ARTICLE

The Alcyonacea (soft corals and sea fans) of Antsiranana Bay, northern Madagascar

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ABSTRACT

During the past two decades, the Alcyonacea (soft corals and sea fans) of the western Indian Ocean have been the subject of numerous studies investigating their ecology and distribution. Comparatively, Madagascar remains understudied. This article provides the first record of the distribution of Alcyonacea on the shallow fringing reefs around Antsiranana Bay, northern Madagascar. Alcyonacea accounted for between one and 16 % of the reef benthos surveyed; 11 genera belonging to four families, and several unidentified gorgonians (sea fans) were recorded. Abundant and diverse Alcyonacea assemblages were recorded on reefs that were exposed with high water clarity. However, abundant and diverse communities were also observed on sheltered reefs with low water clarity, high sediment cover and relatively low hard coral cover, implying potential competitive advantage under these conditions. Where prevailing environmental conditions were relatively moderate, the Alcyonacea assemblages were generally characterised by low diversity and an abundance of *Sinularia* and *Sarcophyton*. Because of the current lack of knowledge about the coral reefs in Antsiranana Bay, it was not possible to suggest any appropriate management actions. We propose that this account should be built upon with similar studies of other reef taxa. This series would address the paucity of published information from this part of the western Indian Ocean, and would provide the baseline information necessary to inform future management plans for the area.

RÉSUMÉ

L'intérêt porté aux Octocoralliaires et leurs propriétés ne cesse de croître à l'échelle mondiale, en étant à la fois prisés par l'aquariophilie mais également recherchés dans la recherche médicale. Durant les deux dernières décennies, les Octocoralliaires de la région sub-équatoriale de l'Afrique de l'Est ont fait l'objet de nombreuses études portant sur leur écologie et leur distribution, mais, le nord de Madagascar restait très peu étudié. Cet article décrit pour la première fois l'abondance, la diversité et la distribution des Alcyonacea et des Gorgonacea rencontrés dans la baie d'Antsiranana, l'une des plus grandes baies naturelles du monde, et fournit ainsi des informations essentielles sur la région pour le développement éventuel de stratégies de conservation. Les Octocoralliaires représentent entre 1 et 16 % de la couverture benthique des récifs étudiés ; onze genres d'Alcyonacea, appartenant à quatre familles, et de nombreuses espèces de Gorgonacea (coraux cornés) ont été enregistrés. Il a été observé que les récifs les plus exposés avec les eaux les moins turbides étaient favorables à une biodiversité d'Octocoralliaires plus élevée. Toutefois, des communautés abondantes et diverses d'Octocoralliaires ont également été observées sur des récifs protégés aux eaux relativement turbides avec des niveaux de sédimentation et une présence d'algues élevés, mais avec une faible couverture de coraux durs (Scléractiniaires) ; ceci pourrait impliquer un certain avantage compétitif des Octocoralliaires dans de telles conditions. Là où les conditions environnementales étaient modérées, les assemblages d'Octocoralliaires étaient généralement caractérisés par une faible biodiversité et une forte abondance d'espèces des genres *Sinularia* et *Sarcophyton*. Par manque de connaissances des récifs coralliens de la baie d'Antsiranana, il n'a pas été possible de conduire des études similaires sur les autres taxons. Toutefois, cette étude présente les premières données de base, qui lorsqu'elles seront complétées par d'autres études plus approfondies, pourront fournir les informations nécessaires à l'élaboration de plans de gestion appropriés pour la baie d'Antsiranana.

KEYWORDS: Alcyonacea, octocorals, soft corals, Antsiranana Bay, *Sarcophyton* and *Sinularia*.
MOTS CLEFS : Alcyonacea, octocoralliaires, Baie d'Antsiranana, *Sarcophyton* et *Sinularia*.

