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TEMPORAL CHANGES IN COMMUNITY STRUCTURE OF FOUR CORAL REEF AREAS OFF MAURITIUS

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ABSTRACT

Information on temporal changes in the community structure of Mauritian coral reefs is lacking. In this study multivariate techniques are used to analyse changes in reef structures at four locations around the island with relevant bearings to the coastline (shore, back and fore reefs) and exposed to different levels of human activities: Trou aux Biches (TAB, tourism), Bambous Virieux (BV, agriculture), Bel Ombre (BELO, agriculture and tourism) and Ile aux Benitiers (IAB, control). No significant changes in community structure occurred at BELO (back reef), IAB (shore and fore reefs) and TAB (fore reef). Consistent changes, although not significant, were observed at the shore reefs of BELO and BV and back reefs of IAB and BV where the position of the reef structure in 2005, on MDS ordination, were furthest away from the initial reef structure. At BELO (shore reef), a significant shift from foliaceous non-*Acropora* to dead corals in the later years was noted. Branching *Acropora* was the most dominant lifeform category at the back reefs of BELO and BV. The main contributing lifeforms at the other reefs were: tabulate *Acropora* at IAB back reef and massive non-*Acropora* at TAB fore reef. Abiotic forms dominated the substrate of other coral reefs: dead coral at TAB back reef, rubbles at IAB shore reef and rock at IAB fore reef. Large scale analysis of percentage cover of lifeforms showed that the coral reefs off Mauritius could be assigned to four main types of coral reefs, with identical community structure: (i) the fore reefs at IAB and TAB (rock and massive non-*Acropora*), (ii) the shore reefs at BELO and BV (macroalgae and submassive non-*Acropora*), (iii) the back reefs at BELO and BV together with the shore reef at IAB (branching *Acropora*), (iv) the back reefs at IAB and TAB (dead coral and tabulate *Acropora*). The coral reefs around the island could be divided into two major areas, along a diagonal southwest-northeast axis, with proper reefs off the south and east coasts but with an abiotic dominant substrate off the north and west coasts. The patterns in the reef community structure could not be linked to any of the recorded environmental parameters (sea surface temperature, salinity, pH and dissolved oxygen). It is postulated that these parameters were not the appropriate indicators for monitoring the observed changes in the coral reefs.

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1 INTRODUCTION

1.1 Background

The Republic of Mauritius, situated in the south-western part of the Indian Ocean, consists of one main island, Mauritius, located at latitude 20° 17" S and longitude 57° 33" E, and a group of outer islands and islets namely: Rodrigues, St. Brandon, Agalega, Tromelin and the Chagos Archipelagos. It forms part of the volcanic chain of Mascarene Islands and is located 800 km east of Madagascar (Figure 1). With a population of 1.2 million, Mauritius has a land area of 1,864 km^2 and claims an Exclusive Economic Zone of 1.9 million km^2 (Ministry of Finance and Economic Development 2005)

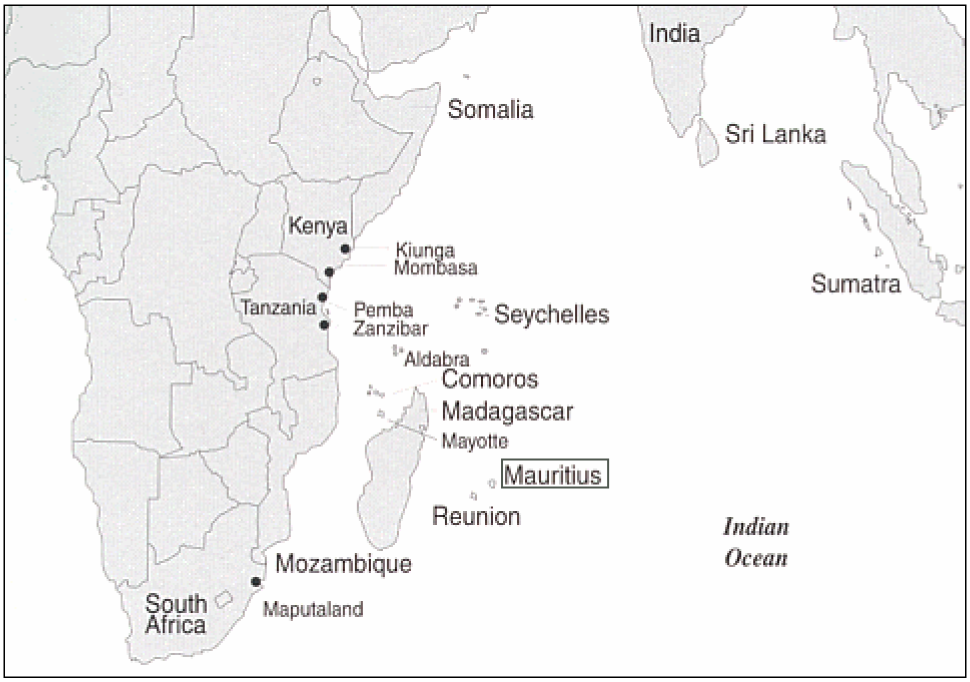

Figure 1: Location of Mauritius.

Mauritius has a diversity of geographical features that include a large plateau in the central region ranging in altitude between 300 and 600 m and three main mountain ranges roughly encircling the plateau with the highest peak reaching 815 m. Due to the volcanic composition of the island, all of its coastal parts now consist of dark coloured porous volcanic rocks. The country enjoys a subtropical climate and is prone to cyclonic depressions from December to April. There are two seasons, a hot and wet summer and a cool and dry winter. The average sea surface temperature is 25°C.

The island has a coastline of about 240 km and 150 km of fringing reefs (Figure 2) enclosing lagoons with a total area of 243 km^2 (Ministry of Fisheries and Marine Resources 1995). The reef is only a few hundred metres away from the shore off the west coast, but lies a few kilometres away off the southeastern coast. It contains a shallow lagoon, usually 1-2 m deep, except for channels and basins in certain areas. Mauritius is almost completely encircled by fringing reefs, with substantial lagoon and barrier reef developments on the eastern and southwestern coasts. The sheltered fringing reefs are characterised by large colonies of table and branching *Acropora* spp. followed by *Montipora* spp., *Porites* spp. and *Pavona* spp. The latest coral inventory on the reefs of Mauritius revealed the presence of 159 species of scleractinian corals (Moothien Pillay *et al.* 2002). Below 20 m there is usually only a thin layer of coral rock overlying volcanic rocks (Olivier *et al.* 2004).

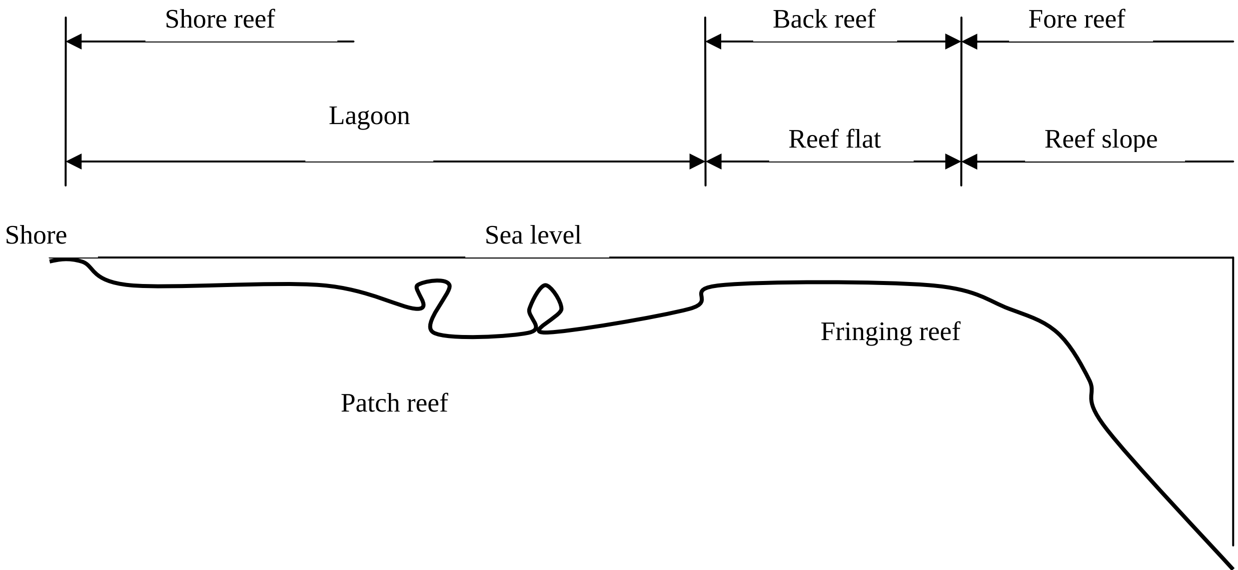

Figure 2: Zonation of coral reef in Mauritius, showing the different terminologies used in this study (modified from Moothien Pillay *et al.* 2002).

Mauritius is a small, multi-ethnic island, viewed as a tropical idyll for tourists and frequently cited as a successful example of economic development of a small island developing state. The population density is high but stable, and there is a good education system and low unemployment. The country has achieved successful development by concentrating heavily on three economic sectors: the sugar industry, textile manufacturing, and tourism. The economic success has not however been without ecological cost. Mauritius went through rapid industrialisation in the early 1970s and, in the absence of strict enforcement of regulations, the environment has been under increasing stress. Because of its small size, Mauritius, nearly all land-based activities impact directly on the coastal zone (Ministry of Fisheries 1995). Rapid tourism development has also given rise to unplanned development along the coastline. Anthropogenic activities, such as tourism, are believed to have a detrimental impact on the status of coral reefs. Hotel rooms, which are mostly along the coastline, have increased from 4,600 in 1990 to 10,600 in 2004 (Ministry of Finance and Economic Development 2005), thus increasing pressure on the limited resources in this area. The coastal lagoons and coral reefs have been degraded by the rapid development through agricultural, industrial and urban run-off, eutrophication, overfishing and are used heavily by the coast based tourism industry (Turner *et al.* 2000).

1.2 Purpose of this study

A monitoring programme on coral reefs biota and environmental variables has been carried out since 1996. Analyses of the monitoring data have been restricted to summarising statistics, e.g. percentage coverage of particular key biological attributes, in order to describe trends in the general health of coral reefs. No analyses have been carried out in order to quantify the trends in community structure and link such trends to environmental variables. The term "community" here refers to any assemblage data (% cover in terms of lifeform categories) and it does not imply internal structuring of the species composition, for example, by competitive interactions.

1.2.1 Aim

In light of the paucity of information on changes in community structure of Mauritian coral reefs and the ever increasing need to effectively manage the resources they offer, the present study is aimed at analysing the data on percentage substrate cover for a set of lifeform categories, collected by the Albion Fisheries Research Centre through the Regional Coral Reef Monitoring Network, using multivariate analysis techniques.

1.2.2 Objectives

- Analyse temporal trends in community structure of four coral reef areas off Mauritius in relation to environmental variables.
- Identify the causal relationship between changes in coral communities and environmental parameters.

1.2.3 Goals

- Identify community patterns through clustering and ordination of transects from the four locations.
- Statistically test for spatial and temporal differences in the structure of coral communities.
- Identify which coral lifeform categories characterise individual coral communities within the transects.
- Link the community differences to patterns in the environment.

2 AN OVERVIEW OF THREATS AND THE STATUS OF CORAL REEFS

2.1 Global threats to coral reefs

Coral reefs offer a realm of economic and social goods to humans (Moberg & Folke 1999). In short, they are a source of income, recreation, biodiversity, food, and natural protection against shoreline erosion and storm damage. However, the worldwide coral reef scenery is degrading. Many documents have reported over the past three decades evident signs of deterioration in coral reef communities at the local, regional and global level (Wilkinson 2002). Those reports do not paint a better panorama for the future of coral reefs, the ecosystem that has been called the rainforest of the oceans (Bellwood & Hughes 2001). Compiled information suggests that such a trend is in part a response to physical and biological natural disturbances. For example, modern corals around the world are experiencing high levels of stress due to what seems to be an ongoing cycle of global climate change similar to those engraved on fossil coral records (Kleypas *et al*. 2001). Reefs have had the capacity to recover from the perturbations imposed by natural processes in the past. But, more recently, anthropogenic activities are also stressing and quickly degrading such fragile communities to the limits or beyond recovery (Wilkinson 2002). Increased fresh water run-off, sedimentation, nutrification, oil pollution, over-fishing or destructive fishing practices, improper watershed management, ship groundings or people tramping over corals are some of the human related factors that endanger reefs directly or indirectly (Wilkinson 2002). Other factors include global greenhouse gases and aerosols emissions, ozone-depleting chemicals usage, and land-use land-cover changes that are all triggering or contributing to global warming and its effects on corals (Kleypas *et al.* 2001). In order to improve our understanding of inherent coral reef processes and effective conservation practices it is important to assess better methods of characterising the environment and separating the relative influence of natural and anthropogenic stressors at various scales (Bellwood and Hughes 2001).

According to Wilkinson (2004), a series of new and emerging threats to global corals reefs has become a focus of attention in recent decades, amongst others, coral bleaching and global climate change; diseases of corals and other reef organisms; plagues of predators like the crown of thorns starfish (*Acanthaster planci*) and invasive species which have been introduced into coral reefs. He also adds that these threats are in addition to natural stresses that have always existed on coral reefs such as storms, freshwater inundation and seismic and volcanic events. Wilkinson (2004) mentions that predator plagues like the crown of thorns starfish have been increasingly reported around areas of human activities with two strong hypotheses advanced: the plagues might have been initiated and certainly exacerbated by either overfishing of key starfish predators and/or increases in nutrient runoff from the land might have favoured the planktonic stages of the starfish.

Direct human pressures on reefs have, until recently, been the dominant factors damaging coral reefs through a range of stresses: pollution through unsustainable land-based human activities such as poorly regulated agriculture and urban and industrial development resulting in the release of excess amounts of sediments and nutrients; and over-fishing and over-exploitation of coral reef fisheries (Wilkinson 2004). Modification and engineering practices in coastal development projects around the world have also affected the coral reefs, whereby there is the practice of sea reclamation, which pours sediments into shallow areas, displacing sea areas in exchange for increased terrestrial amenity (Wilkinson 2004).

2.2 Threats to coral reefs in the South West Indian Ocean (SWIO)

The damage to coral reefs in the SWIO region is caused by both natural and man-made disturbances. The natural threats include cyclones (November to February), coral bleaching occurring during the warmest months from February to April and crown of thorns starfish (COTs) outbreaks, which occur very rarely (Wilkinson 2004). A COTs outbreak was recorded by Koonjul *et al*. (unpublished (a)) in a lagoon on the east coast of Mauritius. She reported that COTs are essentially nocturnal and feed by forcing the stomach out through the mouth and turning it inside out, in a process called eversion. It usually locates itself on the coral polyps, everts its stomach, spreads it over the coral, secretes digestive enzymes onto the coral tissue and then absorbs the digested tissue as it withdraws its stomach, leaving the white skeleton of the coral colony. Occurrence of COTs in high numbers on a reef might cause grazing of live corals, leading to coral death (Koonjul *et al.* unpublished (a)).

The reefs of the SWIO have come under increasing pressure from anthropogenic impacts: urbanisation of the coast in Seychelles and Mauritius; development of tourism and related activities in Seychelles and Mauritius; in-filling of reefs in Seychelles; dredging and extraction of coral material through very destructive methods in Seychelles, Mauritius and Comoros; over-exploitation and destructive fishing methods in all island states; pollution through agriculture and aquaculture in Seychelles, through urban wastes in Mauritius, Comoros and Madagascar, through terrigenous sedimentation in Mauritius and Madagascar and through coastal erosion mainly in Madagascar (Indian Ocean Commission 1998). 500,000 tonnes of lagoonal coral sand has been extracted annually by manual methods in Mauritius (Ministry of Fisheries 2004b). Ramessur (2004) mentioned that this activity has been damaging the seabed and its communities, altering the seafloor geometry to allow bigger waves to reach the shore, thus causing widespread beach erosion. He also includes smothering of benthic communities by fine clogging sand in suspension and reduced primary productivity as other effects of the sand mining activities. A ban on extraction of shallow depth marine sediments was thus imposed in October 2001 and was viewed as an important measure towards lagoon rehabilitation in the island (Ministry of Fisheries 2004b).

Moreover, in Madagascar, fishermen walk over reef flats dragging nets, which cause substantial damage to corals (Wilkinson 2004). Similarly, dynamite fishing in the Comoros causes great damage. Turner *et al.* (2000) stated that the coral reefs in Mauritius were still healthy, but all survey sites showed some signs of degradation particularly from boat and anchor damage and also cyclones. To counteract the anchor damage caused to corals, permanent mooring buoys have been installed in heavily used and ecologically sensitive areas in Reunion and Mauritius (IELS 1998).

Most coral reefs of Madagascar, Mauritius and Reunion recovered immediately after the 1998 bleaching event and mortality was minor (Wilkinson 2004). The major impacts of this bleaching event were in the Comoros and Seychelles, but widespread and relatively mild in Mauritius. According to Wilkinson (2004), the observed bleaching event might have been a synergy of factors like an increased sea surface temperature (SST) and solar radiation, exacerbated by increased rainfall leading to decreased salinity and increased terrestrial runoff. *Acropora* species were found to be more affected on the reef flat yet non-*Acropora* species were more susceptible on the reef slope. The recovery at most damaged sites appear to be encouraging with the exception of the Seychelles, where very low rates of natural recovery even in protected areas have been observed (Wilkinson 2004).

In Mauritius, chemical and bacterial pollution from industrial or domestic sources constitutes a serious public health problem and also damages the reefs (Wilkinson 2004). Residential and tourist developments are concentrated but lack adequate sewage treatment systems, therefore there is chronic water pollution around urban and tourist areas (Wilkinson 2000). Only the three main towns were connected to sewerage systems in 2000, which discharge into the sea near water currents that carry the wastes offshore. There is now an ongoing project to connect all the major residential and industrial agglomerations to sewer networks and treatment facilities (Wilkinson 2004).

