	Eutrophic lake	Schalles et al., 1998
Chesapeake Bay, East US	2.55	1950-1959	Harding & Perry, 1997
Chesapeake Bay, East US	8.76	1970-1979	Harding & Perry, 1997
Chesapeake Bay, East US	7.59	1985-1994	Harding & Perry, 1997
Kaneohe Bay, Hawaii	0.68	Before sewage diversion	Smith et al., 1981
Kaneohe Bay, Hawaii	0.55	After sewage diversion	Smith et al., 1981
Barbados, Caribbean	0.42	Less impacted coral reef site	Tomascik & Sander, 1985
Davies reef, GBR, Australia	0.57	Offshore reef (landward)	Furnas et al., 1990
Davies reef, GBR, Australia	0.32	Offshore reef (seaward)	Furnas et al., 1990
Florida Keys, US	0.26	Pre-bloom situation	Szmant & Forrester, 1996
Florida Keys, US	2.28	Post-bloom situation	Szmant & Forrester, 1996
Coroa Vermelha reef, Brazil	1.22	Inshore reef, near urban area	This study
Ponta Grande reef, Brazil	0.86	Inshore reef	This study
Recife de Fora reef, Brazil	0.34	Offshore reef (landward), MPA	This study
Recife de Fora reef, Brazil	0.26	Offshore reef (seaward), MPA	This study

In terms of nutrient distribution, seawater TON concentrations in Coroa Vermelha and Ponta Grande are similar to those at the nearshore fringing reefs of Ghardaqa, in the Red Sea (Table 7.4), an arid zone with no river inflow and whose major nutrient sources are sewage outfalls. Higher TON concentrations are found only in heavy impacted fringing reefs of the Caribbean (Jamaica, Table 7.4), the Pacific Ocean (Guam, Table 7.4) or in the north coast of Brazil (Guarajuba reef, Table 7.4), where groundwater discharge, untreated sewage from urban areas and terrestrial run-off are causing nutrient enrichment of the coastal reefs.

However, TON concentrations in Coroa Vermelha and Ponta Grande are considerably higher than most Caribbean reefs (for instance, Barbados, US Virgin Islands, Martinique and Florida Keys). Even the Recife de Fora, whose TON concentrations varied between 0.41 and 1.16 $\mu$ M, presented values above those coral reef locations (Table 7.4).