INTRODUCTION

Members of the order Alcyonacea (soft corals and sea fans) are commonly considered to be less functionally important in tropical coral reef ecosystems than the reef-building Scleractinia. However, many Alcyonacea do contribute to reef growth over time, and many are zooxanthellate, thus contributing to primary productivity (Fabricius and Alderslade 2001). They are an important component of coral reef assemblages, providing a source of

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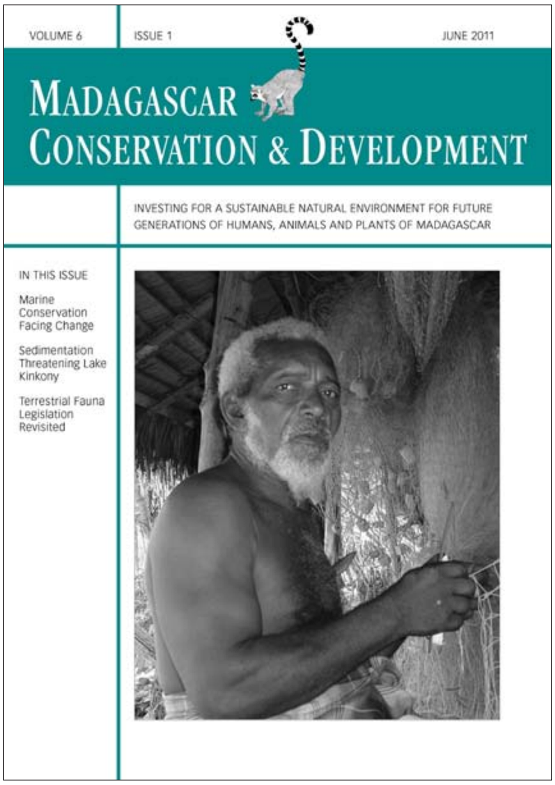

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food and habitat for other organisms (Fabricius and Alderslade 2001). In addition, Alcyonacea are amongst the most conspicuous and impressive members of reef communities, making them important to the diving tourism sector (Allen and Steene 2003) and the marine aquarium trade (Wabnitz et al. 2003). Their biological properties also hold potential value for medical research (e.g., Duh et al. 2002) and for the development of marine antifouling agents (e.g., Changyun et al. 2008).

Alcyonacea are vulnerable to the many potential threats facing coral reefs globally, including coastal development, overexploitation, destructive fishing, pollution and climate change (Burke et al. 2011). In 1999 it was predicted that corals would not be able to adapt quickly enough to the warming of tropical oceans to avert a decline in the quality of the world's reefs (Hoegh-Guldberg 1999). Since then, threat levels have increased dramatically (Burke et al. 2011) and there is a risk that some lesser-studied reefs and reef components will suffer a decline before their status has been fully understood. It is therefore important that biological assessments and long-term monitoring programmes are undertaken in understudied locations.

During the last two decades, the Alcyonacea of East Africa and the western Indian Ocean have been the subject of research in Tanzania, South Africa, Kenya, Mozambique (summarised in Benayahu et al. 2003) and Seychelles (Malyutin 1992). There remains, however, limited information on their distribution in Madagascar. Despite boasting an estimated 3,540 km of coral reef formations (Cooke et al. 2003), Madagascar's marine environment has often been overshadowed by its exceptional terrestrial wildlife. Further, not all previous coral reef studies from Madagascar have considered Alcyonacea in any detail.

In the 1970s, surveys of the coral reefs around Toliara, southwest Madagascar, recorded 44 Alcyonacea genera, 18 of which were gorgonians (sea fans) (Pichon 1978). A 2007 survey reported that soft corals comprised, on average, about five percent of the substrate on reefs in this southwest region (Nadon et al. 2007). Verseveldt (1969, 1971) listed 17 Alcyonacea genera collected from the reefs around Nosy Be and other islands in the northwest of Madagascar. More recent surveys in the northwest recorded 22 genera in five families (excluding gorgonians) (Turak 2003), and reported that soft corals comprised between zero and 64 % of reef benthos (Webster and McMahon 2002, McKenna 2003). A study of five marine protected areas in northern Madagascar recorded soft coral cover of between eight and 23 % (Harding and Randriamanantsoa 2008).

Antsiranana Bay, in northern Madagascar, is distinct to these previously surveyed locations in terms of its oceanographic nature; no study has yet examined the coral reef communities in this semi-enclosed bay. We describe the bay as semi-enclosed because of the narrowness of two openings separating it from the Indian Ocean (<1 km across) compared to its major axis length (approximately 15 km) (Healy and Harada 1991). The oceanographic characteristics (wave climate, temperature and salinity structure) in the bay are therefore likely to differ to those of the surrounding open ocean, potentially giving rise to a different ecosystem within (Healy and Harada 1991). Further, the ocean currents around Madagascar differ markedly from coastline to coastline. Open to the east coast, Antsiranana Bay is under the influence of the South Equatorial Current, whereas most of these previous studies were in the Mozambique Channel, effectively in the lee of the island (Cooke et al. 2003).