Many of the reefs around Mauritius have been degraded by human activities. Problems include high levels of sedimentation and pollution arising from the clearance of the forest and subsequent agricultural runoff (Goreau 2005). Sugar cane plantation is the main cause of agricultural pollution in Mauritius with cane fields occupying 88.5% of the 80,000 hectares of available cultivated land (Wilkinson 2004), which either discharge directly into the sea or into rivers. Wilkinson (2004) also stated that rainwater runoff carries fertilisers, pesticides and large amounts of sediment into the lagoon, resulting in localised eutrophication and sediment damage to the corals.

Tourism contributed 6.8% of the GDP in 2004, being the second largest sector in the economy of Mauritius. The number of hotel rooms were 6,000 in 1995 and have increased to 11,000 in 2004 (Ministry of Finance and Economic Development 2005). The tourist arrivals increased from 400,000 in 1995 to 700,000 in 2004. Most hotels are concentrated in a few areas, which results in serious sanitation problems (IELS 1998). The 1991 'Environment Protection Act' requires all hotels with over 75 rooms to be linked to sewage treatment, and be preceded by an EIA, however, many hotels were built prior to this and do not comply with these standards. Hotel operators deal only with visual aspects (cleaning the adjacent beaches and lagoons, and the embellishment of the yards) and leave the Government to deal with wastewater treatment (Wilkinson 2000). This is now an urgent issue to resolve before adverse publicity ruins tourist and public confidence in the clean image promoted by Mauritius. Tourism is a critical sector of the economy, and Mauritius had 718,861 arrivals in 2004 (Ministry of Finance and Economic Development 2005). The island state is classed as having a high level of reef-based tourism as over 70% of the total tourists take part in reef-based activities (Westmacott and Cesar 2000). To cater for this industry coastal development has added significant impacts, notably through pollution, but also through coral and shell collection for sale to tourists as well as direct diver impacts (Olivier *et al.* 2004). The tourists, plus the local population of 1.2 million, make Mauritius one of the most densely populated countries of the region (Wilkinson 2004).

2.3 Biodiversity in the South West Indian Ocean (SWIO)

The SWIO region is an excellent habitat model displaying reef development that reflects a high degree of endemism and biodiversity (Indian Ocean Commission 1998). There are 320 species of hard (scleractinian) corals, including seven endemic species, out of which *Pectinia africanus, Acropora roseni, Pocillopora indiannia* and *Horastrea indica* are regional endemics and *Montipora kellyi, Pocillopora fungiformis* and *Stylophora madagascarensis* are found only on the south coast of Madagascar (Wilkinson 2004). Unlike the Pacific Ocean, where diversity has a marked decrease with distance from Australasia, in the Indian Ocean diversity falls only slightly from Southeast Asia (Indian Ocean Commission 1998). Over 60 coral reef genera have been recorded in the barrier reef off Madagascar and it is estimated that the Tulear reefs in the southwest coast exhibits about 10,000 species (Indian Ocean Commission 1998). Several coral reefs such as the Aldabra atoll, in Seychelles, have been singled out as globally significant (Indian Ocean Commission 1998). Mauritius has a diversity of corals with 159 hard coral species out of which, *Acropora* is the most dominant genera, followed by *Montipora*, *Porites* and *Pavona* (Moothien Pillay *et al*. 2002). In the central SWIO, there are 316 species of algae, 8 seagrass species, 351 sponges, 71 octocorals, 55 sea anemones, 165 carridean shrimps, 22 sea spiders, 376 gastropods, 200 bivalves, 150 echinoderms and more than 400 species of reef fish (Wilkinson 2004). This list focuses on larger specimens and many smaller species are still to be discovered. Many habitats of threatened species, such as sea turtles especially Hawksbills (*Eretmochelys imbricata*), coelacanths (*Latimeria chalumnae*) and dugongs are also present in this region (Indian Ocean Commission 1998).

Coral reefs of the Indian Ocean are among the most diverse and biologically productive in the world. In addition to their global significance, they provide basic sustenance for thousands of people in the islands and they protect coastlines from the high seas. The perception that the islands are representations of paradise and have thus avoided the impacts of human development is fast eroding. With growing populations, increasing tourism and fishing pressure, many islands' coastal and marine ecosystems are threatened (Kleypas *et al*. 2001).

2.4 Monitoring of coral reefs in the South West Indian Ocean (SWIO)

In most of the SWIO island states, monitoring of the coral reefs started after the 1998 coral bleaching event with the formation of the Regional Coral Reef Monitoring Network. This network functions as the Global Coral Reef Monitoring Network (GCRMN) South West Indian Ocean Island States node and is currently being supported by the Global Environment Facility (GEF) and the European Union (EU), through the Indian Ocean Commission (Wilkinson 2004). The regional network is strengthening national monitoring capacity and raising awareness and educating local populations. The frequency of monitoring has increased in each country from once to twice yearly and some countries have initiated socio-economic studies, in parallel with reef monitoring, to assist in better management of the resources (Wilkinson 2004). This regional monitoring programme is now able to alert reef managers in the event of problems, and is an integral tool for coastal planning and management.

The main goal of the regional monitoring programme is to assist in the conservation of the high biodiversity of coral reefs and their socio-economic value and in the sustainable management of their resources, through a monitoring network within the SWIO region (Indian Ocean Commission 1998). The main objectives are amongst others: to link, in a coral reef network, stakeholders of the SWIO islands; to provide, in the form of decision-making tools for the integrated management of coastal zones, information and data on the status and trends of coral reefs for their conservation and sustainable management; and to participate in the GCRMN and help to achieve its objectives.

2.5 Status of coral reefs in the South West Indian Ocean (SWIO)

The total area coverage of coral reefs is 5,270 km^2 in the five island states of the SWIO. Though few studies have been conducted to assess marine biodiversity, there are indications that this region is rich in biodiversity and endemic species (Wilkinson 2004). The importance of the reefs to these small countries is high, given that their economies are heavily dependent on tourism and fishing. Moreover, these reefs are of utmost importance for coastal protection, especially from the frequent strong cyclones affecting the region.

Wilkinson (2004) mentioned that there were low levels of exploitation of fish and other commercial species in the SWIO region and most of the reefs were in a pristine state 100 years ago, with sparse impacts other than cyclones during the summer months. He also added that apart from areas near ports and unregulated coastal developments, many of the reefs were in a relatively healthy condition in 1994. Reef management was poorly developed in those years and there was a lack of awareness and political will for reef conservation. Since the 1998 coral bleaching event, coral cover have declined significantly on many reefs, especially in shallow areas (Wilkinson 2004). In 2004, signs of recovery at a relatively slow rate were recorded at many sites and there has been a marked increase in awareness for the need for coral reef management and conservation and all the island nations have established active monitoring programmes in a view to assist in environmental decision-making (Wilkinson 2004).

Baseline data on coral reef status across the five Indian Ocean island nations of Comoros, Madagascar, Mauritius, Seychelles and Reunion were very sparse when the catastrophic 1998 El Niño associated coral bleaching and mortality hit this region (Wilkinson 2000). Prior to the 1998 bleaching, the reefs of Comoros and the Seychelles were in good to excellent condition except for some damage near centres of population and some over-fishing. But bleaching devastated these reefs with large-scale mortalities leaving many reefs with less than 5% coral cover, down from levels of over 50% (Wilkinson 2000). Coral bleaching was more severe in the Seychelles and Comoros than in Madagascar, Mauritius and Reunion, where there was recovery within a few months (Wilkinson 2002). The coral reefs of Mauritius have escaped the mass bleaching event of 1998. The high rates of survival have, in part, been related to overcast and windy conditions for much of February and March 1998, which were associated with cyclone *Anacelle* and which mitigated the warming impacts observed elsewhere in the region (Turner *et al.* 2000). The minor occurrence of bleaching was thought to be a regular and normal event related to large environmental fluctuations experienced in the lagoons (Turner *et al.* 2000). At the Trou aux Biches site, there was less than 6% bleaching and 27% partial bleaching, especially amongst the *Acropora* species (Wilkinson 2002). The Albion Fisheries Research Centre, Mauritius reported observations from two sites and concluded that bleaching affected 39% and 31% of live corals in the shallow bays of Balaclava Marine Park and Blue Bay Marine Park respectively. Partial bleaching was 27% in both areas and total bleaching in Balaclava and Blue Bay was 12% and 4% respectively (Goorah *et al.* unpublished). The reefs of Mauritius also suffered a minor bleaching event in 2003 and 2004 (Koonjul *et al.* unpublished (b)). In 2003, as mentioned by Wilkinson (2004), coral bleaching was observed at four other sites by mid February in Mauritius and by June, 95% of the bleached corals had recovered, while 2% were still recovering and 3% had died. A similar trend was observed again in 2004, but coral mortality was slightly higher (Wilkinson 2004).

The regional monitoring network of the GCRMN reported that the coral cover on the reef flat at the Trou aux Biches site in Mauritius is relatively stable with a predominant branching

Acropora species: 45% in 1998, 43% in 1999, 44% in 2000, 48% in 2002 and 37% in 2003 (Wilkinson 2000, 2002 & 2004). Coral cover on the reef slope had a predominance of the *Porites* species and showed some variations: 43% in 1999, 44% in 2000, 39% in 2002, 50% in 2003 and 38% in 2004 (Wilkinson 2000 & 2004). The Trou aux Biches site is on the sheltered north-western coast near major tourist developments including a public beach and is partially degraded by recreational activities (Wilkinson 2000). There was apparently a normal population of fishes, with damselfish and butterfly fish well represented and abundant herbivorous species (Wilkinson 2002). It was also reported that agricultural pressures were increasing and the water clarity decreasing.

Rodrigues, which is part of the territory of Mauritius, is the oldest of the volcanic islands and has a highly developed reef structure, although a true barrier reef has not formed (Bigot *et al.* 2002). The island is totally encircled by reefs, with wide shallow reef flats extending out from the shore. In the east this narrows to 50 m in places but is more typically 1-2 km wide, while at its widest extent in the west it reaches 10 km. Seagrasses are widespread in the lagoon, and reef flats and mangrove communities are reported to be increasing. The outer slopes are steep, and have 50-70 % coral cover (Olivier *et al.* 2004).

3 MULTIVARIATE ANALYSIS TECHNIQUES IN STUDIES ON CORAL REEFS

Multivariate analysis techniques have been widely used by various authors in different studies on coral reefs. Benzoni *et al.* (2003) investigated the coral communities in the north-western Gulf of Aden, Yemen for their composition, structure and bioconstruction potential. They used hierarchical cluster analysis based on Euclidean distance to identify the main coral community types and multidimensional scaling (MDS) to look for possible environmental correlates to the patterns of coral community distribution. Rajasuriya *et al.* (1998) described the variety of reef types and habitats that are found in north-western Sri Lanka, by means of the MDS using Bray-Curtis similarity index and analysis of similarities (ANOSIM) randomisation test. An investigation of the fauna and coral community structure in response to recurring mass mortality in the southern Arabian Gulf, Dubai, UAE, was performed by Riegl (1999), where he used multivariate techniques (hierarchical cluster analysis and MDS) to detect patterns within the data set and ANOSIM to compare the community characteristics over time. Multivariate techniques were again used in a coral reef resource assessment done in a marine park in Thailand where data on both biotic and abiotic parameters of the coral reef communities and reef fish community structure were analysed (Comley *et al.* 2005). Changes in coral and fish community composition within dynamited reefs in the northern Red Sea were also determined by using hierarchical cluster analysis, MDS and ANOSIM randomisation test (Riegl and Luke 1998). Live coral cover and species richness of corals in a marine protected area in Pacific Panama were compared using the Bray-Curtis similarity index, then sorted using MDS and tested for any statistical differences using ANOSIM (Guzman *et al.* 2004).

4 METHODOLOGY

Data on the substrate cover were collected using the Line Intercept Transect method as described by English *et al*. (1997) for a set of lifeform categories and the percentage cover was calculated accordingly. Average percentage cover was plotted using MS Excel and the analysis of variance was done in the R statistical software (R Development Core Team 2005). The environmental parameters (sea surface temperature, pH, salinity and dissolved oxygen) were monitored periodically using the respective sampling and analysis methods as described in Chooramun *et al.* (unpublished). Statistical techniques were used for multivariate analysis of the community structure of the coral reefs using the PRIMER v5 (Plymouth Routines In Multivariate Ecological Research) software package (Clarke and Warwick 2001).

4.1 Line Intercept Transect

The Line Intercept Transect (LIT) technique is generally used in terrestrial ecology to assess plant ecology. It has been adopted by coral reef ecologists, and, as in the present case, the LIT method has been used to assess coral reefs. The procedure fuses a classification system based on structural attributes of lifeforms rather than species level data (English *et al*. 1997).

The LIT method is the most widely used technique for benthic monitoring of coral reefs and consists of laying a transect tape marked in centimetres along the reef at the desired location generally parallel to the reef edge and recording the distance of each lifeform category covering the substratum. A 20 m transect length was used to be consistent with the Global Coral Reef Monitoring Network protocols (English *et al.* 1997). The different transects were marked with steel rods at 5 m intervals. For easy relocation, yellow plastic tags were attached to these rods and GPS coordinates recorded. Permanent transects, which can be repeatedly sampled over time, were used because they require considerably less effort and comparisons between times seem intuitively convincing (Jeury de Grissac 1997).

A diver laid the 20 m tape along the marked transect. Another diver recorded the presence of the different lifeform categories on an underwater slate by using the corresponding codes (Figure 3) and the intercept distances in centimetres for each category. The diver was equipped with either snorkelling or scuba gear, depending on the water depth at each of the stations.

Table 1: Lifeform categories and codes used in data collection of substrate cover.

Categories	**Codes**
Algal Assemblage	AA
Branching Acropora	ACB
Branching non-Acropora	CB
Coralline Algae	AC
Dead Coral	CX
Dead coral with algae	CXA
Digitate Acropora	ACD
Encrusting Acropora	CA
Encrusting non-Acropora	CE
Foliaceous non-Acropora	CF
Macroalgae	AD
Massive non-Acropora	CM
Mushroom coral	CL
Other	OT
Rock	RO
Rubble	DEB
Sand	SA
Soft Coral	CMO
Sponge	EP
Submassive Acropora	ACS
Submassive non-Acropora	CS
Tabulate Acropora	ACT
Turf Algae	AG
Zoanthid	ZO

The LIT method is used to estimate the cover of an object or group of objects within a specified area by calculating the fraction of the length of the line that is intercepted by the object. At each point where the benthic lifeform changes, the diver recorded the transition point in centimetres and the code of the lifeform (Figure 3). Hence, along the length of a transect (XY) a number of transition points (T) were recorded for each of the lifeforms. The length of each lifeform encountered under the transect (L) was the difference between the transition points recorded for each lifeform (English *et al*. 1997).

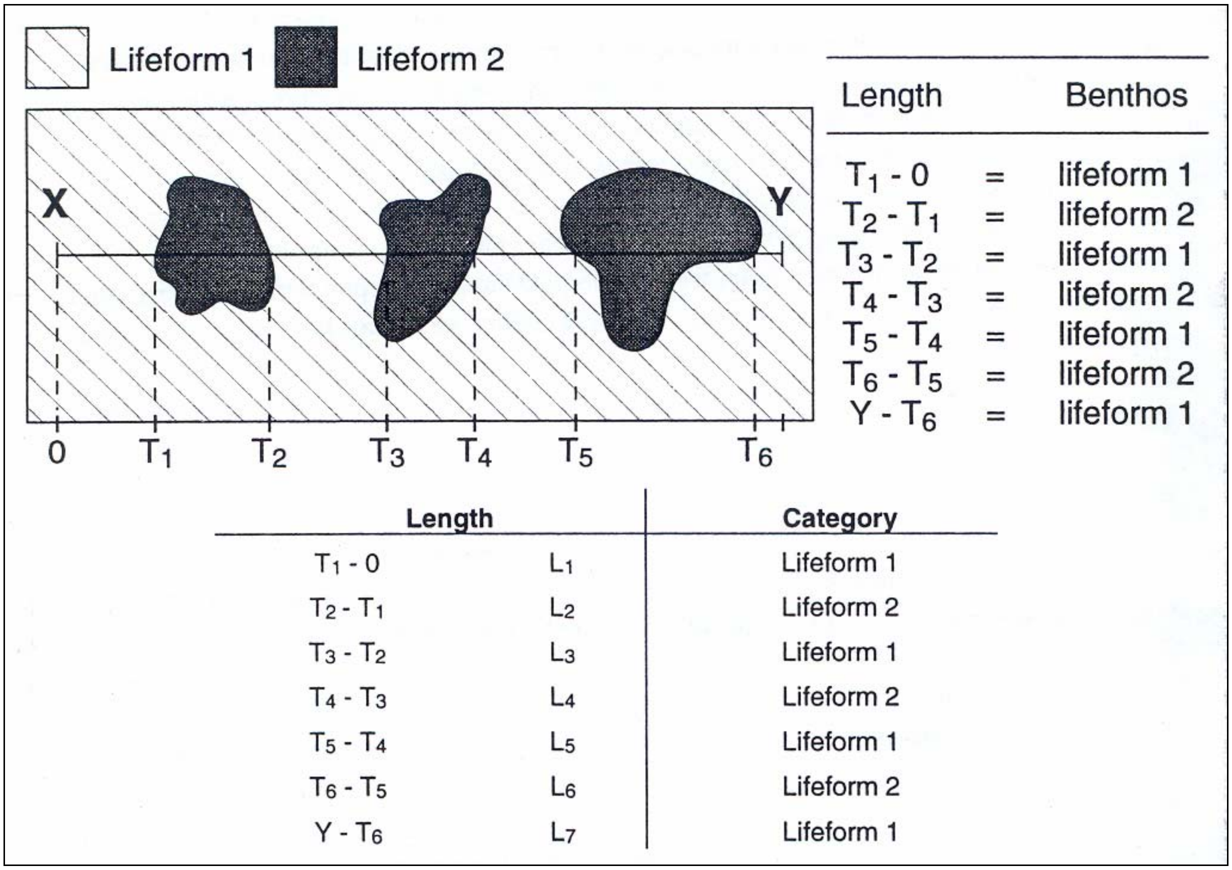

Figure 3: Schematic diagram of a transect (XY) showing the transition points (T) for each lifeform crossed by the transect. The difference between consecutive transition points is the "length" of the lifeform (English *et al*. 1997).