**Table 7.4** - Typical TON and SRP concentrations (in  $\mu$ M) reported for some coral reefs around the world.

Sites	TON	SRP	Comments	References
Discovery Bay, Jamaica				
- Groundwater springs	20.68 $\pm$ 5.80	0.26 $\pm$ 0.06	Groundwater inputs	Lapointe, 1997
- Semi-enclosed grottos	13.00 $\pm$ 3.00	0.14 $\pm$ 0.06		
- Back-reef	8.18 $\pm$ 2.30	0.14 $\pm$ 0.05		
- Fore-reef	4.61 $\pm$ 1.58	0.13 $\pm$ 0.03		
Pago Bay, Guam - Pacific Ocean	4.16 $\pm$ 4.27	0.23 $\pm$ 0.20	Fringing reef flat	Marsh, 1977
Tumon Bay, Guam: bloom water	3.57 $\pm$ 3.12	0.59 $\pm$ 0.24	Groundwater input &	
Tumon Bay: non-bloom water	8.04 $\pm$ 5.75	0.22 $\pm$ 0.12	terrestrial runoff	
Guarajuba reef, Brazil - Dry season	6.09	0.35	Near-urban area	Costa et al., 2000
Guarajuba reef - Rainy season	8.19	1.42	Groundwater inputs	
Papa Gente reef, Brazil - Dry season	0.46	0.13	Undeveloped area	
Papa Gente reef - Rainy season	1.77	0.18		
Ghardaqa, Red Sea, Egypt	1.86-3.14	0.29-0.33	Nearshore reefs	Abou-Aisha et al., 1995
Safaga, Red Sea, Egypt	0.73-1.64	0.73-0.88	Sewage inputs	
Quseir, Red Sea, Egypt	0.85-1.86	4.18-5.93		
Houtman Abrolhos Is., Australia	0.83-1.50	0.22-0.50	Sed. Remineralization	Crossland et al., 1984
Florida Keys, USA				
- Long Key - inshore	1.07 $\pm$ 0.56	0.17 $\pm$ 0.08	Florida Bay inputs	Szmant & Forrester, 1996
- Long Key - offshore	0.32 $\pm$ 0.40	0.11 $\pm$ 0.09		
- Biscayne National Park - inshore	0.58 $\pm$ 0.52	0.02 $\pm$ 0.02		
- Biscayne National Park - offshore	0.16 $\pm$ 0.16	0.01 $\pm$ 0.01		
- Key Largo - inshore	0.46 $\pm$ 0.17	0.01 $\pm$ 0.20		
- Key Largo - offshore	0.22 $\pm$ 0.12	0.02 $\pm$ 0.03		
La Reunion - Indian Ocean	0.47 $\pm$ 0.07	0.11 $\pm$ 0.01	Groundwater inputs	Naim et al., 1997
- submarine beach	10.4 $\pm$ 4.1	0.16 $\pm$ 0.03		
- reef front	0.37 $\pm$ 0.04	0.11 $\pm$ 0.01		
Southeastern Florida, USA	0.43 $\pm$ 0.29	0.19 $\pm$ 0.11	Groundwater inputs	Lapointe, 1997
- groundwater inputs	0.89 $\pm$ 0.27	0.19 $\pm$ 0.04		
Martinique, Caribbean	0.53-0.62	0.10-0.28	Near-urban area	Littler et al., 1993
Barbados, Caribbean	0.35-0.45	0.06		Tomascik & Sander, 1985
U.S. Virgin Islands, Caribbean	0.28-0.51	0.08-0.10		Adey & Steneck, 1985
Tikehau atoll, French Polynesia	0.03-0.06	0.10-0.11	Oceanic atoll	Charpy et al., 1998
Great Barrier Reef, Australia	0.05	0.08		Furnas et al., 1997
Coroa Vermelha, Brazil	1.88-3.64	0.53-0.91	Near-urban area	This study
Ponta Grande, Brazil	1.74-2.56	0.46-0.86	Groundwater inputs	
Recife de Fora, Brazil	0.41-1.16	0.20-0.46	Offshore reef	

Values of TON above  $1\mu\text{M}$  were found only in waters enriched by sewage effluents (Smith et al., 1981), groundwater springs (Lapointe, 1997), reef lagoons with high rates of remineralization (Crossland et al., 1984) or areas close to marinas and canals (Szmant & Forrester, 1996). Reefs with extremely low TON concentrations, like the Great Barrier Reef in Australia (TON:  $0.05\mu\text{M}$ ) and the atolls of the Indian Ocean (TON:  $0.03\text{-}0.06\mu\text{M}$ ), receive nutrient supply mainly from sediment resuspension and from water column/benthic microbial regeneration (80-90% of total nutrient demand), according to Furnas et al. (1997). Upwelling is also a major nutrient contributor to offshore reef areas (Szmant & Forrester, 1996) with only 10% of the total nutrient demand to come from external sources.

If the comparison is based on SRP concentrations, the study reefs present the highest values among the sites depicted in Table 7.4, with the only exception being the nearshore reefs of Safaga and Quseir, in the Red Sea (Abou-Aisha et al., 1995), which receive a large phosphorus loading from phosphate factories near the coast. Such a high level of phosphorus input to the study area contributed to the extremely low TON:SRP ratios. Such a low TON:SRP ratio in both nearshore and offshore reefs either suggests that there is a strong source of P to the area or that N is rapidly metabolized (Szmant & Forrester, 1996). Both possibilities seem likely, although the data do not provide any evidence of the latter. In either case, such TON:SRP ratios also reflect the importance of SGD as a significant pathway for nutrients and other dissolved solutes into Porto Seguro Bay, especially to the nearshore reefs where wastewater disposal practices are likely to be adding large amounts of nitrogen and phosphorus to the subsurface each year.