This study provides the first record of the distribution of Alcyonacea on the shallow fringing reefs around Antsiranana Bay, northern Madagascar. The authors intend this record to be one of a series describing the shallow-water coral reefs and associated habitats in Antsiranana Bay. The complete series will address the paucity of published information from this part of the western Indian Ocean, and will be useful to inform any future management plans for Antsiranana Bay.

METHODOLOGY

SURVEY AREA. The field study was conducted between January and December 2008, in Antsiranana Bay (formerly Diego-Suarez Bay), northern Madagascar (Figure 1). The bay lies at latitude 12.2ºS and is one of the largest natural harbours in the world with an approximate surface area of 160 km^2. It is tidal (approximately 1 m range; Cooke et al. 2003), open to the Indian Ocean in the east, and subject to freshwater input from the land during the rainy season between November and March (pers. obs.). The bathymetry is characterised by a deep central section with an average depth of approximately 40 m, which extends from the opening of the bay to the north and the west. The southern and eastern portions are shallower, with an average depth of approximately 15 m. Measured surface water temperature ranged between 24 and 30ºC throughout the year. Much of the coastline of the bay, and the numerous islands within, is fringed by shallow coral reefs, mangroves and seagrass beds.

The city of Antsiranana, with a population circa 80,000 (Cornell University 2001) is located on the south coast of the bay (Figure 1). It is a port, serving commercial shipping and tourist cruise ships. The rest of the bay, however, remains relatively undeveloped. There is one small resort, Ramena, with a population circa 4,000 (Cornell University 2001), and two coastal villages with fewer than 100 dwellings each. Despite this, we identified numerous anthropogenic pressures on the reefs in Antsiranana Bay; fishing, boat damage, pollution and coastal deforestation. Natural pressures included cyclone damage, land slides and sedimentation, to which the bay may be particularly susceptible because of its enclosed nature (Healy and Harada 1991). The coral reefs in the bay are also likely to be under threat from climate change induced

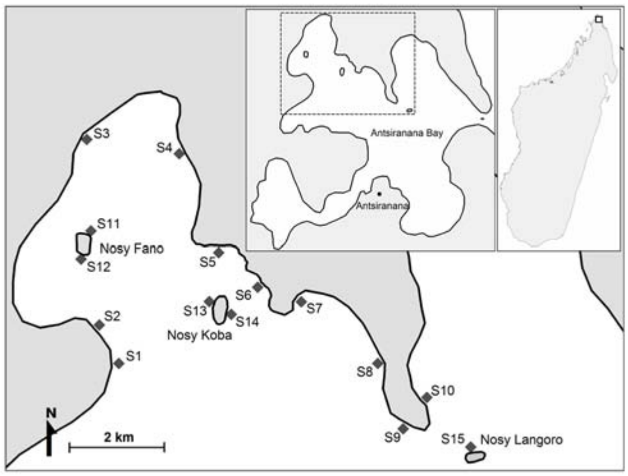

FIGURE 1. Study sites (S1 to S15) included in this survey (points indicate centre of site). Location of survey area in Antsiranana Bay, northern Madagascar, is shown as an inset.

bleaching, as found in other parts of Madagascar (Harding and Randriamanantsoa 2008).

This study was limited to the shallow coral reefs in the northwest portion of Antsiranana Bay for logistical reasons. This area was selected as it was considered to support the majority of the bay's shallow coral reefs. However, large areas of reef are also present in the northeast portion of the bay, which warrants further investigation.

STUDY SITES. Fifteen study sites were selected in the northwest of Antsiranana Bay (Figure 1). Each site spanned a distance of approximately 1,000 m and contained shallow (≤20 m) fringing coral reefs. Ten sites (S1 to S10) were along the main coastline of the bay, while five were around islands within the bay: Nosy Fano (S11 and S12), Nosy Koba (S13 and S14) and Nosy Langoro (S15). Sites were characterised by their prevailing environmental conditions (i.e., maximum depth, exposure and water clarity).

MAXIMUM DEPTH. The approximate maximum depth (D) of the reef was estimated for each site. Values of D were categorised on an ordinal scale ('Maximum Depth') as 1 (D = 0-10 m), 2 (D = 11-15 m) or 3 (D = 16-20 m), and labelled as Shallow, Moderate and Deep, respectively (Table 2).