This measure of cover, usually expressed as a percentage, is considered to be an unbiased estimate of the proportion of the total area covered by that object (English *et al*. 1997). After calculating the length of the transition points recorded along the transect (Figure 3), the percentage cover of a lifeform category was calculated:

$$\textit{Percentage cover} = \frac{\textit{Total length of category}}{\textit{Length of transect}} \times 100$$

$$\textit{Percentage cover of lifeform 1} = \frac{L_1 + L_3 + L_5 + L_7}{Y} \times 100$$

$$\textit{Percentage cover of lifeform 2} = \frac{L_2 + L_4 + L_6}{Y} \times 100$$

4.1.1 Statistical analysis

Total average percentage substrate cover of individual categories and annual average percentage cover of algae and live coral categories on the coral reefs were plotted in MS Excel, with standard deviations of the latter percentage cover. One-way ANOVA was used to test for the null hypothesis that the mean annual average percentage cover of algae and live coral categories at individual coral reef being equal over the period of study using the R statistical software (R Development Core Team 2005). In cases where the null hypothesis was rejected, a pairwise multiple comparison test, Tukey test, was carried out to determine between which annual means differences existed.

4.2 Study areas

The Albion Fisheries Research Centre monitors twelve sites around Mauritius through the Regional Coral Reef Monitoring Network (Ministry of Fisheries 2004a). These sites were selected in relation to the different types of coastal activities taking place in the respective regions. Only four sites were chosen for the purposes of this project, namely: Bel Ombre, Bambous Virieux, Ile aux Benitiers and Trou aux Biches (Figure 4 and Table 2).

Figure 4: Location of the four monitoring sites in this study.

Table 2: Summary of selection criteria used for the choice of the four study areas.

Location	**Agricultural run off**	**Terrigenous inflow**	**Hotels**	**Hotels (in construction)**	**Public beach**	**Control site**
Bel Ombre	X			X		
Bambous Virieux	X	X				
Ile aux Benitiers						X
Trou aux Biches			X		X	

4.2.1 Trou aux Biches

The Trou aux Biches monitoring site is leeward in the northwest of Mauritius and was selected due to its location in an area with highly developed tourist activities and a very well frequented public beach. Two stations have been chosen, one on the reef flat (back reef) and one on the outer slope (fore reef).

The back reef station is 3m deep at high tide and is dominated by branching *Acropora* (Bigot *et al*. 2002). It is partly damaged by recreational activities, and the Crown of Thorns Starfish *(Acanthaster planci)* can sometimes be seen (Ahamada *et al*. 2003).

The fore reef station is located 50 m off the fringing reef and around 100 m north of the pass of Mon Choisy. Its depth varies from 8-9 m. Massive *Porites* is the dominant form of coral (Bigot *et al*. 2002).

4.2.2 Bambous Virieux

The Bambous Virieux monitoring site is windward in the south-eastern coast of Mauritius and is located near a fishing village in a mountainous area. This site was selected due to its location near a catchment's area, which receives agricultural run-offs. The lagoon at this site is 5 km wide and 2-3 m deep, with a deep channel in the centre. It is also close to a large pass that is subjected to the influence of the Grand River South East, which impacts this lagoon by large terrigenous inflows, accompanied by fertilisers and agricultural wastes (Bigot *et al*. 2002). Sand mining was a major activity in this area (Wilkinson 2000), prior to its prohibition as of October 2001. Two monitoring stations have been established on the internal fringing reef namely, back reef and shore reef.

The shore reef station is adjacent to a jetty at Bambous Virieux and to a recently dredged boat passage. The three transects are parallel to each other and to the fringing reef, and the first one runs up to the slope of the deep channel to a depth of about 5m (Bigot *et al*. 2002). This station is situated at about 250 m from the shoreline. The back reef station is located south of Pointe du Diable in the lagoon at about 200 m south of the deep channel. Coral cover is dominated by *Pavona* spp. and *Porites* spp. (Bigot *et al*. 2002).

4.2.3 Bel Ombre

Bel Ombre is a coastal village located in the southern part of the island. The lagoon is about 700 m wide and the fringing reef is interrupted by a main pass. This site was initially selected due to its proximity to the Bel Ombre sugar factory. The site is exposed to trade winds, which are mostly in the south and southeast direction. The lagoon in the sub tidal zone is dominated by dense patches of seagrass, namely, *Syringodium isoetifolium* and *Halodule universes* (Ministry of Fisheries 2000). Major coastal developments comprising of the construction of hotels have been carried out in the region of Bel Ombre. The coastal sugar factory has ceased to operate since hotels have been constructed in its place. The shore reef station is just off the wharf adjacent to the pass and the back reef station is located inside the patch reef within the lagoon at a depth of 2 m. The dominant coral species are *Porites* and *Montipora* (Goreau 2005). The first transect starts at the slope of the channel at a depth of about 4 m.

4.2.4 Ile aux Benitiers

The islet, "Ile aux Benitiers," is found close to a fishing village in the south-western coast of Mauritius where the lagoon is approximately 2 km wide. This region is relatively undeveloped in terms of tourism industry and human settlement. This site has been chosen as the control site for the monitoring of coral reefs around Mauritius as no coastal development has been undertaken in this region. Three stations were established: the fore reef, back reef and the shore reef stations.

The back reef and fore reef stations are opposite each other to the north of the islet "Ile aux Benitiers". The shore reef station is further north and at a depth of 4-5 m at high tide. The most dominant coral species are *Acropora grandis* and *Pavona cactus* (Ahamada *et al*. 2003).

The back reef station is at a depth of 2-3 m at high tide and is dominated by the table coral, *Acropora hyacinthus* (Ahamada *et al*. 2003), whereas there is a high coral diversity at the fore reef, which is 6 m deep.

4.3 Measurement of environmental parameters

The environmental parameters were monitored periodically over the study period to understand the temporal changes. It should be noted that the frequency of sampling was not standardised over the period of study and that sampling for measurement of these parameters was not performed on the same day as coral reef monitoring.

4.3.1 Sea surface temperature (SST)

Water temperature is a fundamental environmental parameter and is measured in degrees Celsius. On measurement of the temperature, the sensor of a digital thermometer was submerged at depth of 0.5 m for a few minutes before the value of the water temperature was recorded (Chooramun *et al.* unpublished). It should be noted that the digital thermometer was regularly calibrated with a certified thermometer.

4.3.2 Salinity

Salinity was measured using an electronic laboratory conductivity meter, which had been regularly calibrated with standard seawater (Chooramun *et al.* unpublished). The same water samples as for the pH measurements were used for salinity.

4.3.3 pH

Completely filled and tightly closed glass bottles that have been rinsed with the water sample were used for storage and transportation of samples. These bottles were stored refrigerated in the dark prior to pH measurement, which was done using an electronic laboratory pH meter within 24 hours of collection of the water samples. It should be noted that the pH meter had been regularly calibrated with standard pH solutions at pH 7 and pH 9 before use (Chooramun *et al.* unpublished).

4.3.4 Dissolved oxygen (DO)

The Winkler method was used to determine the concentration of dissolved oxygen in the water samples. The basis of the Winkler method is that oxygen in a seawater sample is made to oxidise iodine ions to iodine in the presence of an alkaline solution of manganese (II) ions (Codispoti 1988). The amount of iodine generated is then determined by titration with a standard thiosulfate solution. The end point is located using starch as a visual indicator for the presence of iodine. The amount of oxygen present in the original sample can then be computed from the titre.

4.3.5 Statistical analysis

Data from different reefs were pooled and averaged per location. MS Excel was used to plot the annual average values of the parameters at individual coral reefs and to calculate their standard deviations. One-way ANOVA was used to test for the null hypothesis that the average value of the respective parameters being equal over the period of study using the R statistical software (R Development Core Team 2005). In cases where the null hypothesis was rejected, a pairwise multiple comparison test, Tukey test, was carried out to determine between which annual means differences existed.

4.4 Multivariate analysis

A multivariate analysis attempted to reduce the complexity of the (high-dimensional) community data by taking a particular (low-dimensional) "view" of the structure it exhibited (Clarke and Warwick 2001). These techniques were characterised by the fact that they based their comparisons of two (or more) transects on the extent to which these transects shared particular lifeform categories, at comparable levels of abundance (Clarke and Warwick 2001). In other words, it was based only on the similarity matrix between transects, as defined by the biologist to reflect the particular aspects of community structure that were biologically meaningful in the study (Clarke 1993). Either explicitly or implicitly, all multivariate techniques were founded on such similarity coefficients, calculated between every pair of transects (Clarke and Warwick 2001). These then facilitated a clustering of transects into groups which were similar, or an ordination plot in which, for example, the transects were "mapped" (usually in two or three dimensions) in such a way that the distances between pairs of transects reflected their relative dissimilarity of lifeform categories composition. The strategy was to observe any pattern of similarities and differences across the transects (i.e. let the biology "tell its own story") and only later, was this compared with known or hypothesised inter-relations between the transects based on environmental factors (Clarke and Warwick 2001). Using numerous examples, Clarke and Warwick (1993) showed that multivariate methods of data analysis were more sensitive in detecting differences in community structure between samples in space, or changes over time, in comparison to univariate techniques.

The percentage cover data were first organised per transects (rows) and lifeform categories (columns), and then imported into the PRIMER v5 software which was used in this study. PRIMER v5 consists of a range of univariate, graphical and multivariate routines for analysing matrices of species (lifeform categories in this case) by percentage coverage that aroused in biological monitoring of the coral reefs and studies in community structure, together with associated physicochemical data (Clarke and Gorley 2001). The basic routines of the package covered in this study were: hierarchical clustering into transect groups (CLUSTER); ordination by non-metric multidimensional scaling (MDS); permutation-based hypothesis testing (ANOSIM), an analogue of ANOVA which tested for differences between groups of transects from different times and locations; identifying the lifeform categories primarily providing the discrimination between two observed transect clusters (SIMPER) and the linking of the community structures to environmental variables (BIO-ENV).

4.5 Hierarchical cluster analysis (CLUSTER)

Cluster analysis aimed at finding “natural groupings” of transects such that transects within a group were more similar to each other than transects in different groups. A matrix of Bray-Curtis index of similarity was constructed using square root transformed percentage cover data. The Bray-Curtis index is a measure of the distance (similarity) between every pair of transects. A similarity value of 0% meant that there was no similarity among a pair of transect, while 100% suggest that the transects were identical (Clarke and Warwick 2001).

The hierarchical agglomerative clustering method takes the similarity matrix as its starting point and successively fuses the transects into groups and the groups into larger clusters, starting with the highest mutual similarities then gradually lowering the similarity level at which groups are formed (Clarke and Warwick 2001). The process ends with a single cluster containing all transects. The result of the hierarchical clustering was represented by a dendogram, with the *x* axis representing the full set of transects and the *y* axis defining a similarity level at which two transects or groups are considered to have fused. This was done by the CLUSTER routine of PRIMER v5.

4.6 Non-metric Multidimensional Scaling (MDS)

The percentage coverage data were further analysed by means of multivariate non-metric MDS using the Bray-Curtis similarity index in square root transformed data. The method of non-metric MDS attempted to place the transects on a “map”, usually in two dimensions, in such a way that the rank order of the distances between transects on the map exactly agreed with the rank order of the matching similarities, taken from the triangular similarity matrix (Clarke and Warwick 2001). MDS is a 3-dimensional ordination of transects brought down to a 2-dimensional plot. Thus, the MDS ordination produced a plot where each data point represented a transect and the relative distance among them illustrated their relative similarity. If successful, and success measured by a stress coefficient which reflected lack of agreement in the two sets of ranks, the ordination gave a simple and compelling visual representation of “closeness” of the lifeform categories for any two transects (Clarke 1993). The quality of the MDS plots was indicated by the stress value. Values <0.2 gave a potentially useful 2-dimensional picture, stress <0.1 corresponded to a good ordination and stress <0.05 gave an excellent representation (Clarke and Warwick 2001). Each MDS analysis was performed 10 times as per the PRIMER v5 default setting.

4.7 Analysis of Similarities (ANOSIM)

A pre-requisite to interpreting community differences between transects should be a demonstration that there were statistically significant differences to interpret. The formal demonstration that the quantitative information and the a priori transect groupings were related was achieved by a one-way ANOSIM test (Clarke 1993). This analysis was built on a non-parametric permutation procedure applied to the same rank similarity matrix underlying the classification or ordination of the transects. It was more applicable to the presently used data sets than a multivariate analysis of variance as it did not assume normality of data and allowed for the dominance of zero counts in the typical transect data-set. It tested against the null-hypothesis that there were no differences in community composition between transects (Clarke and Green 1988). Two terms were important in the ANOSIM significance test: P (significance level) and Global R. Global R indicated the degree of similarity between the tested groups with values between -1 and 1. If all transects within groups is more similar to each other than any transect from different groups, the value of R is 1. Values close to zero indicated that the similarity between groups was very high, showing a low difference between them (Clarke and Warwick 1993). The important message of the pairwise tests was not so much the significance level (which can often be low because of the few transects in each group), but the pairwise R values, since that gave an absolute measure of how separated the groups were, on a scale of 0 (indistinguishable) to 1 (all similarities within groups were less than any similarity between groups): R>0.75 for well separated groups, R>0.5 indicated overlapping but clearly different and R<0.25 for groups that were barely separable at all (Clarke and Gorley 2001).

4.8 Determining discriminating lifeform categories (SIMPER)

For a transect group (either defined a priori and confirmed by an ANOSIM test, or identified as a result of cluster analysis), an important practical requirement was to identify which lifeform categories primarily accounted for the observed community difference within the transects (Clarke and Gorley 2001). This was accomplished by the SIMPER (similarity percentages) routine of PRIMER v5 and the lifeform categories were listed at a 90% cut-off value. The output obtained took each transect group on its own and decomposed the similarities of all within-group transect comparisons into their contributions from each lifeform category. This gave the lifeform categories, which were typical of a group, in the sense that they were found at high abundances in most transects (Clarke and Gorley 2001).

4.9 Linking the community structures to environmental variables (BIO-ENV)

The environmental variables (SST, salinity, pH and DO) were first analysed in their own and their multivariate patterns compared to that of the percentage cover data. The extent to which the patterns matched reflected the degree to which the environmental data “explained” the community structures (Clarke and Gorley 2001).

The environmental data were first organised per transects (rows) and environmental parameters (columns), and then imported into the PRIMER v5 software. As the environmental variables were on mixed measurement scales, the Bray-Curtis similarity index, which assumed a common measurement scale, was not appropriate. Instead, the variables were first normalised (subtract the mean, divide by the standard deviation) to put them on a common, dimensionless measurement scale and standard (Euclidean), distance was then used as the measure of distance of the transects from each other (Clarke and Gorley 2001). Scatter plots of all pairwise combinations of the environmental variables, also called a draftsman plot, would then be expected to show roughly linear relationships and a symmetric distribution of points (elliptic contours, rather than heavily skewed). Ordination was then done by Principal Components Analysis (PCA), which used Euclidean distance as its similarity measure.

Two separate matrices were supplied to the BIO-ENV routine. The first was the transects similarity matrix, as used for earlier routines (CLUSTER, MDS, etc), which was referred to here as the fixed similarity matrix. The second was that of the environmental variables. The BIO-ENV routine calculated a measure of agreement between the two similarity matrices, the fixed biotic matrix and each of the possible abiotic matrices. This was done by rank correlating the matching elements in the two similarity matrices (with a weighted Spearman rank correlation in this case). A rank coefficient was appropriate because the similarity matrices being compared were computed by entirely different types of coefficients (Bray-Curtis compared with Euclidean distance). However, it should be noted that one should always be aware that the linking of biological patterns to those of environmental variables for an observational study, by whatever statistical means it was carried out, can never be a demonstration that certain abiotic variables were the cause of the biological pattern (Clarke and Gorley 2001).

5 RESULTS

5.1 Average percentage substrate cover of lifeform categories

5.1.1 Bel Ombre

5.1.1.1 Shore reef

At the shore reef monitoring station of Bel Ombre, for the whole period of study, the cover of live coral was 48% and that of algae was 23%. Dead coral was found to be at 20% coverage and the abiotic substrate (rock, rubble and sand) had a mean of 9% over the years (
a). There had been an insignificant decline in the coverage of algae ($F_{[6, 20]} = 2.354$, $p = 0.070$) (Figure 6a), whereas live coral had a constant average percentage cover ($F_{[6, 20]} = 0.310$, $p = 0.925$).

5.1.1.2 Back reef

The analysis of the average percentage cover of lifeforms indicated that the substrate at Bel Ombre back reef (
d) was almost equally dominated by algae and live coral over the period of study (35% and 36%, respectively). Dead coral and abiotic categories had a relatively low coverage (12% and 15%, respectively). During the early phase of the study period (1998-1999), algae and coral covered similar proportions of the reef area with an average annual coverage of 32-41% (Figure 6d). Algae coverage remained constant (39-42%) throughout the study period ($F_{[5, 18]} = 0.456$, $p = 0.804$), but mean live coral cover, however, dropped significantly to 21% in 2000 ($F_{[5, 18]} = 4.785$, $p = 0.006$, Tukey HSD). By 2003, it had recovered (47%), but has declined since then, and reached a significant low (24%) in 2005.