## 7.2. Future perspectives: management and monitoring strategies

The rational utilization and management of coastal zone habitats and marine resources is a major challenge to modern, high energy consuming societies. Conflicting uses, over-exploitation of resources, and partial or total destruction of habitats are urgent problems that confront managers and decision-makers (Ogden & Gladfelter, 1986). The past two to three decades have seen a plethora of initiatives under the general theme of 'coastal zone management', aiming to achieve 'sustainable development' (Yap, 2001). Despite this effort, environmental problems along the world's coastlines continue to worsen, associated generally with relentless increases in human population (GESAMP, 2001).

Although population growth and urban expansion have been rapid (a 84% increase between 1990 and 2000), the Brazilian Discovery Coast remains relatively sparsely populated (25.9 hab/km<sup>2</sup>). Porto Seguro and Santa Cruz Cabralia cities, however, hold more than 93,000 of the total 146,000 inhabitants of the whole Discovery Coast (IBGE, 2000). Such a concentrated urban pressure has led to extensive land modification over the last 10 years, especially along the river margins. As a consequence, runoff resulting from land-based agricultural and urban activities has generated an increase in sediment loads to the coastal areas. Adding to the problem, untreated sewage is continuously discharged into the rivers and from them to the coast, but none of these threats have been evaluated so far.

The inshore waters of the Porto Seguro Bay have a comparatively poor water quality, with elevated nutrients and chlorophyll *a* levels. Some of this inshore enrichment may be related to natural terrestrial-to-offshore gradients, but it is likely that much of it may derive from nutrient-rich surface runoff and groundwater percolation. Offshore reefs, although presenting better water quality than nearshore ones, are already under significant nutrient stress, especially during the rainy season, when the runoff is intensified and groundwater seepage may not be confined to the shoreline (as observed by D'Elia et al., 1981).

### **7.2.1. Management implications**

Since nutrient enrichment and sedimentation are the main effects of river runoff, managers should target land use practises along the rivers. One such initiative is to encourage the preservation of mangrove areas along the river margins, especially in the estuary, as they are relentlessly being cut for pier constructions and land claims.

The tourist activity is also in need of regulation. During peak periods, about 2500 people visit the Marine Park in just one day, representing a serious threat to the coral reef community, either by damaging the reef directly (loose swimming by beginners, collection of coral fragments, etc) or indirectly (e.g. increasing sedimentation, litter build-up, etc) – see for instance Riegl & Velimirov, 1991; Hawkins & Roberts, 1992, 1993, 1994; Hawkins et al., 1999.

Another important measure would be to regulate the fishery in the area, as algal takeover of coral-reef communities is promoted not only by increasing nutrient flux, but also by declining herbivore populations. Legal protection and/or restoration of herbivore populations (especially herbivorous fish) must also be considered. This may be achieved by better enforcement of MPA regulations in the Recife de Fora Marine Park, and also by extending the park itself to include other reef areas.

### **Community involvement**

Marine Protected Areas have a significant role to play in protecting key sites and raising consciousness of the need for, and benefits of, marine conservation. The fishing community must be included in the process and, to this end, an environmental education campaign may be established. Additionally, securing community support for MPAs will require the development of management plans that are compatible with traditional practises for the use and conservation of the marine resources. These traditional practises may include, to some extent, the right to fish, the right of access and passage, and the right to use stretches of the reef as a landing place.

Co-operation with local communities is most likely to be achieved where it can be shown that it is in the interest of local people to establish and manage the MPA.

In parallel to this initiative, alternative means of subsistence should be provided (aquaculture being a suitable option) in order to guarantee the full participation of the fishing community. Coastal programs that have had some degree of success are those that have managed to bring about income generation (Yap, 2001). Providing opportunities for sustainable development, and demonstrating that sustainable benefits will flow from management of resources, is fundamental to secure community co-operation.