EXPOSURE. In northern Madagascar, the southeastern trade winds prevail between April and October, and cyclones are common during the rainy season (Cooke et al. 2003). Exposure to wind and waves was calculated for each site according to a modified segment method developed by Sjøtun and colleagues (Sjøtun and Fredriksen 1995, Sjøtun et al. 1998), based on the Baardseth Index (Baardseth 1970). For each site, the number of 9º segments exposed to open sea was determined on a nautical chart. Each site was assigned a relative wind force value (e) based on the mean force and frequency of wind between January 2005 and January 2008 (wind data from www.windguru.cz; data not shown), the wind being given in 8 directions (i):

$$e = \sum_{i=1}^{8} \frac{n_i F_i}{100} S_i$$

where S_i is the number of open segments in a given direction, n_i is the number of observations of wind from a given direction, and F_i is the average speed of wind from a given direction {i = 1 to 8}. The relative influence of the local topography was represented in the number of segments containing open sea only at radii of 0.5, 7 and 100 km from the centre of the site. One value of e was calculated for each radius, e_1, e_2, e_3, respectively. The value of the total exposure (E) was calculated from:

$$E = 0.1[e_1 + (10e_2) + (100e_3)]$$

where e_1 is the relative wind force value for segments of radius 0.5 km, e_2 constitutes the relative wind force value for segments of radius 7 km, and e_3 represents the relative wind force value for segments of radius 100 km. Values of E were then categorised on an ordinal scale ('Exposure') as 1 (E = 0-50), 2 (E = 51-125) or 3 (E = 126-200), and labelled as Sheltered, Moderate and Exposed, respectively (Table 2).

WATER CLARITY. The mean horizontal visibility (V) was recorded along marked transects at each site between September 2007 and September 2008 (n = 15 observations for each site; data not shown). Values of V were then categorised on an ordinal scale ('Water Clarity') as 1 (V = 0-5 m), 2 (V = 6-10 m) or 3 (V = 11-15 m), labelled as Turbid, Moderate and Clear, respectively (Table 2).

SURVEY METHODS

Each of the 15 study sites was surveyed using two techniques: 1) the line intercept transect (LIT) method was used to measure the percentage cover of Alcyonacea at each site; and 2) the rapid ecological assessment (REA) method was used to assess the abundance of each Alcyonacea genus and the alcyonacean diversity at each site.

LINE INTERCEPT TRANSECT (LIT) METHODOLOGY. Benthic cover was recorded using the LIT method on two replicate 20 m transects laid parallel to the reef contour (Markham and Browne 2007). Substrate types were recorded as rock, rubble, recently killed coral, sand, sediment, algae, hard coral (i.e., Scleractinia and *Millepora*), soft coral (i.e., Alcyonacea including gorgonians), sponge, or other (Browne et al. 2007, see also Hodgson et al. 2004). The depth of each survey was measured and categorised as 1 (1-5 m), 2 (6-10 m) or 3 (11-15 m) for subsequent analysis. This measure of survey depth was independent of the indicator of characteristic Maximum Depth assigned to each site. However, for sites where Maximum Depth was 'shallow', it followed that survey depths were restricted to <10 m.

We surveyed between two and 16 pairs of transects at each site, depending on logistical constraints. Results were averaged over pairs of transects and then over study sites to provide a mean percentage cover of each substrate type for each site. We calculated Spearman rank-order correlations for the non-averaged transect data to assess whether there was any relationship between Alcyonacea cover and other biological and bio-physical parameters.

RAPID ECOLOGICAL ASSESSMENT (REA) METHODOLOGY. The composition of the Alcyonacea communities in the bay was investigated in more detail using the one-off REA method (Fabricius and McCorry 2006). This method was chosen because time for these surveys was limited and this technique is considered to provide a good representation of rare genera within a large area of reef (Fabricius and McCorry 2006).