5.1.2 Bambous Virieux

5.1.2.1 Shore reef

Over the study period, the mean percentage covers of live coral and algae were almost at the same level (41% and 39%, respectively) at the shore reef station of Bambous Virieux (
b), with 14% of dead coral cover and 5% of the abiotic category. There was no significant change in annual average cover of algae and live coral during the study period (algae: $F_{[6, 23]} = 0.279$, $p = 0.941$; live coral: $F_{[6, 23]} = 0.1.862$, $p = 0.131$; Figure 6b).

5.1.2.2 Back reef

Live coral was highly dominant at the back reef station of Bambous Virieux over the study period (53%) with low average percentage covers of algae (14%), dead coral (14%) and abiotic categories (19%) (
e). This observation was even more obvious in Figure 6 (e) where the coverage of live coral evolved around 50% over the years ($F_{[6, 26]} = 0.828$, $p = 0.559$). Mean algal coverage decreased significantly from 26% in 1998 to 6% in 2004 ($F_{[6, 26]} = 3.312$, $p = 0.015$, Tukey HSD), with a somewhat increased value in 2005 (14%).

5.1.3 Ile aux Benitiers

5.1.3.1 Shore reef

At the shore reef station of Ile aux Benitiers, the live coral cover was 30% during the years under study, similar to the cover of dead coral and abiotic substrate (25% and 32%, respectively;
c). Algae had a relatively low substrate cover (13%). During the early phase of the study period (1998-1999), algal coverage was 25% (Figure 6c) but decreased significantly thereafter ($F_{[6, 23]} = 2.742$, $p = 0.037$, Tukey HSD) and was absent in 2005. No significant difference was observed in the mean live coral cover over the years ($F_{[6, 23]} = 1.622$, $p = 0.186$).

5.1.3.2 Back reef

During the study period, the live coral dominated the substrate at the back reef station of Ile aux Benitiers (51%) while dead coral cover was at 28% (
f). Algae and abiotic categories amounted to 7% and 14%, respectively. There was no significant difference of mean algal cover (Figure 6f) over the years ($F_{[6, 25]} = 1.894$, $p = 0.122$). Highly significant variations of live coral cover were observed ($F_{[6, 25]} = 5.605$, $p = 0.001$, Tukey HSD), with a constant decline after 1999 to a low value of 7% in 2005.

5.1.3.3 Fore reef

At the fore reef station of Ile aux Benitiers, the abiotic substrate cover was higher than that of live coral coverage over the whole study period (43% and 37%, respectively), while dead corals and algae accounted for 5% and 11% of the surveyed area, respectively (
h). In 1998, algae were completely absent on the substrate, but reached an average of 21% cover in 1999 (Figure 6h), which remained relatively constant until 2002 and then decreased to almost zero thereafter. This temporal trend was, however, not significant ($F_{[6, 20]} = 1.703$, $p = 0.172$). There was no significant difference in the live coral cover during the study period ($F_{[6, 20]} = 1.224$, $p = 0.336$) though it increased gradually from 37% in 1998 to 47% in 2000, then decreased to 23% in 2004.

5.1.4 Trou aux Biches

5.1.4.1 Back reef

The back reef station of Trou aux Biches had 41% of live coral coverage over the years (
g), with dead coral cover at 29% being the next dominant feature of the coral reef, while algae and the abiotic substrate were respectively, 11% and 19%. There was a relatively constant coverage of live corals from 1998 to 2005 (Figure 6), evolving around 40% ($F_{[6, 26]} = 0.398$, $p = 0.873$). Significant difference was noted in the mean algae coverage between 1998 and 2005 ($F_{[6, 26]} = 3.483$, $p = 0.012$, Tukey HSD).

5.1.4.2 Fore reef

Live coral and abiotic substrate dominated the substrate of the fore reef station of Trou aux Biches at 41% and 39% respectively (

i), with a low coverage of algae and dead corals (7% and 10%, respectively). There was a relatively constant average coverage of live coral from 1998 to 2002 (Figure 6i), with a slight decrease from 2002 to 2005. However, there was no significant trend in the live coral cover ($F_{[6, 21]} = 1.214$, $p = 0.338$). No significant difference was also observed in mean algal coverage during the period of study ($F_{[6, 21]} = 1.16$, $p = 0.364$).

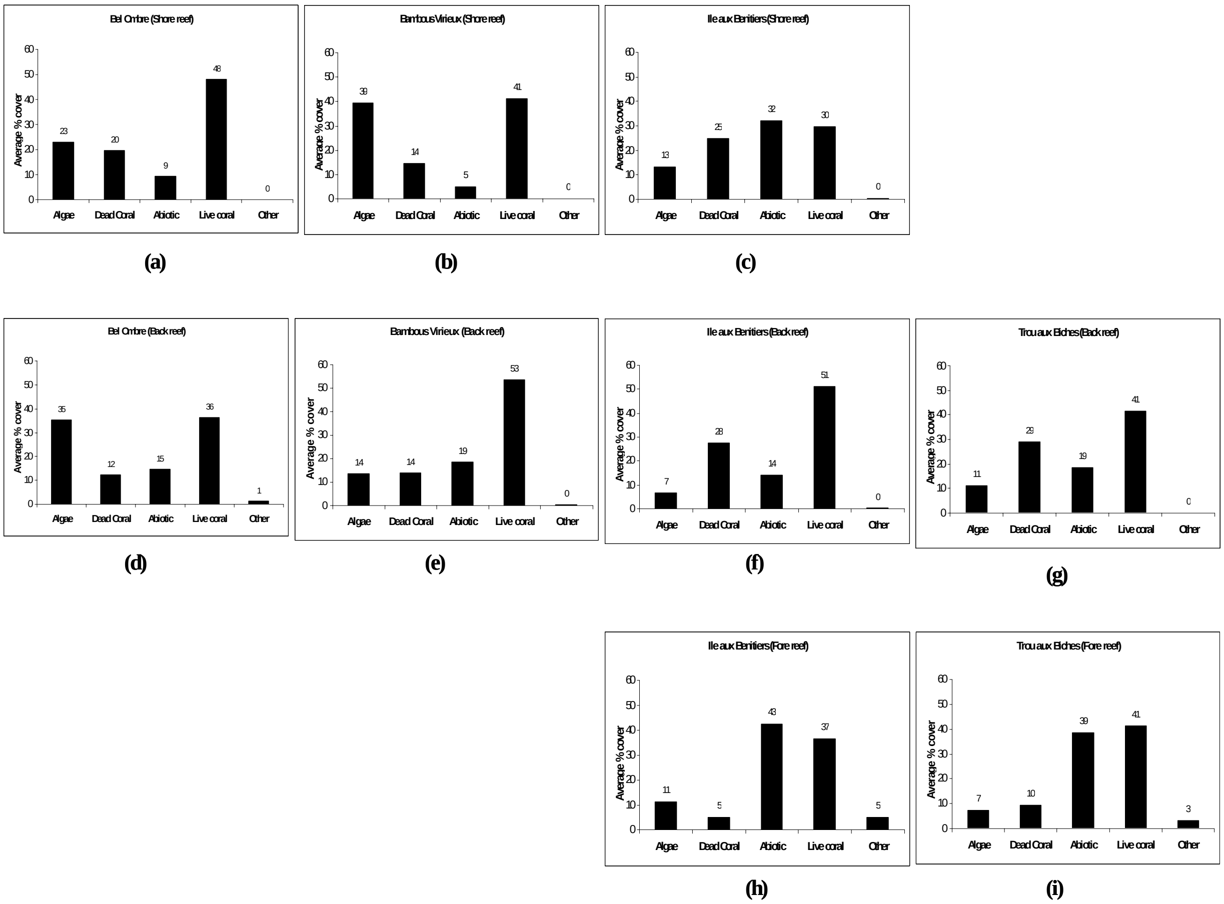

Figure 5: Total average percentage substrate cover of individual categories on coral reefs from four locations off Mauritius during the period 1998-2005. Abiotic substrate included rocks, rubbles and sand, whereas zoanthids, sponges and soft corals were grouped in the “other” category. No monitoring was carried out in 2001.

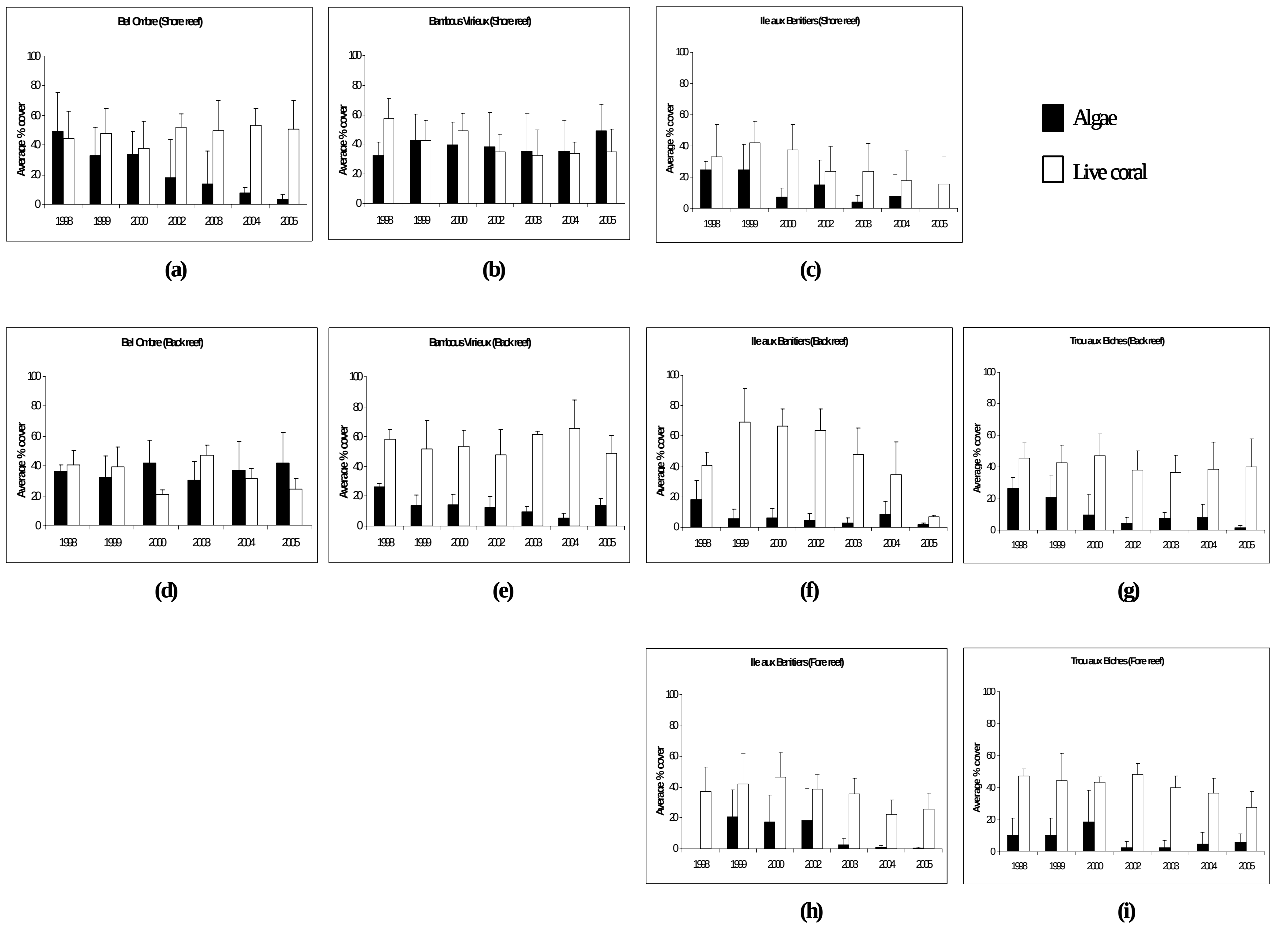

Figure 6: Annual average percentage cover of algae and live coral on coral reefs from four locations off Mauritius during the period 1998-2005 + 1 SD. At each location, monitoring was carried out on three transects on two or three types of reefs (shore reef, back reef and fore reef). No monitoring took place in 2001.Environmental parameters.

Analysis of the temporal trend in the environmental parameters was carried out on annual average values per location (pooled data across different coral reefs). A summary of the analysis of variance (ANOVA) of the physicochemical parameters at the four locations is presented in.

Table 3: Results of one-way ANOVA of environmental parameters at each location (SST: sea surface temperature, DO: dissolved oxygen).

Parameters	Location	Sum of squares	df	Mean square	F ratio	P value
SST	Bel Ombre	57.117	7	8.160	2.012	0.080
	Bambous Virieux	24.123	7	3.446	0.399	0.896
	Ile aux Benitiers	73.555	7	10.508	2.999	0.012
	Trou aux Biches	27.710	7	3.959	1.283	0.289
Salinity	Bel Ombre	19.384	7	2.769	6.295	0.0001
	Bambous Virieux	191.211	7	27.316	6.083	0.0001
	Ile aux Benitiers	4.480	7	0.640	3.441	0.005
	Trou aux Biches	12.691	7	1.813	11.071	0.0000003
PH	Bel Ombre	0.609	7	0.087	5.904	0.0001
	Bambous Virieux	0.713	7	0.102	3.247	0.100
	Ile aux Benitiers	0.134	7	0.019	1.879	0.0980
	Trou aux Biches	0.525	7	0.075	3.338	0.0080
DO	Bel Ombre	2.383	7	0.340	0.576	0.771
	Bambous Virieux	3.577	7	0.511	0.451	0.862
	Ile aux Benitiers	9.363	7	1.338	1.084	0.390
	Trou aux Biches	5.847	7	0.835	0.672	0.694

A summary of the annual average sea surface temperature (SST), salinity, pH and dissolved oxygen (DO) during the period of study at the nine coral reefs are given in.

Table 4. Mean SST varied in the range of 22.90-29.00°C at Bel Ombre, 24.80-27.80°C at Bambous Virieux, 23.5-28.00°C at Ile aux Benitiers and 24.5-27.75°C at Trou aux Biches. Mean salinity values ranged from 33.25 to 35.50 at Bel Ombre, 27.97-35.38 at Bambous Virieux, 33.20-35.63 at Ile aux Benitiers and 33.60-36.00 at Trou aux Biches. The mean pH and DO values were both within the limits of the *Guidelines for Coastal Water Quality* (appendix) which states that pH should be between 7.5 and 8.5, and DO values should be greater than 5 mg/L.

Table 4: Summary of environmental parameters from 1998 to 2005 at the different coral reef areas off Mauritius.