### **Building capacity**

Acceptance of the need for protected areas and broader management strategies appears to be growing but its realization depends upon human resources to implement the plans and strategies. Increased funding, strong institutional support and specifically tailored control measures will be ineffective unless a pool of trained personnel for protected area development and management expands rapidly. Therefore, training and capability building are fundamental requirements for enabling marine resources to be managed on a sustainable basis.

The Discovery Coast lacks centres of research and education but some initiatives to change this situation have been recently attempted by either the Federal or State governments. In 1995, the Santa Cruz State University (UESC) was established, aiming to explore and develop the region's natural vocation to the coast and its coastal resources. Some courses on environmental management & development and oceanography are already in place, with others in process of being authorized. On the Federal front, one of the most recent graduation courses in oceanography was established at the Federal University of Espirito Santo (2000), raising to five the number of such courses in the country at that time (the number is actually seven, with the addition of two new courses: one in 2000, at the Federal University of Para, and another to start in 2002 at the University of Sao Paulo).

Such initiatives reflect the growing recognition of the importance of coastal resources and the need to improve the number of environmental scientists working in this field. Sadly they are occurring in a very isolated way, and little cooperation between them or induction from the government has happened so far. Local (municipal) governments and the private sector are also urged to contribute in this effort by helping establish and supporting new marine research and education centres within the Discovery Coast, preferably by acting in partnership.

### **Monitoring program**

Once a management plan is in place, it is necessary to evaluate the effect and effectiveness of that plan. To this end, monitoring programs should be established and conducted. This monitoring should be also capable of distinguish between natural and human-induced effects and to determine trends over time. Evaluating the occurrence and magnitude of trends requires a commitment to long-term monitoring (multiple years), and consistent data collection through a networks of sites that represent the target population. In addition it should:

- a) be built on a foundation of existing successful 'keystone' environmental monitoring and research programs, in order to allow inter-comparisons and evaluation of long-term trends.
- b) be cost efficient, by providing the best possible sound results with the available resources. In order to accomplish that goal, a careful selection of methods and techniques for both sampling and statistical treatment is necessary, and a pilot study should be undertaken before any definition is made, in order to test the adequacy of the chosen protocols.
- c) be adaptive so it can evolve and innovate, as new and improved methodologies came into place, without losing the value of historical data sets.
- d) allow timely data accessibility to federal and state agencies, other public organizations, and the private sector, providing technical and educational support for the establishment of relevant policies and protective measures.

### Future research

Research and funding priorities for the future should include:

1. Patterns and dynamics of algal and coral fecundity, dispersal and recruitment, and the ways these variables are influenced by nutrient availability. Such information will help establishing how different the ecology of the Brazilian reef communities are from the well known reef systems that occur in the Caribbean and the Indo-Pacific.
2. Controls on herbivore populations and grazing rates, at cross-shelf, among reef and regional reef-zone scales, allowing the identification of the relative contribution of top-down and bottom-up forces controlling macroalgal abundance, as well as the specific responses of coral reef assemblages to multiple stressors.
3. Coral-algal interactions, especially competition, and specifically in areas of low herbivory or low topographic complexity. These experiments aim to reveal the extent of the contribution of each factor (herbivory, topographic complexity) in structuring the reef benthic community and how they affect the coral-algal interactions.
4. Quantification of the nutrient dynamics at higher temporal resolutions (diel and lunar cycles, for instance), and fluxes between the sediment-water interface. Such a protocol will clearly establish the fate and pathway of nutrients in the study reefs, and may include the use of natural geochemical tracers (radium isotopes, for instance).
5. Measurements of ammonium ( $\text{NH}_4^+$ ), dissolved organic nitrogen (DON) and phosphorus (DOP) will provide additional information on the level of nutrient exchanges between the various pools (dissolved and particulate, organic and inorganic).
6. Development of tissue C:N:P and other ratios as bioindicators of reef nutrient status.