Sites were visually surveyed within a 10 m belt along a 50 m transect laid parallel to the reef contour. Estimates were recorded for the Relative Abundance (RA) of each Alcyonacea genus on a rating scale of 0-5 (Fabricius and McCorry 2006), where 0 = absent; 1 = one or few colonies covering <1 % of the benthos; 2 = uncommon, covering 1-5 % of the benthos; 3 = common, covering 6-10 % of the benthos; 4 = abundant, covering 11-20 % of the benthos; and 5 = dominant, covering >20 % of the benthos. The total number of different Alcyonacea genera encountered during each survey was also recorded as a measure of diversity, referred to as the Generic Richness (GR) (Fowler et al. 1999).

We surveyed between one and four belt transects at each site, depending on logistical constraints. For each of the study sites, results were averaged over transects to provide the median RA of each Alcyonacea genus and an overall mean GR. We calculated Spearman rank-order correlations to assess whether diversity (GR) was related to other biological or bio-physical parameters (i.e., mean LIT data). We also carried out hierarchical cluster analysis to group similar study sites with regard to their Alcyonacea community compositions. For this analysis, each study site was defined as a set of variables, i.e., the median RAs of each Alcyonacea genus and the mean GR. Carried out in SPSS version 16.0 (SPSS 2007), using a within-groups linkage method and Pearson correlation measure, this procedure analyses the sets of variables simultaneously, and identifies relative dissimilarity between them (Dytham 2005).

RESULTS

CONTRIBUTION TO BENTHIC COVER. The results from the LIT survey are shown in Table 1. On average, over 20 % (21.0 ± 15.9) of the shallow fringing reef benthos surveyed in Antsiranana Bay was occupied by living corals. At Sites 10 and 15, this rose to over 40 % (44.4 ± 18.2 and 43.0 ± 22.6 respectively). The percentage cover of Alcyonacea, labelled 'soft corals', ranged from one percent (0.9 ± 0.9) at Site 7 to 16 % (15.5 ± 12.5) at Site 15 and was positively correlated with that of hard corals ($r_s = 0.2$, $P = 0.01$).

Coral cover was observed to increase with increasing exposure ($r_s = 0.2$, $P = 0.01$) and water clarity ($r_s = 0.3$, $P < 0.01$). The percentage cover of Alcyonacea was also independently positively correlated with water clarity ($r_s = 0.2$, $P < 0.01$) and survey depth ($r_s = 0.2$, $P < 0.01$), but not exposure. As would be expected, the percentage cover of sediment on the reef benthos was higher at sites with low exposure ($r_s = 0.3$, $P < 0.01$) and low water clarity ($r_s = 0.3$, $P < 0.01$). However, no direct relationship was observed between sediment and Alcyonacea cover or coral cover in general.

ALCYONACEA COMMUNITY COMPOSITION. Eleven genera of Alcyonacea belonging to four families (Alcyoniidae, Nephtheidae, Xeniidae and Tubiporidae) were recorded on the shallow fringing reefs surveyed in Antsiranana Bay. In addition, sea fans were observed at four of the study sites; these were not identified to genus level but were classified as a single taxon and labelled as 'Gorgonian' (Table 2).

The most abundant Alcyonacea genera recorded across all sites were *Sinularia*, *Sarcophyton* and *Rhytisma*, all members of the Alcyoniidae. *Sinularia* and *Sarcophyton* were the only genera observed at all sites. Although no taxa were recorded as dominant anywhere, *Sinularia*, *Sarcophyton* and *Anthelia* were all classified as abundant at certain sites. *Anthelia*, however, was only recorded at two sites in total; abundant in one but one/few in the other. All other genera were observed as uncommon, one/few or absent (Table 2).

Site 9 supported the most diverse Alcyonacea community with a GR of 7 (± 0). The least diverse communities were observed at Sites 11 and 12 (GR = 2 ± 0) (Figure 2 and Table 2). A positive correlation was observed between alcyonacean diversity (GR) and the percentage cover of sediment ($r_s = 0.6$, $P < 0.05$) but no other relationships were significant.

Hierarchical cluster analysis grouped the sites into two main clusters: Cluster 1 comprised {S 11, 12, 5, 2 and 14}; Cluster 2 comprised {S 6, 8, 1, 13, 7 and 9}. Sites 3, 4, 10 and 15 were outliers, i.e., the Alcyonacea community compositions observed at these sites were relatively dissimilar to each other and to all the other sites. This dissimilarity appears to be due to a relatively high generic richness (>4) and the presence of rarer genera, e.g., *Heteroxenia* at Sites 3 and 4, and *Anthelia* at Sites 10 and 15 (Table 2). Further, none of these reefs supported an abundance of *Sarcophyton* or *Sinularia*, despite a relatively high percentage cover of Alcyonacea in most cases (Tables 1 and 2).