BELO SR	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
SST	25.68 (1.56)	25.84 (2.14)	25.20 (3.68)	27.00 (2.17)	23.80*	26.73 (2.93)	26.40 (0.85)	29.00 (0.71)
Salinity	35.18 (0.21)	35.38 (0.48)	35.25 (0.07)	34.97 (0.15)	33.25 (0.21)	34.43 (1.03)	34.45 (0.64)	33.25 (1.77)
PH	8.28 (0.05)	8.44 (0.09)	8.40 (0.14)	8.23 (0.06)	8.35 (0.07)	8.20 (0.10)	8.30 (0.00)	8.10 (0.00)
DO	8.35 (1.33)	8.46 (1.05)	8.45 (0.07)	8.07 (0.59)	8.05 (0.35)	7.60 (0.78)	8.40 (0.99)	7.95 (1.20)
BELO BR								
SST	25.30 (2.20)	25.68 (2.06)	25.35 (3.04)	26.8 (2.42)	22.90*	26.97 (3.52)	26.00 (0.00)	28.50 (0.71)
Salinity	35.13 (0.28)	35.50 (0.22)	34.80 (0.57)	34.87 (0.23)	34.45 (0.07)	33.33 (1.27)	34.25 (0.78)	34.10 (0.99)
PH	8.28 (0.25)	8.44 (0.09)	8.35 (0.21)	8.20 (0.10)	8.20 (0.00)	8.00 (0.20)	8.20 (0.00)	8.15 (0.07)
DO	7.93 (0.53)	8.48 (0.37)	8.25 (0.21)	7.57 (0.51)	7.60 (0.14)	8.57 (0.58)	7.85 (0.78)	8.65 (1.34)
BV SR								
SST	26.70 (2.25)	25.15 (1.44)	24.80 (3.54)	25.95 (7.14)	26.00 (3.54)	26.93 (2.65)	27.13 (4.25)	27.05 (2.76)
Salinity	34.70 (1.15)	35.24 (0.38)	34.60 (0.00)	34.80 (0.14)	34.70 (0.28)	31.53 (3.40)	34.53 (0.71)	30.00 (3.68)
PH	8.40 (0.17)	8.44 (0.09)	8.35 (0.07)	8.25 (0.07)	8.15 (0.21)	8.17 (0.15)	8.10 (0.36)	8.25 (0.07)
DO	8.33 (2.46)	8.04 (0.84)	8.60 (0.00)	8.15 (0.49)	7.90 (0.14)	8.37 (0.40)	8.27 (0.76)	8.30 (0.42)
BV BR								
SST	27.95 (1.48)	25.43 (1.15)	27.80*	26.15 (7.57)	26.45 (2.90)	27.13 (2.22)	27.40 (3.92)	27.40 (2.26)
Salinity	35.10 (0.00)	35.38 (0.21)	35.30*	34.90 (0.28)	34.55 (0.07)	27.97 (6.09)	35.23 (1.71)	30.55 (2.47)
PH	8.65 (0.21)	8.35 (0.24)	8.30*	8.35 (0.07)	8.15 (0.07)	8.20 (0.10)	8.10 (0.30)	8.45 (0.07)
DO	9.20 (3.11)	8.53 (0.87)	7.80*	7.85 (0.49)	7.25 (0.64)	8.53 (1.15)	8.73 (1.04)	8.25 (0.64)
IAB SR								
SST	26.30 (1.95)	25.23 (2.69)	24.17 (2.54)	26.20 (3.25)	27.25 (2.47)	23.20*	25.90 (2.26)	28.00*
Salinity	35.00 (0.51)	35.12 (0.41)	35.63 (0.61)	34.75 (0.21)	34.85 (0.07)	33.20*	35.10 (0.28)	34.90*
PH	8.37 (0.06)	8.28 (0.11)	8.33 (0.23)	8.25 (0.07)	8.15 (0.07)	8.20*	8.15 (0.07)	8.10*
DO	7.33 (0.79)	7.40 (0.83)	7.53 (0.55)	7.15 (0.78)	8.05 (0.35)	8.30*	7.60 (0.85)	8.00*
IAB BR								
SST	27.45 (1.70)	25.18 (2.11)	24.37 (2.04)	26.50 (2.83)	26.90 (2.26)	23.70*	26.50 (2.12)	28.00*
Salinity	34.98 (0.66)	35.30 (0.14)	35.37 (0.81)	34.90 (0.00)	34.95 (0.07)	34.90*	34.85 (0.21)	34.70*
PH	8.33 (0.06)	8.30 (0.14)	8.33 (0.15)	8.35 (0.07)	8.25 (0.07)	8.30*	8.25 (0.07)	8.20*
DO	9.28 (1.80)	9.06 (1.02)	6.93 (0.64)	7.15 (1.20)	7.85 (0.49)	8.50*	9.25 (0.07)	8.60*
IAB FR								
SST	25.77 (1.36)	25.15 (2.90)	23.50*	26.20 (3.25)	28.00*	23.60*	27.50*	28.00*
Salinity	34.83 (0.38)	35.45 (0.07)	34.60*	34.75 (0.21)	34.60*	34.30*	34.70*	34.90*
PH	8.30 (0.14)	8.20 (0.00)	8.30*	8.30 (0.00)	8.20*	8.30*	8.30*	8.20*
DO	6.40 (0.60)	6.90 (0.42)	7.90*	7.35 (0.49)	8.20*	8.60*	9.40*	8.20*
TAB BR								
SST	26.93 (1.60)	25.24 (1.64)	26.70 (0.99)	25.77 (1.94)	26.30 (3.11)	27.00 (3.25)	26.37 (1.44)	27.75 (1.77)
Salinity	35.13 (0.30)	35.40 (0.48)	36.00 (0.42)	34.67 (0.12)	34.20 (0.14)	33.80 (0.14)	34.50 (0.85)	33.60 (0.28)
PH	8.33 (0.21)	8.28 (0.24)	8.35 (0.07)	8.33 (0.06)	8.10 (0.14)	8.05 (0.21)	8.23 (0.06)	8.05 (0.21)
DO	8.40 (1.77)	8.22 (1.61)	8.00 (0.00)	8.07 (0.80)	8.05 (0.49)	8.25 (1.06)	7.77 (0.32)	8.30 (0.42)
TAB FR								
SST	24.80*	24.96 (1.59)	26.55 (0.78)	24.50 (0.00)	26.25 (3.18)	26.70 (3.39)	26.10 (2.09)	27.65 (1.77)
Salinity	34.90 (0.42)	35.34 (0.45)	35.85 (0.49)	34.65 (0.35)	34.65 (0.07)	34.50 (0.00)	34.67 (0.15)	34.70 (0.14)
PH	8.20 (0.00)	8.24 (0.17)	8.30 (0.00)	8.30 (0.14)	8.10 (0.14)	8.00 (0.28)	8.20 (0.00)	7.95 (0.21)
DO	7.15 (0.64)	6.70 (0.59)	6.65 (0.07)	8.40 (1.56)	7.05 (0.49)	8.45 (1.06)	7.23 (0.46)	8.20 (1.84)

The respective parameters (SST: sea surface temperature; DO: dissolved oxygen; salinity; and pH) were averaged over each year. The standard deviations are given in parentheses. Only one sampling was done over certain years at some monitoring stations (*). BELO BR: Bel Ombre back reef; BELO SR: Bel Ombre shore reef; BV BR: Bambous Virieux back reef; BV SR: Bambous Virieux shore reef; IAB BR: Ile aux Benitiers back reef; IAB FR: Ile aux Benitiers fore reef; IAB SR: Ile aux Benitiers shore reef; TAB BR: Trou aux Biches back reef; and TAB FR: Trou aux Biches fore reef.

5.1.5 Sea surface temperature

The annual average sea surface temperatures (SST) between 1998 and 2005 at the different locations are shown in Figure 7. At Bel Ombre, mean SST varied between 23°C and 29°C ($F_{[7, 36]} = 2.012$, $p = 0.080$. (Figure 7). Bambous Virieux had a mean high temperature of 27°C in 1998 and a low of 25°C in 1999 with no significant difference observed ($F_{[7, 32]} = 0.399$, $p = 0.896$). The mean SST was 23°C in 2003 at Ile aux Benitiers and increased significantly to 28°C in 2005 ($F_{[7, 42]} = 2.999$, $p = 0.012$, Tukey HSD). The SST values ranged from 25°C to 27°C at Trou aux Biches with no significant difference noted over the years under study ($F_{[7, 35]} = 1.283$, $p = 0.289$).

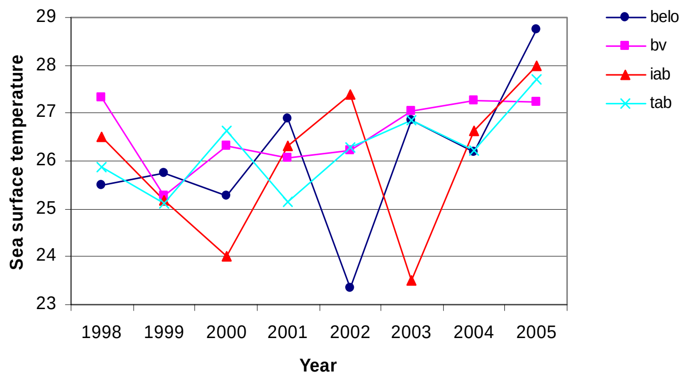

Figure 7 : Annual average sea surface temperature (°C) at the four study sites 1998-2005. (belo: Bel Ombre; bv: Bambous Virieux; iab: Ile aux Benitiers; tab: Trou aux Biches).

5.1.6 Salinity

The trend of the annual average salinity at the four study sites for the period 1998-2005 is given in Figure 8. Most of the salinity values were found to be between 33.7 and 35.9 over the study period, with two outliers for Bambous Virieux where they decreased significantly to 29.8 and 30.1 in 2003 and 2005 respectively ($F_{[7, 33]} = 6.083$, $p = 0.0001$, Tukey HSD, Figure 8). The salinity at Bel Ombre dropped significantly from 35.4 in 1999 to 33.9 in 2002 ($F_{[7, 38]} = 6.295$, $p = 0.0001$, Tukey HSD). Fairly constant values were observed at Ile aux Benitiers with the exception of 2003, when a significant drop to 34.1 was observed ($F_{[7, 44]} = 3.441$, $p = 0.005$, Tukey HSD). At Trou aux Biches, there was a highly significant increase in salinity values from 35.0 in 1998 to 35.9 in 2000, but declined significantly to 34.2 in 2005 ($F_{[7, 35]} = 11.071$, $p = 0.0000003$, Tukey HSD).

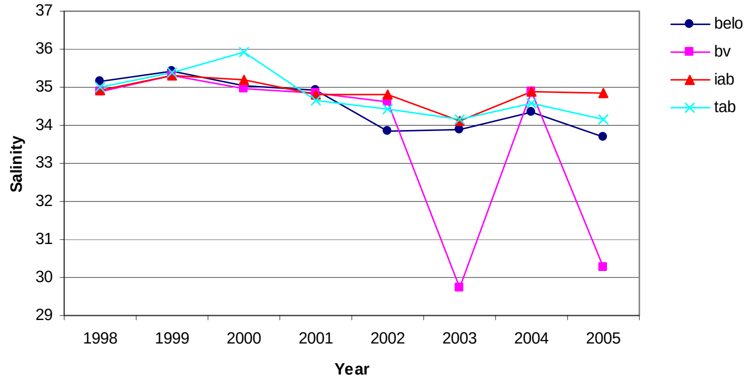

Figure 8: Annual average salinity at the four study sites 1998-2005. Descriptions of reefs are the same as in Figure 7.

5.1.7 pH

The annual mean pH values at the study sites were found to be ranging from 8.00 to 8.55 (Figure 9), which is within the limits of the Guidelines for Coastal Water Quality (Ministry of Environment 1999). The Guideline states that pH values should be between 7.5 and 8.5. During the period of study, average pH values declined significantly from 8.4 in 1999 to 8.1 in 2005 at Bel Ombre ($F_{[7, 38]} = 5.904$, $p = 0.0001$, Tukey HSD, Figure 9). A similar significant difference in pH values was also observed at Bambous Virieux where the pH value dropped from 8.5 in 1998 to 8.1 in 2004 ($F_{[7, 33]} = 3.247$, $p = 0.010$, Tukey HSD). On the other hand, pH was relatively constant at Ile aux Benitiers over the years ($F_{[7, 41]} = 1.879$, $p = 0.098$). During the first half of the study period, a relative constant pH was observed in the mean pH values at Trou aux Biches, but a significant decline was noted after 2001 ($F_{[7, 34]} = 3.338$, $p = 0.008$, Tukey HSD).

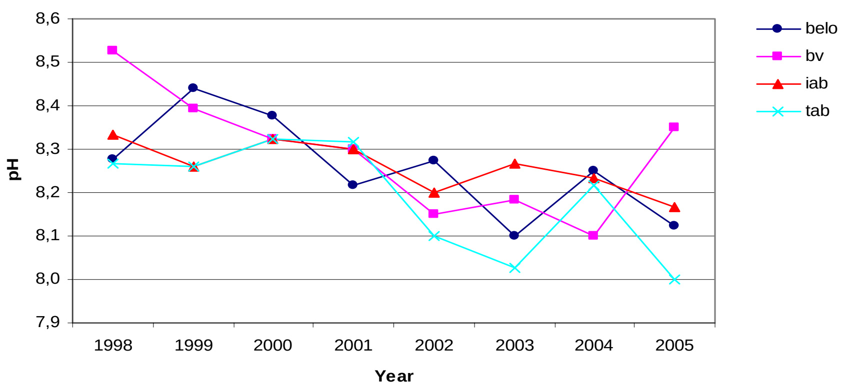

Figure 9: Annual average pH at the four study sites during 1998-2005. Descriptions of reefs are the same as in Figure 7.

5.1.8 Dissolved oxygen

Figure 10 depicts the annual average dissolved oxygen concentrations from 1998 to 2005 at the study sites. Annual average dissolved oxygen values ranged between 7.22 and 8.77 mg/L at all monitoring stations and were found to be within the limits of the Guidelines for Coastal Water Quality (Ministry of Environment 1999) which states that it should be greater than 5 mg/L of seawater. Relatively constant levels of dissolved oxygen were noted at Bel Ombre ($F_{[7, 38]}$ = 0.576, p = 0.771, Figure 10) with a concentration of 8.14 mg/L in 1998 and 8.30 mg/L in 2005. There were more variations observed at Bambous Virieux (8.77 mg/L in 1998 and 7.58 mg/L in 2002), though not significant ($F_{[7, 33]}$ = 0.451, p = 0.862). Similar trends were also recorded at Ile aux Benitiers ($F_{[7, 44]}$ = 1.084, p = 0.390) and Trou aux Biches ($F_{[7, 35]}$ = 0.672, p = 0.694) with no significant difference in concentrations.

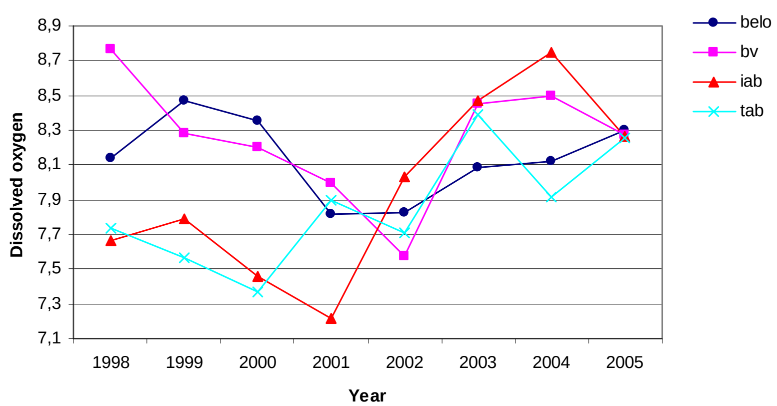

Figure 10: Annual average dissolved oxygen (mg/L) at the four study sites 1998-2005. Descriptions of reefs are the same as in Figure 7.

5.2 Multivariate analysis

5.2.1 Community structure of coral reefs at four locations off Mauritius

5.2.1.1 Bel Ombre

After analysis, the transects at Bel Ombre were seen to separate into three distinct clusters, the shore reef 1 (BESR1), the shore reef 2 (BESR2) and the back reef (BEBR) at a similarity of 60% (Figure 11a). It was observed that the shore reef transects of the early phase of the study period were grouped within the cluster BESR1 (1998-2000), while those of the latter phase were within BESR2 (2002-2005). All the back reef transects were clustered within BEBR. One-way ANOSIM confirmed that significant differences existed in community structure between the transects (global R = 0.991, p = 0.001) (Figure 11). The MDS ordination supported the identification of the transect groups which were well dispersed (Figure 11b). There was a clear upward shift for the similarity points representing transect type BESR1, while those for BESR2 had an anticlockwise shift towards the 2002 position. The shifting for the back reef points (BEBR) were more localised between the years.

Foliaceous non-*Acropora* corals accounted for 32.3% of the average within group similarity of BESR1, followed by submassive non-*Acropora* corals (15.5%) and macroalgae (13.8%) (Table 6). Dead corals had 24.2% contribution at BESR2, while that of foliaceous non-*Acropora* and tabulate Acropora were 21.7% and 19.2%, respectively. Transect BEBR had a contribution of 32.6% of branching *Acropora* and 22.9% of turf algae for the average within group similarity.

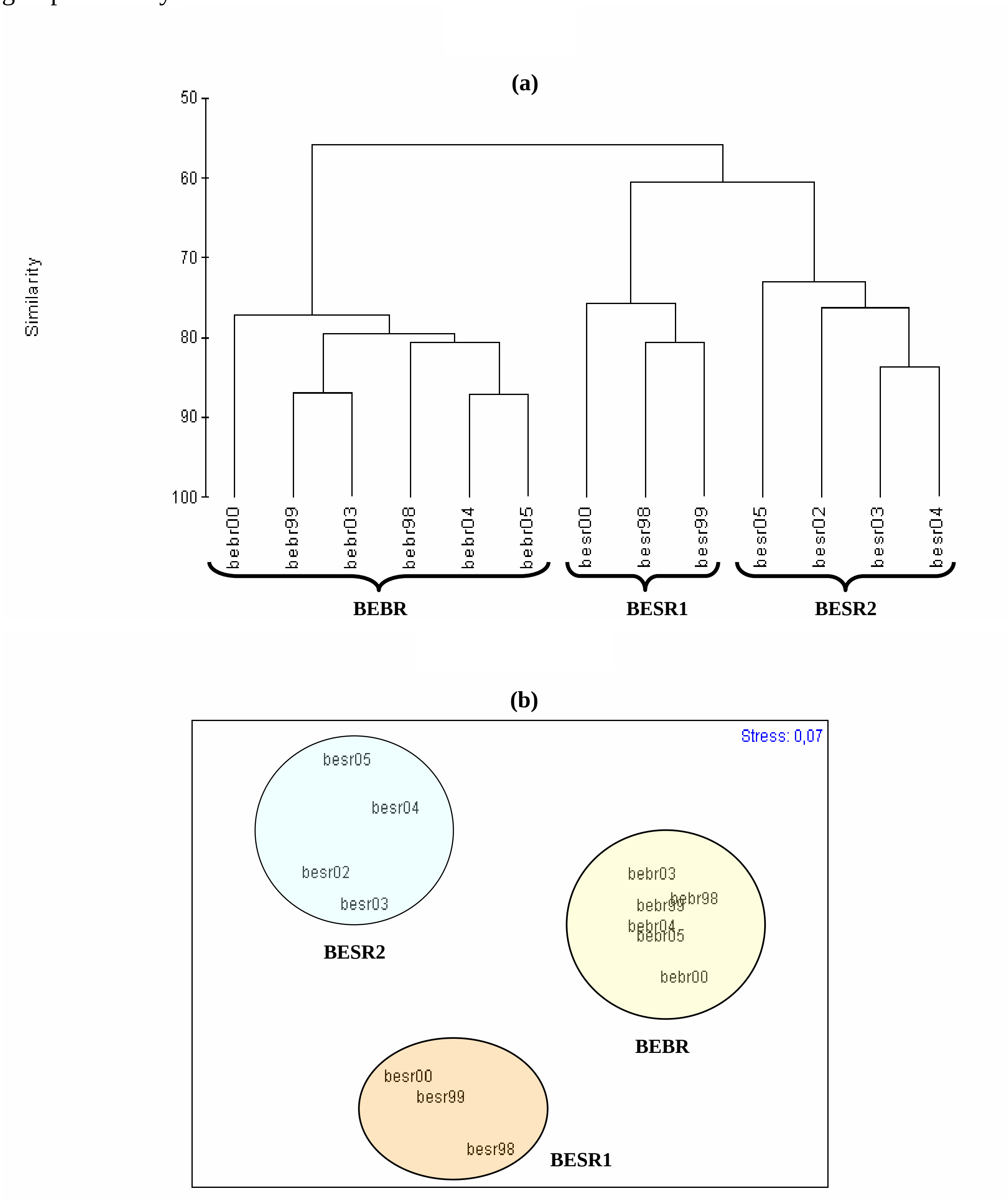

Figure 11: Dendogram for hierarchical clustering (a) and MDS ordination (b) of the percentage substrate cover of the transects at Bel Ombre (Bray-Curtis similarity, stress = 0.07; BESR1: shore reef transects 1; BESR2: shore reef transects 2; BEBR: back reef transects).