DISCUSSION

ABUNDANT ALCYONACEA IN NORTHWEST ANTSIRANANA BAY. Of the 12 Alcyonacea taxa recorded during this study, three (*Sinularia*, *Sarcophyton* and *Rhytisma*, all members of the family Alcyoniidae) were the most abundant (Table 2). This dominance has also been observed on fringing reefs in northwest Madagascar (McKenna 2003) and in other regions, e.g., Seychelles, Mozambique and South China Sea (Malyutin 1992). *Sinularia* and *Sarcophyton* have long been considered to be amongst the most prolific soft corals in the Indo-Pacific (Verseveldt 1980, Malyutin 1992), thriving in a variety of conditions ranging from shallow turbid environments to clear-water reefs (Fabricius and Alderslade 2001). They are known to be rapid colo-

TABLE 1. Contributions to benthic substrate (%) at each study site (mean values with standard deviations in brackets). Hard coral: *Scleractinia* and *Millepora*, Soft coral: Alcyonacea.

Substrate	Site														
Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Hard coral	10.4 (6.9)	17.6 (9.6)	24.0 (21.8)	10.8 (7.7)	12.0 (7.3)	17.0 (12.5)	5.1 (3.3)	18.9 (20.6)	22.2 (10.4)	40.3 (18.3)	26.4 (8.4)	22.9 (12.8)	12.8 (11.4)	12.6 (8.3)	27.5 (19)
Soft coral	1.2 (1.2)	2.5 (3.5)	1.6 (2.1)	3.7 (7.0)	1.6 (1.6)	4.7 (3.1)	0.9 (0.9)	1.8 (2.5)	2.2 (2.2)	4.1 (4.0)	4.9 (4.6)	3.0 (3.3)	7.1 (6.1)	3.4 (4.8)	15.5 (12.5)
Rock	20.1 (15.8)	19.9 (9.9)	42.1 (28.3)	9.3 (7.8)	13.9 (10.1)	10.9 (10.3)	24.1 (25.8)	10.9 (5.8)	16.0 (8.7)	11.9 (16.7)	23.9 (21.4)	15.0 (7.5)	14.1 (12.9)	19.4 (26.2)	6.9 (7.8)
Rubble	47.1 (20.8)	36.1 (19.6)	3.8 (6.5)	22.4 (20.9)	31.6 (25.3)	28.2 (24.6)	36.9 (21.7)	38.1 (23.)	31.3 (15.7)	27.1 (21.7)	10.5 (12)	34.0 (22.1)	21.6 (21.2)	23.2 (22.1)	14.3 (25.6)
Recently killed coral	0.2 (0.6)	0.1 (0.1)	0.3 (0.4)	0.2 (0.4)	0.1 (0.1)	0 (0)	0.3 (0.9)	0 (0)	0 (0)	0.1 (0.1)	0 (0)	0.1 (0.1)	0.1 (0.1)	0 (0)	0.9 (1.9)
Sand	7.2 (15.6)	13.5 (10.3)	7.0 (11.6)	14.6 (24.5)	37.1 (27.6)	28.4 (18.7)	25.0 (23.3)	17.5 (11.4)	25.7 (16.5)	0.6 (1.5)	29.9 (21.3)	19.0 (17.7)	34.6 (27.6)	37.9 (27.5)	18.5 (26.6)
Sediment	0.1 (0.2)	0 (0)	13.4 (28.2)	33.2 (31)	0 (0)	2.5 (9.0)	0.3 (0.7)	1.9 (2.6)	0 (0)	2.9 (8.6)	0 (0)	0 (0)	5.3 (17.3)	0.1 (0.1)	3.9 (9.5)
Algae	9.2 (24.6)	2.3 (4.3)	7.3 (9.7)	3.7 (5.1)	1.0 (2.7)	4.4 (11.5)	2.7 (3.2)	3.2 (4.4)	0.3 (0.5)	12.3 (14.4)	0.1 (0.3)	0.5 (0.9)	1.0 (1.6)	0.1 (0.1)	11.5 (13.2)
Sponge	0.6 (1.3)	0.2 (0.2)	0.1 (0.2)	1.5 (2.5)	0.6 (0.8)	1.3 (2.1)	1.8 (3.6)	4.1 (5.7)	1.9 (1.9)	0.6 (1.3)	0.1 (0.0)	0.1 (0.1)	0.9 (1.2)	0.4 (0.3)	1.0 (0.7)
Other	3.9 (4.4)	7.8 (5.8)	0.4 (0.2)	0.6 (1.0)	2.1 (2.7)	2.6 (3.1)	2.9 (3.6)	3.6 (4.1)	0.4 (0.1)	0.1 (0.1)	4.2 (3.9)	5.5 (5.8)	2.5 (3.3)	2.9 (3.6)	0 (0)