Table 5: One-way analysis of similarities (ANOSIM) and pairwise tests for the differences in community structures between the transects at Bel Ombre (R: comparative measure of the degree of separation of the reefs; p: significant level). Data were square-root transformed for analyses. Descriptions of transect groups are the same as in **Error! Reference source not found.**.

	R	**p**
Global test	0.991	0.001
Pairwise tests		
Reefs		
BEBR - BESR1	1.000	0.012
BEBR - BESR2	1.000	0.005
BESR1 - BESR2	0.907	0.029

Table 6: Lifeform categories principally responsible for the clustering patterns between transects at Bel Ombre identified by the similarity percentages analysis (SIMPER). Lifeform categories listed at a 90% cut-off cumulative value. Descriptions of transect groups are the same as in Figure 3.

Reef	**Categories**	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
BESR1	Foliaceous non-Acropora	23.89	21.33	24.63	32.27	32.27
	Submassive non-Acropora	11.14	10.26	7.62	15.52	47.79
	Macroalgae	14.00	9.14	2.21	13.83	61.62
	Algal Assemblage	11.96	7.56	1.32	11.43	73.05
	Dead Coral	14.26	7.54	1.29	11.41	84.46
	Turf Algae	11.85	2.41	0.58	3.64	88.10
	Mushroom Coral	2.46	1.69	8.80	2.56	90.66
BESR2	Dead Coral	23.41	16.33	2.02	24.23	24.23
	Foliaceous non-Acropora	15.49	14.58	10.86	21.65	45.88
	Tabulate Acropora	14.07	12.96	11.56	19.24	65.12
	Sand	8.93	7.70	6.84	11.43	76.55
	Macroalgae	9.67	5.36	1.45	7.96	84.51
	Submassive non-Acropora	8.08	3.04	0.75	4.51	89.02
	Rubble	5.15	2.33	1.06	3.46	92.49
BEBR	Branching Acropora	29.08	23.39	4.03	32.58	32.58
	Turf Algae	20.67	16.45	3.40	22.91	55.49
	Dead Coral	12.94	8.61	1.60	12.00	67.48
	Sand	10.68	8.31	3.20	11.57	79.05
	Macroalgae	9.18	6.10	2.28	8.50	87.55
	Algal Assemblage	6.77	3.23	1.19	4.50	92.05

5.2.1.2 Bambous Virieux

Two well-defined groups of transects were revealed at the similarity level of 70% at Bambous Virieux (Figure 12a). These were the shore reef (BVSR) and the back reef transects (BVBR). ANOSIM test yielded a global R = 0.994 and p = 0.002 (Table 7). Ordination based on the percentage substrate cover showed that the transect groups were clearly separated, with the similarity points of the initial year of the study always being at the bottom of the groups and rising to the left in subsequent years (Figure 12b).

Macroalgae accounted for 22.7% of the average within group similarity of BVSR, 20.5% for massive non-*Acropora* and 15.2% for submassive non-Acropora (Table 8). The main contributing lifeform category resulting in the cluster BVBR was branching *Acropora* (36.5%), followed by submassive non-*Acropora* at 15.0%.

Table 7: Results of one-way analysis of similarities (ANOSIM) for the differences in community structures between the transects at Bambous Virieux (R: comparative measure of the degree of separation of the reefs; p: significant level). Pairwise tests could not be performed due to the clustering into only two groups. Data were square-root transformed for analyses.

	R	**p**
Global test	0.994	0.002
Pairwise tests	Not applicable	

Table 8: Lifeform categories principally responsible for the clustering patterns between the transects at Bambous Virieux identified by similarity percentages analysis (SIMPER). Lifeform categories listed at a 90% cut-off cumulative value. Descriptions of transect groups are the same as in Figure 12.

Reef	**Categories**	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
BVSR	Macroalgae	18.37	14.58	3.02	22.74	22.74
	Massive non-Acropora	15.58	13.16	6.73	20.52	43.26
	Submassive non-Acropora	14.33	9.74	1.50	15.19	58.45
	Dead Coral	15.47	8.18	1.00	12.76	71.21
	Algal Assemblage	13.72	7.67	1.51	11.96	83.17
	Foliaceous non-Acropora	7.05	4.36	1.88	6.80	89.97
	Turf Algae	5.29	2.62	1.19	4.09	94.07
BVBR	Branching Acropora	31.03	27.84	4.84	36.51	36.51
	Submassive non-Acropora	13.63	11.41	4.11	14.95	51.46
	Rubble	12.84	9.95	3.07	13.05	64.50
	Turf Algae	11.36	9.03	2.97	11.83	76.34
	Dead Coral	12.56	7.94	1.37	10.41	86.74
	Sand	5.02	3.24	1.58	4.25	91.00

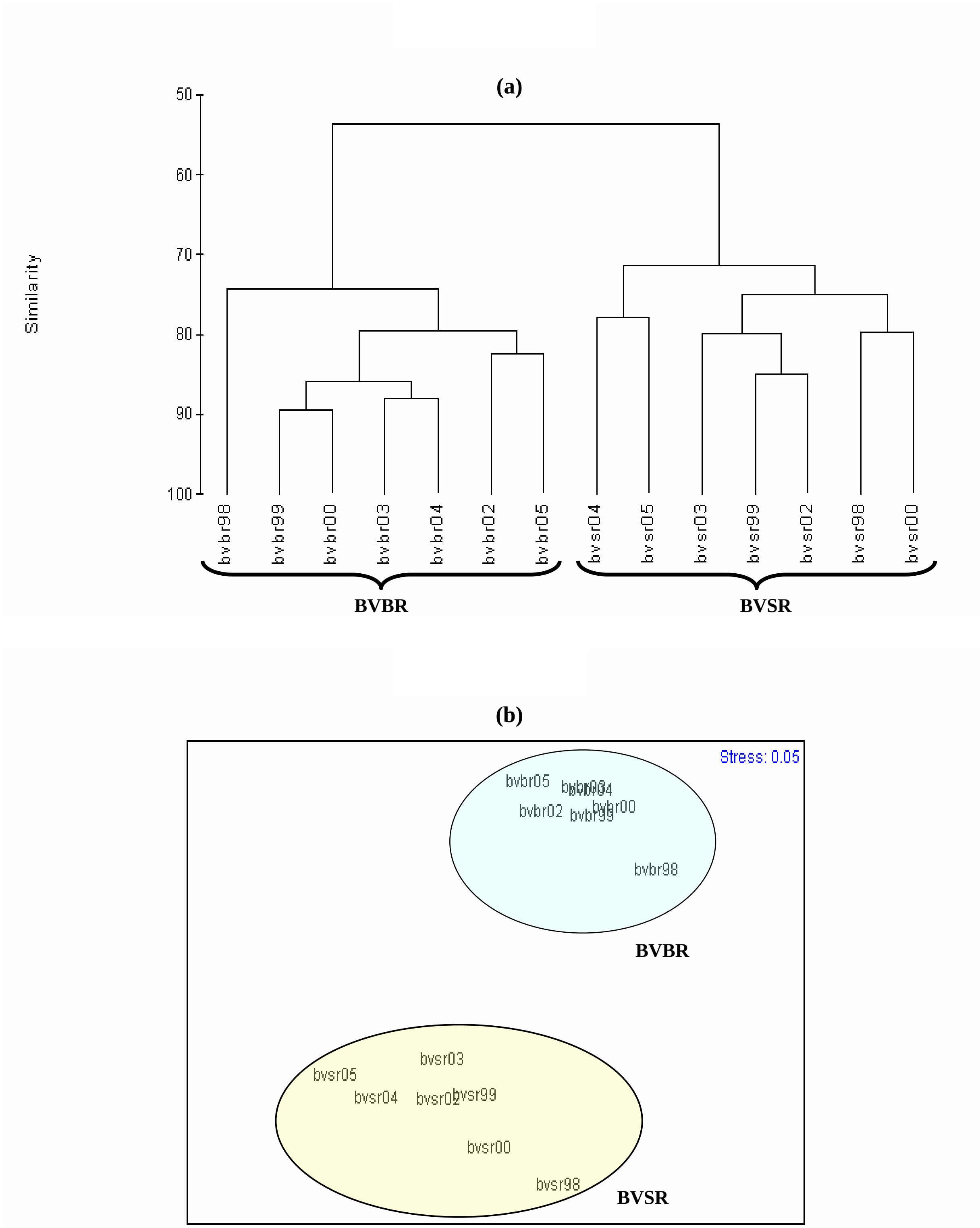

Figure 12: Dendogram for hierarchical clustering (a) and MDS ordination (b) of the percentage substrate cover of the transects at Bambous Virieux (Bray-Curtis similarity, stress = 0.05; BVSR: shore reef transects; BVBR: back reef transects).

5.2.1.3 Ile aux Benitiers

Figure 13(a) shows the dendogram produced from hierarchical cluster analysis on data from Ile aux Benitiers. Three distinct clusters were obtained at a similarity level of 55%: the shore reef (ISR), back reef (IBR1) and fore reef (IFR) transect groups. The back reef transect of 1998 (IBR2) was found to be segregated on its own. Significant differences were obtained between the clusters (global R = 0.968, p = 0.001), with the exception of pairs consisting of IBR2 (Table 9).

The similarity point representing the transect IBR2 was found to lie in the middle of the other three clusters on the MDS plot (Figure 13b). The transect points for the three reef zones of Ile aux Benitiers (ISR, IBR1 and IFR) formed respective tight and discrete groups. For the shore reef transects (ISR), there was a clear shift to the upper left between 1998 and 2002. In the subsequent years, there was a gradual return towards the initial position in a horse-shoe shape curve, but recovery to the 1998 condition was not complete. The shift in the similarity points representing the fore reef transects (IFR) was more pronounced in the beginning of the study period, with a gradual return to the original position thereafter. There was a relative downward shift in the points representing IBR1, with a mild stabilisation in the middle of the study period.

SIMPER analysis showed that rubbles and dead corals were the main contributory categories in the ISR transects with 27.7% and 25.2%, respectively (

Table 10). Tabulate *Acropora* accounted for 40.7% of the average similarity within IBR1 transects, while dead coral was at 32.2%. The fore reef transects IFR had 35.9% and 23.3% respective contributions from rock and encrusting non-*Acropora*.

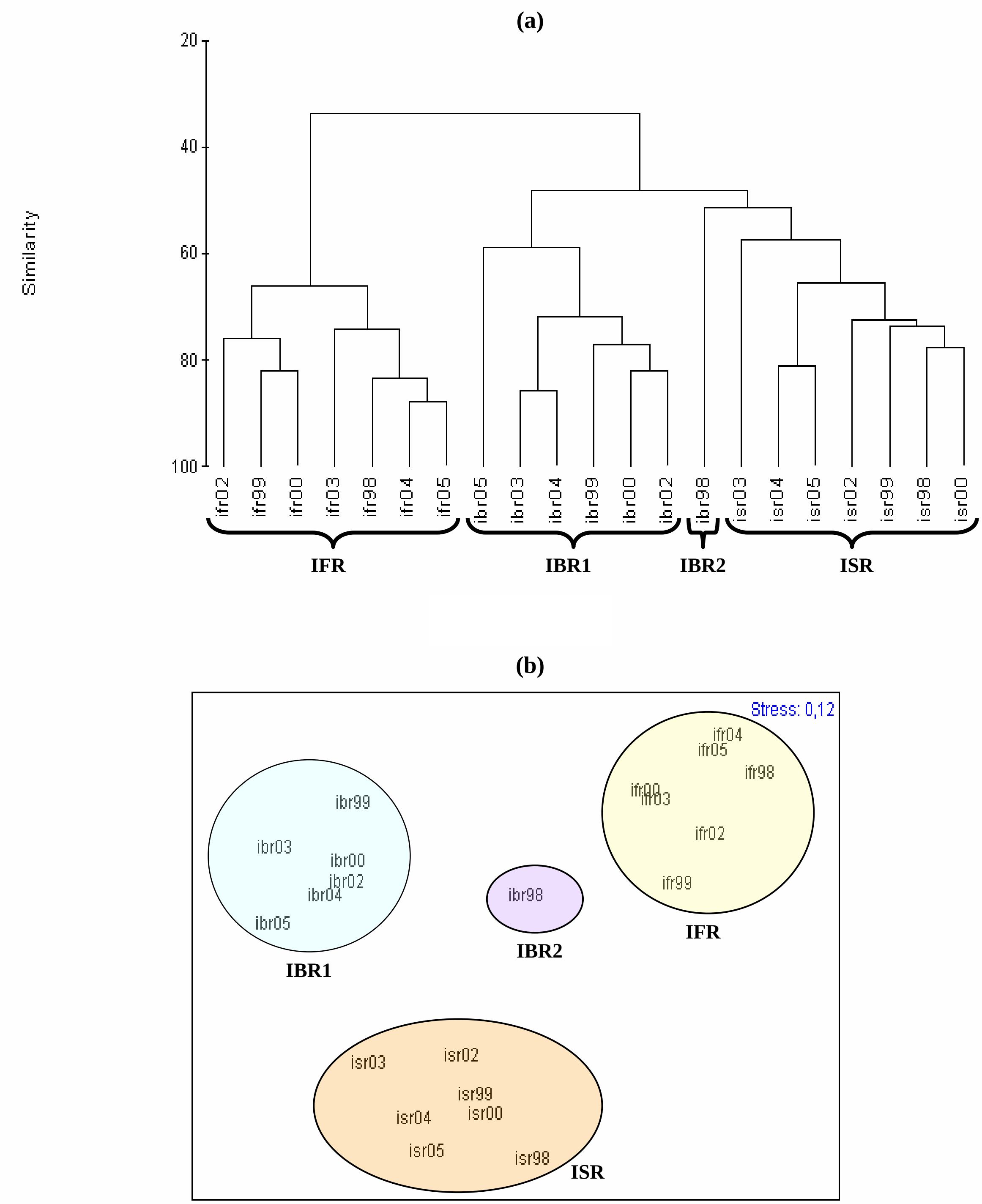

Figure 13: Dendogram for hierarchical clustering (a) and MDS ordination (b) of the percentage substrate cover of the transects at Ile aux Benitiers (Bray-Curtis similarity, stress = 0.12; ISR: shore reef transects; IBR1: back reef transects 1; IBR2: back reef transect 2; IFR: fore reef transects).

Table 9: Results of one-way analysis of similarities (ANOSIM) and pairwise tests for the differences in community structure between the transects at Ile aux Benitiers (R: comparative measure of the degree of separation of the reefs; p: significant level). Data were square-root transformed for analyses. Descriptions of the transect groups are the same as in Figure 13.

	R	p
Global test	0.968	0.001
Pairwise tests		
Reefs		
IBR2 - IFR	0.973	0.125
IBR2 - ISR	0.850	0.125
IBR2 - IBR1	0.844	0.143
IFR - ISR	0.999	0.001
IFR - IBR1	1.000	0.001
ISR - IBR1	0.907	0.003

Table 10: Lifeform categories principally responsible for the clustering patterns between the transects at Ile aux Benitiers identified by similarity percentages analysis (SIMPER). Lifeform categories listed at a 90% cut-off cumulative value. Descriptions of the transect groups are the same as in Figure 13.

Reef	Categories	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
ISR	Rubble	24.36	16.34	1.36	27.66	27.66
	Dead Coral	28.02	14.88	1.05	25.19	52.84
	Foliaceous non-Acropora	10.87	10.13	11.60	17.14	69.99
	Branching Acropora	12.89	8.32	1.52	14.07	84.06
	Turf Algae	5.96	2.81	1.07	4.76	88.82
	Sand	4.74	2.79	1.14	4.72	93.55
IBR1	Tabulate Acropora	36.62	25.36	1.42	40.68	40.68
	Dead Coral	31.15	20.04	1.71	32.15	72.84
	Sand	14.41	9.09	1.79	14.58	87.42
	Branching Acropora	10.33	5.03	1.32	8.06	95.48
IBR2	--	NA	NA	NA	NA	NA
IFR	Rock	37.26	22.60	1.34	35.91	35.91
	Encrusting non-Acropora	18.03	14.69	4.54	23.34	59.25
	Massive non-Acropora	10.73	9.80	7.53	15.57	74.82
	Sand	7.88	4.35	1.29	6.91	81.73
	Soft Coral	4.60	3.65	44.7	5.80	87.53
	Submassive non-Acropora	5.27	3.29	1.21	5.23	92.76

5.2.1.4 Trou aux Biches

Transects done at Trou aux Biches showed differentiation into two major clusters, namely the back reef (TBR) and the fore reef (TFR) transects at a similarity level of 60% (Figure 14a).

Due to the insignificant differences between the sub-clusters (TFR1, TFR2 and TFR3) of the fore reef transects, these were put together into one cluster (TFR). This indicated the similarity of the sub-groups in cluster TFR (global R = 0.995, p = 0.001) (Table 11).

The distance map supported this interpretation (Figure 14b). Two distinct point clouds correlated to the clusters in Figure 14a. The biggest point cloud (transect group TFR, Figure 14b) was not separable into sub-clusters, as mentioned earlier. In this cluster, there was a shift to the upper right between 1998 and 2002, with a gradual return to the starting point in the subsequent years, though recovery to the 1998 condition was not complete. For the back reef transects (TBR), there was an upward shift in the similarity points in 1998 and 1999, but forming a very tight group in the years thereafter.

The principal categories responsible for the similarity in TBR were dead corals (30.3%) and branching *Acropora* (26.2%), while massive non-*Acropora* and rocks contributed 32.1% and 23.6%, respectively, to the average similarity within TFR (Table 12).

Table 11: Results of one-way analysis of similarities (ANOSIM) and pairwise tests for the differences in community structure between the transects at Trou aux Biches (R: comparative measure of the degree of separation of the reefs; p: significant level). Data were square-root transformed for analyses. Descriptions of transect groups are the same as in Figure 14.

	R	**p**
Global test	0.995	0.001
Pairwise tests	Not applicable	

Table 12: Lifeform categories principally responsible for the clustering patterns between the transects at Trou aux Biches identified by similarity percentages analysis (SIMPER). Lifeform categories listed at a 90% cut-off cumulative value. Descriptions of transect groups are the same as in Figure 14.

Reef	**Categories**	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
TBR	Dead Coral	28.07	23.81	3.59	30.32	30.32
	Branching *Acropora*	22.21	20.54	8.99	26.16	56.48
	Tabular *Acropora*	16.63	14.48	4.95	18.44	74.91
	Rubbles	7.59	5.15	2.12	6.56	81.47
	Sand	6.19	4.59	3.09	5.84	87.31
	Rock	5.36	3.93	1.90	5.00	92.32
TFR	Massive non-*Acropora*	24.90	20.55	4.91	32.14	32.14
	Rock	21.72	15.10	2.74	23.61	55.74
	Encrusting non-*Acropora*	8.99	6.76	2.72	10.57	66.31
	Sand	11.05	5.92	1.24	9.25	75.57
	Dead coral	10.10	5.17	1.33	8.08	83.65
	Submassive non- *Acropora*	5.46	4.13	2.70	6.45	90.10

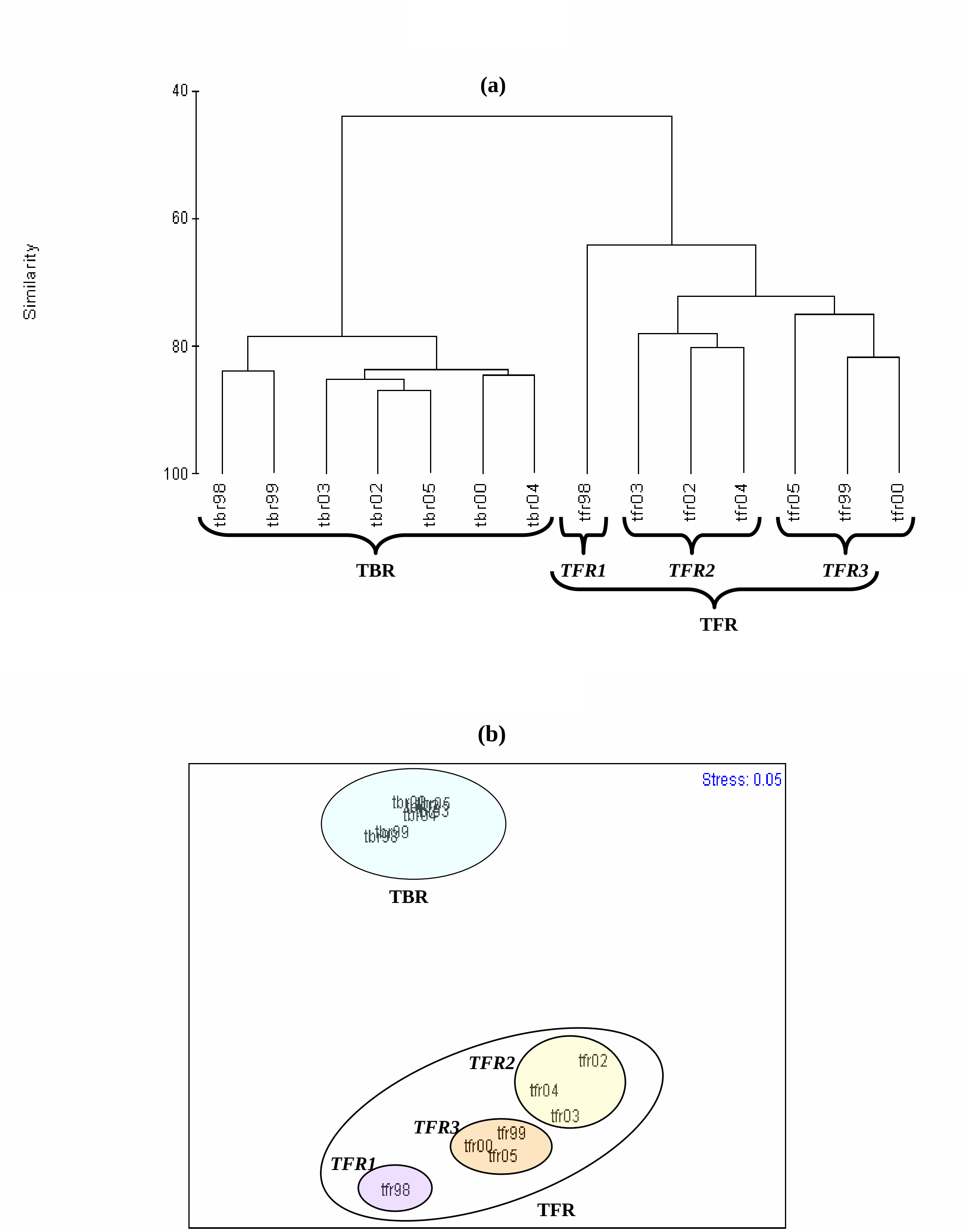

Figure 14: Dendogram for hierarchical clustering (a) and MDS ordination (b) of the percentage substrate cover of the transects at Trou aux Biches (Bray-Curtis similarity, stress = 0.05; TBR: back reef transects; TFR: fore reef transects).

5.2.2 Large scale community structure of coral reefs off Mauritius

Multivariate analysis of the percentage substrate covers of all transects is presented in Figure 15. There appeared to be different community structures among the coral reef areas off Mauritius, generating six meaningful groups of transects at a similarity of 65% (Figure 15a): (A) the fore reef transects at Ile aux Benitiers and Trou aux Biches, (B) the shore reef transects at Bel Ombre and Bambous Virieux, (C) the shore reef transects at Ile aux Benitiers, (D) the back reef transects at Bel Ombre and Bambous Virieux and the shore reef transects at Ile aux Benitiers, (E) the shore reef transects at Bel Ombre, and (F) the back reef transects at Ile aux Benitiers and Trou aux Biches. Other three smaller clusters were (G) the back reef transect at Ile aux Benitiers (1998), (H) the back reef transect at Ile aux Benitiers (2005) and (I) the shore reef transect at Ile aux Benitiers (2003). This was supported by ANOSIM tests for differences in community structures between the transects (global $R = 0.927$, $p = 0.001$) (Table 13).

MDS ordination revealed four main types of transects: A, B, D and F and five minor groups (Figure 15b). The similarity points for these transects formed tight and relatively discrete groups. The points for group A lay above the rest of the other reefs and were at the middle top of the plot. The points representing group B lay to the lower left of those for group A, while those for groups D and F lay exactly below those of group A and the lowest points on the plots were those of group C. It should also be recognised that the points for group E were relatively widely spread over the plot. ANOSIM tests demonstrated that there were significant differences between the groups of transects (Table 13). It was not possible to test the significance of variance between the groups G, H and I as these had only one sample each.

Rock and massive non-*Acropora* corals were the main contributing categories to the clustering pattern in transect group A, contributing 30.7% and 21.6%, respectively to the similarity within this group (Table 13). Macroalgae accounted for 22% of the similarity for group B followed by submassive non-*Acropora* and dead coral substrate (15.9% and 14.4%, respectively). Group C had a contribution of 44.9% and 30.7% from dead coral and rubble substrate, respectively. Group D had branching *Acropora* as the main characteristic of the category (35.6%) and turf algae (15.2%). Dead coral substrate accounted for 24.2% within the similarity of group E, followed by foliaceous and tabulate non-*Acropora* (21.7% and 19.2%, respectively). Group F had dead coral substrate as the main contributing category (31.7%), followed by tabulate non-*Acropora* (28.2%).

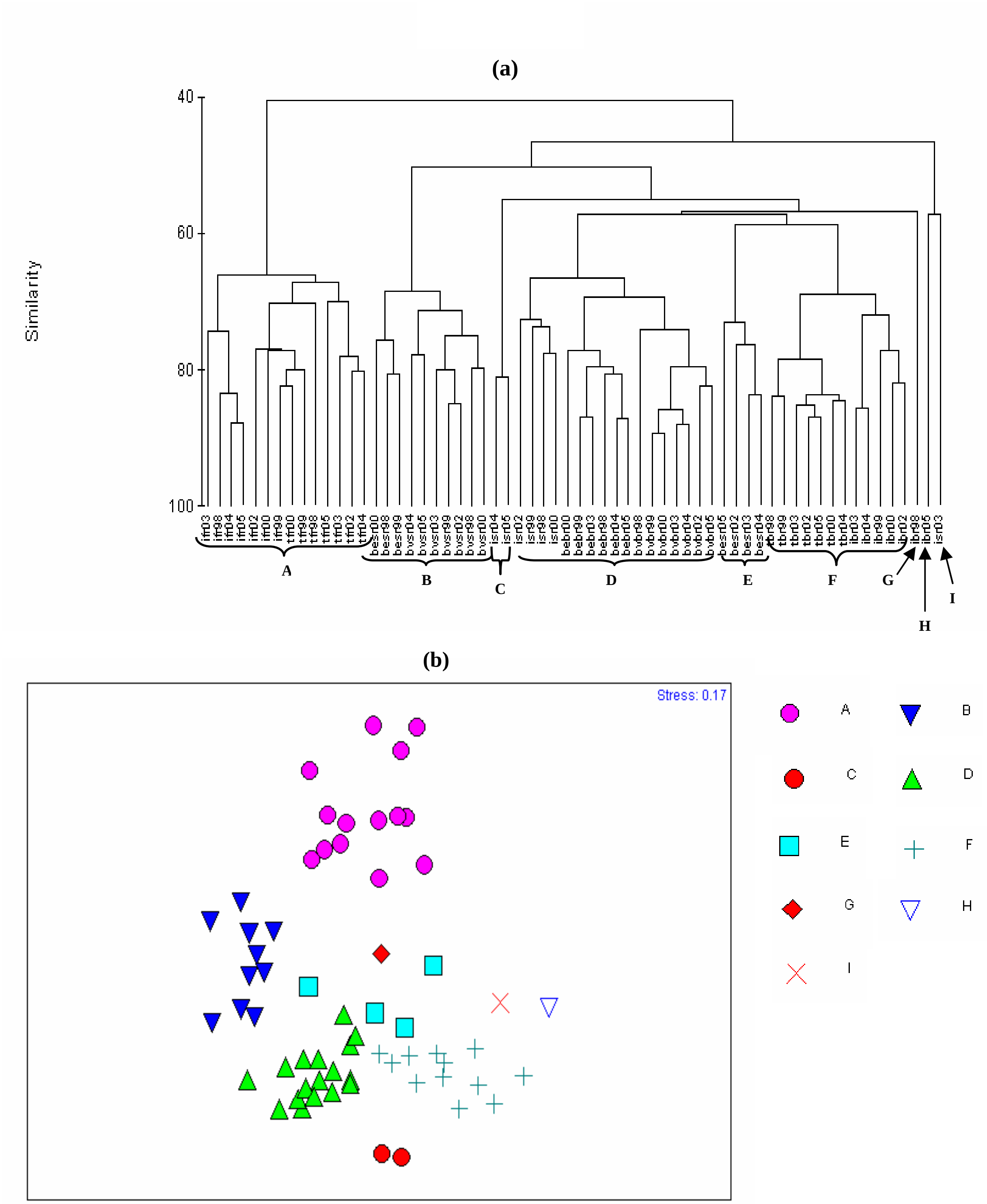

Figure 15: Dendogram for hierarchical clustering (a) and MDS ordination (b) of the percentage substrate cover of the transects at the four study areas (Bray-Curtis similarity, stress = 0.17; A: fore reef transects at Ile aux Benitiers and Trou aux Biches; B: shore reef transects at Bel Ombre and Bambous Virieux; C: shore reef transects at Ile aux Benitiers; D: back reef transects at Bel Ombre and Bambous Virieux and the shore reef transects at Ile aux Benitiers; E: shore reef transects at Bel Ombre; F: back reef transects at Ile aux Benitiers and Trou aux Biches; G: back reef transect at Ile aux Benitiers (1998); H: back reef transect at Ile aux Benitiers (2005); I: shore reef transect at Ile aux Benitiers (2003)).

Table 13: Results of one-way analysis of similarities (ANOSIM) and pairwise tests for the differences in community structure between the transects at the four study areas (R: comparative measure of the degree of separation of the transects, p: significant level). Data were square-root transformed for analyses. Descriptions of transect groups are the same as in Figure 15.

	R	**p**
Global test	0.927	0.001
Pairwise tests		
Reefs		
D - B	0.933	0.001
D - E	0.918	0.001
D - G	0.914	0.056
D - A	0.999	0.001
D - F	0.758	0.001
D - I	0.943	0.056
D - C	0.808	0.006
D – H	1.000	0.056
B - E	0.891	0.001
B - G	0.982	0.091
B - A	0.966	0.001
B - F	0.998	0.001
B - I	1.000	0.091
B - C	1.000	0.015
B - H	1.000	0.091
E - G	1.000	0.200
E - A	0.992	0.001
E - F	0.858	0.002
E - I	1.000	0.200
E - C	1.000	0.067
E - H	1.000	0.200
G - A	0.934	0.067
G - F	0.904	0.077
G - C	1.000	0.333
A - F	1.000	0.001
A - I	1.000	0.067
A - C	0.999	0.008
A - H	0.998	0.067
F - I	0.972	0.077
F - C	0.980	0.011
F - H	0.889	0.077
I – C	1.000	0.333
C - H	1.000	0.333
G - I	NA	NA
G - H	NA	NA
I - H	NA	NA

Table 14: Lifeform categories principally responsible for the clustering patterns between transects at the four study areas identified by similarity percentages analysis (SIMPER). Lifeform categories listed at a 90% cut-off cumulative value. Descriptions of transect groups are the same as in Figure 15.

Reef	**Categories**	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
A	Rock	29.49	18.16	1.64	30.72	30.72
	Massive non-Acropora	17.81	12.78	2.62	21.61	52.34
	Encrusting non-Acropora	13.51	9.71	2.30	16.43	68.76
	Sand	9.47	5.30	1.23	8.96	77.72
	Submassive non-Acropora	5.37	3.78	1.65	6.39	84.11
	Dead coral	7.67	3.46	1.02	5.86	89.97
	Soft coral	3.59	2.48	1.93	4.20	94.17
B	Macroalgae	17.06	13.19	2.56	22.04	22.04
	Submassive non-Acropora	13.37	9.49	1.89	15.86	37.90
	Dead Coral	15.11	8.59	1.12	14.35	52.26
	Algal assemblage	13.19	8.02	1.55	13.41	65.66
	Foliaceous non-Acropora	12.11	6.75	1.27	11.28	76.94
	Massive non-Acropora	11.07	6.43	0.99	10.75	87.70
	Turf algae	7.26	2.87	0.93	4.80	92.49
C	Dead Coral	40.04	36.83	*Out of range*	44.87	44.87
	Rubble	31.79	25.17	*Out of range*	30.66	75.53
	Foliaceous non-Acropora	11.29	10.92	*Out of range*	13.30	88.83
	Sand	6.83	5.17	*Out of range*	6.29	95.13
D	Branching Acropora	27.17	22.11	3.08	35.35	35.35
	Turf Algae	13.84	9.53	1.92	15.23	50.58
	Dead coral	12.93	8.09	1.38	12.94	63.52
	Rubble	13.05	7.38	1.33	11.80	75.31
	Sand	6.98	4.60	1.69	7.35	82.66
	Submassive non-Acropora	7.24	3.66	0.92	5.85	88.51
	Macroalgae	5.83	2.87	0.98	4.59	93.10
E	Dead Coral	23.41	16.33	2.02	24.23	24.23
	Foliaceous non-Acropora	15.49	14.58	10.86	21.65	45.88
	Tabulate Acropora	14.07	12.96	11.56	19.24	65.12
	Sand	8.93	7.70	6.84	11.43	76.55
	Macroalgae	9.67	5.36	1.45	7.96	84.51
	Submassive non-Acropora	8.08	3.04	0.75	4.51	89.02
	Rubble	5.15	2.33	1.06	3.46	92.49
F	Dead Coral	27.04	21.36	2.41	31.72	31.72
	Tabulate Acropora	27.81	19.01	2.19	28.22	59.94
	Branching Acropora	17.78	13.07	1.65	19.41	79.35
	Sand	8.25	5.62	1.98	8.34	87.69
	Turf algae	5.06	2.69	1.26	4.00	91.69
G	--	NA	NA	NA	NA	NA
H	--	NA	NA	NA	NA	NA
I	--	NA	NA	NA	NA	NA

5.2.3 Correlation of environmental parameters to coral community structures

The results from the BIOENV routine showed very low correlation between the data on substrate cover and environmental parameters that have been measured during the monitoring programme. The combination of sea surface temperature and dissolved oxygen had the highest correlation (r = 0.174, weighted Spearman rank correlation, Table 15) and was far from "explaining" the observed patterns in the community structure of the coral reefs. Combinations of more parameters did not improve the "explanation". Thus the patterns in the reef community structure could not be associated with any of the recorded environmental parameters.

Table 15: Results of biota and environment matching (BIOENV). Average values of the environmental parameters were used and normalised. Euclidean distance was the measure of similarity.

Selection of parameters	Correlation coefficient
Temperature & dissolved oxygen	0.174
Temperature, pH & dissolved oxygen	0.147
Dissolved oxygen	0.115
pH & dissolved oxygen	0.103
Temperature, salinity & dissolved oxygen	0.100
Temperature, salinity, pH & dissolved oxygen	0.095
Temperature	0.076
Salinity, pH & dissolved oxygen	0.061
Temperature & pH	0.051
Salinity & dissolved oxygen	0.046

6 DISCUSSION

Although there is no previous work done in describing the community structure of coral reefs off Mauritius, this study succeeded in identifying community patterns through clustering and ordination of the transects and in statistically testing for their spatial and temporal differences. The lifeform categories characterising the individual communities within the transects were also identified, but the observed patterns in community structures could not be associated with the recorded environmental parameters.

6.1 Bel Ombre

At the shore reef, there was a major change in community structure during the study period. At the onset, foliaceous non-*Acropora* dominated the reef (32.3% contribution), but in 2002 dead coral had taken over as the dominating substrate cover followed by foliaceous non-*Acropora* and tabulate *Acropora* (Table 6). A gradual decline in the average algal cover was also noted over the years (Figure 6a), probably due to a decrease in the nutrient levels in the waters. There has been a consistent change in the reef structure throughout the study period. There is no sign of any recovery as the reef structure in 2005 was furthest away from the condition in 1998 than any of the other years. It is likely that the process had already started prior to 1998 and there is no indication of the reef recovering (Figure 11b, BESR1 & BESR2). It is possible that the shore reef at Bel Ombre is developing into a dead reef.

At the back reef station, significant drops in the mean live coral cover were recorded (Figure 6d). However, the reef structure did not change significantly as a whole, but evolved in a circular pattern where the community structure in 2005 had close resemblance to that of 1998 (Figure 11b, BEBR).

In recent years, the nature of the coastal activities in this area has shifted from an agro-industrial area in the past to presently hosting the main tourism related developments in the southern part of the island. Goreau (2005) stated that dead corals in the area were overgrown with dense mats of algae and cyanobacteria formed large slimy mats on live corals, sand and dead corals. This condition was not seen a few years prior to the recent hotel developments in this area indicating that it prevailed only after the onset of coastal developments. This reef was previously reported as being rich and healthy and has been badly damaged by algae and cyanobacteria from very recent nutrient inputs to the coastal waters (Goreau 2005). Since sugar cane cultivation on the nearby hill slopes is not new, the source of nutrients is from land alterations during the development and most likely from leakages from septic systems of new hotel developments (Goreau 2005). In contrast to the statement of Goreau (2005) on the overgrowth of algae in the lagoon at Bel Ombre, the results obtained in this study at the shore reef indicated a decline in the algal cover over the years. This could be explained by the location of the reef monitored by Goreau (2005) being on the other side of the main pass in this area, more to the east of the actual shore reef and closer to the hotel construction sites.

6.2 Bambous Virieux

The results suggested that this location had the highest average live coral out of the four study areas over the whole period of study (
). The community structures at the shore reef and the back reef were dominated by macroalgae and branching *Acropora*, respectively (Table 8). Two very distinct groups of transects were obtained through ordination, representing the shore and back reefs (Figure 12b). The similarity points representing the initial and final years of study were found to be the furthest apart for the respective reef stations, indicating that the community structures in 1998 were different to those in 2005. Although these changes are not significant, the development of the community structures is unidirectional at both reefs and in the near future significant changes might take place, similar to the shore reef at Bel Ombre.

The relatively high average algal cover of the shore reef (Figure 6b) might be due to the site being influenced by the Grand River South East with large inflows of fertilisers and agricultural wastes (Bigot *et al.* 2002). The presence of a deep channel and a large pass between the back reef and the shore reef is likely to help in the flushing rate of the lagoon, thus explaining the significantly low values of algal cover on the back reef (Figure 6e). Wilkinson (2002) mentioned the clear dominance of territorial damselfish and surgeonfish along with butterfly fish at the back reef station. This might be another plausible explanation for a lower algal cover.

6.3 Ile aux Benitiers

The shore reef had a relatively low total average of live coral cover when compared to the other stations around the island (
). Dead corals and rubbles were the dominant categories at this station (

Table 10), though there were indications of a return to the starting point in the ordination plot (Figure 13b, ISR). The circular development indicates that there are ongoing natural fluctuations in the reef structure. The shore reef station is located very close to the beach and seemed to be affected by turbid nearshore waters and sedimentation. However, it is generally accepted that very high rates of sediment accumulation typically lead to smothering and death of the coral polyps, but the impact of low-level accumulation is largely debated (Thomas & Ridd 2005).

Tabulate *Acropora* was the dominant lifeform category at the back reef where a significant decline in average live coral cover was recorded (Figure 6f). Being one of the most fragile species of this genus, these are readily affected by heavy wave actions during bad weather conditions and the very shallow depths at this station worsened the scenario, possibly explaining the decline over the years. It should be noted that an outbreak of Crown of Thorns Starfish was recorded during one of the monitoring surveys in 2004. The presence of herbivorous fish in high numbers might justify the low coverage of algae. No plausible explanations could be found for the clustering of the 1998 transect (Figure 13b, IBR2). The uniform direction in the temporal trend from 1999 to 2005 is a sign of stress, which might eventually drive the reef community to significant changes and to a possible shift to a new reef community in the near future (Figure 13b, IBR1). At the fore reef station of Ile aux Benitiers, which is 6 m deep, rocks were the most dominant category, followed by encrusting non-*Acropora*

Table 10). The gradual return of the similarity points to the original position indicated that the community might be heading back to its 1998 structure (Figure 13b, IFR). This circular development, once again, indicates that there are natural fluctuations in the reef structure. Located on the reef slope, this station is affected by the normal high water movements of the high seas, which can be particularly strong during cyclones. This could explain the high occurrence of encrusting corals, which tends to be more tolerant to high water currents than other groups of corals. The rocky substrate was clean of weedy algae, indicating the low level of nutrients in these waters. Aronson *et al.* (2005) stated that a higher coral cover at a station might be due to the water depth of the reefs which buffers the effects of storm waves and anomalously high summer sea temperatures, and the remote, offshore location of these reefs, which limits human access and exposes them to oligotrophic oceanic waters.

6.4 Trou aux Biches

The average live coral cover was relatively constant at both the back reef and fore reef stations with a noted dominance of dead corals and massive non-Acropora, respectively (Figure 6(g) & (i) and Table 12). The back reef station had a very tightly grouped cloud of points on the ordination plot, indicating a constant community structure over the study period (Figure 14b). On the other hand, the similarity points of the fore reef station were more dispersed on the plot, indicating a more pronounced temporal trend, which showed a gradual return to the original 1998 point. Wilkinson (2002) reported that the back reef had been relatively stable since 2000. He also mentioned that damselfish, butterfly fish and other herbivores were well represented though this location is under increasing pressure from agriculture and tourism. Bigot *et al.* (2002) pointed out the healthy state of the back reef despite important tourism development in this area. The results of this study, coupled with the statements of Bigot *et al.* (2002) and Wilkinson (2002), shows the stability of these reefs despite the relatively higher level of coastal activities in this area.

6.5 Large scale community structure

Despite their distant location, the fore reef transects at Ile aux Benitiers and Trou aux Biches had similar community structures and were found to be grouped in the same cluster (A) (Figure 15b). Rocks, massive and encrusting corals were among the most dominant categories at the fore reefs. These characterising categories are resistant to the strong water movements on the outer reef slope. Similarly, the shore reef transects at Bel Ombre and Bambous Virieux (B), the back reef transects at Bel Ombre and Bambous Virieux and the shore reef transects at Ile aux Benitiers (D) and the back reef transects at Ile aux Benitiers and Trou aux Biches were found to be grouped in their respective clusters (Figure 15b). Both the shore and back reefs at Bel Ombre and Bambous Virieux had more or less similar lifeform categories principally responsible for the clustering patterns (Tables 6 and 8) and both locations are under the influence of agricultural run-offs. The dominance of *Acropora* spp. and dead corals might explain the grouping of the back reefs of Trou aux Biches and Ile aux Benitiers in the same cluster.

One other striking feature of this ordination plot is the segregation of the clusters comprising of dominant biotic categories to the left and those having dominant abiotic categories to the right. This tends to divide the island into two along a diagonal southwest-northeast axis, with proper reefs off the south and east coasts but with an abiotic dominant category in the community structure off the north and west coasts of Mauritius.

The results for coral communities clearly show a marked windward-leeward community differentiation. The lagoons at Bel Ombre and Bambous Virieux are always exposed to the South East Trade Winds and thus have relatively more moderate to rough seas when compared to those at Ile aux Benitiers and Trou aux Biches, which are on the sheltered side of the island. This could explain why fragile corals (*Acropora* spp.) do not thrive on the south and east coasts. Massive, submassive and encrusting non-*Acropora* spp. are more common on the latter reefs.

Most of the major coast-based tourism developments have taken place along the north and west coasts of Mauritius. This could have had induced effects on the coral ecosystems in these regions, thus the dominance of an abiotic substrate. However, this is purely speculative as little is presently known on the impacts of tourism related developments on the coastal and lagoon ecology in Mauritius.

6.6 Environmental parameters

The average sea surface temperatures at the four locations were found to have a minimum of 23°C and a maximum of 29°C between 1998 and 2005 (Figure 7). A significant difference was observed only at Ile aux Benitiers where it increased to 28°C in 2005. Relatively low SST was recorded at Bel Ombre and Ile aux Benitiers in 2002 and 2003, respectively as only one sampling was done at these reefs in those respective years. These samplings were done during the winter months, which accounted for the low SST.

Mean salinity values for all monitoring stations were found to range between 33.7 and 35.9 during the study period, with the exception of Bambous Virieux in 2003 and 2005 where abnormally low values were obtained (Figure 8). Mishandling of the samples or defective equipment might explain these unusually low values.

Although the average pH were found to be within the limits of the Guidelines for Coastal Water Quality (Ministry of Environment 1999), a general decline in these values was observed at all reefs, with significant drops at Bel Ombre, Bambous Virieux and Trou aux Biches (Figure 9). This decrease in pH might be linked to the acidification of oceans with increasing atmospheric carbon dioxide concentrations (Orr *et al.* 2005). The increase in atmospheric carbon dioxide concentrations poses a threat to coral reefs by causing changes in global seawater chemistry leading to a decrease in coral calcification rates, growth rates and structural strengths. Hoegh-Guldberg (2005) mentioned that a combination of changes to sea temperature and carbonate ions availability could trigger large-scale changes in the biodiversity and function of coral reefs. Taking into consideration the observed decline in the pH developments during 1998-2005 and several works done on the acidification of seawater, a closer monitoring of this parameter might prove to be critical. The mean dissolved oxygen concentrations were within the limits of the Guidelines for Coastal Water Quality (Ministry of Environment 1999) at all the monitoring stations and no significant differences were noted between the values across the years of study (Figure 10).

Patterns of the community structures of the coral reefs could not be linked to any of the four environmental parameters taken into consideration in this study (Table 15). It is likely that those measured parameters were not the proper indicators to be used to monitor the observed changes in the coral reefs. Note should also be taken that these parameters were not taken on the very same day as when coral monitoring was done and the sampling frequencies were not standardised. This might in turn have an incidence on the outcome of the analyses. On the other hand, taking into consideration the long lifespan of corals (decades) and the availability of substrate cover data only for a relatively short period (1998-2005), it might be possible that there are longer term changes going on which might have significant effects on the coral communities although these could not be linked to the environmental parameters over the seven years of the present study.

7 CONCLUSIONS AND RECOMMENDATIONS

The analyses of the data on percentage cover for a set of lifeform categories showed different temporal trends in the community structures of the four coral reef areas off Mauritius. Taking into consideration the similar community structures of the back reef and fore reef transects of Ile aux Benitiers and Trou aux Biches and their respective monitoring site selection criteria (control and tourism, respectively), no tourism related impacts could be tagged to the latter reef. Moreover, despite significant changes in community structure in a number of coral reefs, this analysis failed to link these patterns to the environmental parameters considered in this study (sea surface temperature, salinity, pH and dissolved oxygen). This suggested that there were other parameters, not measured, that impacted the reefs. Possible candidates are various anthropogenic activities (e.g. coastal developments, tourism related activities).

In order to help in the identification of the causal relationship between changes in coral communities and environmental changes, the following recommendations could be taken onboard for future monitoring and assessment:

Improvement of existing monitoring protocol:

- A review of the environmental parameters being presently monitored, with a view of including other parameters more likely to be influencing the coral reefs.
- A standardisation of the sampling protocol of monitoring of the environmental parameters. Monitoring of environmental parameters should be done at the respective reef stations on the same day as coral reef monitoring.
- A standardisation of the sampling protocol of coral reef monitoring around the island.

Inclusion of new environmental parameters for monitoring:

- Collection of substrate cover data should be done up to the species level for better resolution in data analysis.
- Collection of data on coral recruitment.
- Water current studies should be done at the reef stations in order to study the drift of coral larvae and their settlements.

Monitoring of human activities likely to have an impact on the coral reefs:

- A survey of the water-based activities should be made at the respective monitoring stations in order to quantify the resource users.
- Data should be collected on the number of pleasure crafts and fishing boats operating in the different regions.
- Data should be collected on the number of permits of operation delivered by the competent authorities for tourism/recreation based water activities (water sports, dive centres, etc).
- Data should be collected on the number of hotels and the rate of room occupancy from the respective regions.
- Local commercial dive operators should provide data on their dive frequencies and the number of divers.
- Data on the number of fishermen by boat and by fishing gear used should be collected.
- Inshore fishermen and local conservation organisations should be regularly consulted as these groups have considerable experience on and in the water and can be a valuable source of local knowledge and expertise.

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APPENDIX

Guidelines for Coastal Water Quality

General Notice No. 620 of 1999

MINISTRY OF ENVIRONMENT, HUMAN RESOURCE DEVELOPMENT & EMPLOYMENT
Department of Environment

The following guidelines are hereunder published for the information of the public with regards to coastal water quality requirements for various activities around the Republic of Mauritius.

Classification	*Principal Beneficial uses/objectives*
Category A - Conservation	
Class A1 - Conservation of coral community Class A2- Conservation of natural areas	A1 -Conservation of coral community A2 -Conservation of natural areas such as mangroves, sea grass, wild life habitat and marine spawning, nursing and feeding grounds.
Category B - Recreation	
Class B1 -Primary contact	B1 -Water sports like swimming, diving, surfing where there is direct contact.
Class B2 -Secondary contact	B2 -Water sports such as boating, fishing and other activities involving less body contact or where direct contact with water may occur but the probability of body immersion is minimal.
Category C - Fisheries	
Class C1 -Aquaculture	C1 -Propagation of marine life such as fish, crabs, shrimps, and other marine fauna.
Class C2 -Shellfish	C2 -Culture of shellfish -oysters, mussels, clams.
Category D - Industrial	
Class D -industrial and others	D -Natural water resources used as a receiving water body for industrial and agricultural discharges (harbour, power station and other industrial activities). There should be no unpleasant odour to people residing nearby.

Each activity requires different water quality and this is indicated underneath:

- Category A is meant for the conservation of the coral community and natural areas.
- Class A1 is intended for the coral ecosystem and requires seawater quality that will not hamper healthy coral growth.
- Class A2 is for the conservation of natural areas as mentioned in the table above and requires a slightly less stringent water quality.
- Category B is intended for recreation purposes.
- Class B1 defines the water quality needed for sports such as swimming, diving, surfing, etc. where there is maximum body contact with the water. For this class the potential health hazards due to pathogenic microorganisms have been considered.

- Class B2 is intended for water sports such as boating, fishing, etc. where there is likely to be minimal body contact with water, and so the quality of the water is less stringent especially with regards to pathogenic micro organisms.
- Class C concerns fisheries.
- Class C1 is intended for the production of fish, crabs, shrimps, etc.
- Class C2 is for the culture of shellfish where the requirements for pathogenic organisms are very stringent.
- Category D comprises the remaining coastal areas, which act as receiving body for industrial and agricultural discharges and include the harbour, power generating plants, and other industrial activities. No limits are imposed for pathogenic microorganisms but there should be no unpleasant odour to people residing nearby.

Coastal water quality requirements for various categories

CATEGORY		**A Conservation**		**B Recreation**		**C Fisheries**		**D Industrial**
Class		A1 Coral Community	A2 Natural Areas	B1 Primary Contact	B2 Secondary Contact	C1 Aquaculture	C2 Shellfish	D Industrial & others
Parameters	***Unit***							
PH	-	7.5-8.5	7.5-8.5	7.5-8.5	7.5-8.5	7.0-8.5	7.0-8.5	7.0-9.0
Temperature	0C	ambient	ambient	ambient	ambient	ambient	ambient	ambient
Suspended Solids	mg/l	5	5	5	10	15	15	15
Dissolved Oxygen	mg/l	>5	>5	>5	>5	>5	>5	>2
Chemical Oxygen Demand1	mg/l	2	2	3	3	5	5	5
Total Coliforms	CFU3/100 ml	1000	1000	1000	5000	1000	702	---
Faecal Coliforms	CFU/100 ml	200	200	200	1000	200	142	---
Nitrate-Nitrogen	mg/l	0.2	0.3	0.8	0.8	0.8	0.8	1.0
Phosphate	mg/l	0.04	0.05	0.08	0.08	0.08	0.08	0.1
Oil & Grease	mg/l	Not detectable by N-hexane extraction method						
Phenol	mg/l	0.05						
Arsenic	mg/l	0.05						
Cadmium	mg/l	0.02						
Cyanide	mg/l	0.01						
Chromium	mg/l	0.05						
Copper	mg/l	0.05						
Lead	mg/l	0.05						
Total Mercury	mg/l	0.0005						

1 by alkaline potassium permanganate method
2 organisms per 100 ml by MPN method
3 CFU: Colony Forming Unit