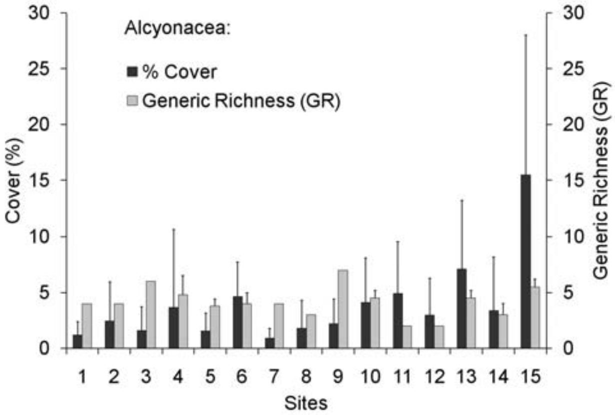

FIGURE 2. Percentage cover (%) and Generic Richness (GR) of Alcyonacea at each study site (mean values with standard deviations indicated where n>0).

nisers; sometimes considered as reef invaders, they are capable of dominating vast areas of reef (e.g., on the Great Barrier Reef, Fabricius 1998). They are also known to release toxins and cause mortality or growth inhibition in adjacent hard corals (Maida et al. 1995), thus out-competing them for space. In fact, during this study, *Sarcophyton* was observed over-growing a *Turbinaria* (Scleractinia: Dendrophilliidae) colony. Their competitive nature allows them to form large, species-poor stands (Fabricius 1998), as were observed on the shallow (less than one metre) reef flats of Sites 5, 6, 8 and 9. Large, species-poor aggregations are broadly considered a sign of poor reef health (Fabricius 1998). *Sinularia*, however, are the greatest contributors of alcyonarian spiculite to benthic sediments (Konishi 1981); their presence in large numbers may therefore contribute to reef-building and constitute an important component of stable reef communities.

Rhytisma is characteristically found encrusting over living or non-living hard substrates (Fabricius and Alderslade 2001). Rock and rubble contributed to the benthos at all study sites (Table 1), which explains the presence of *Rhytisma* at most of them. During this study, *Rhytisma* was observed encrusting over large areas of *Galaxea* (Scleractinia: Oculinidae) as well as non-living substrates.

All other genera were recorded in low abundance except *Anthelia*, which were locally abundant at Site 15 (Nosy Langoro) (Table 2). *Anthelia* are non-pulsating feathery Xeniids, largely reliant on water flow for a constant supply of food, and are normally found between six and 20 m depth (Gosliner et al. 1996); hence conditions for this genus seem to be favourable at Nosy Langoro (Table 2).

FACTORS AFFECTING THE DISTRIBUTION OF ALCYONACEA.

Although no linear relationship was found, high alcyonacean diversity (GR) often coincided with a high percentage cover of Alcyonacea (i.e., at Sites 4, 10, 13 and 15, Figure 2). The Alcyonacea community compositions of these sites were shown to be relatively dissimilar to one another and to the other sites surveyed. Three of these sites (S 4, 10 and 15) were characterised by relatively extreme environmental conditions compared to the rest of the bay (Table 2). Sites 10 and 15 were characterised as being amongst the deepest (i.e., Maximum Depth), most exposed and least turbid (Table 2); they also had a high percentage cover of hard corals and a low percentage cover of sediment (Table 1). In contrast, Site 4 was characterised as being amongst the shallowest (i.e., Maximum Depth), least exposed and most turbid (Table 2); it also had a low percentage cover of

TABLE 2. Clustering of study sites (S1 to S15) and the characteristic environmental conditions of each site. Sites were clustered according to their Alcyonacea community composition, i.e., median Relative Abundance (RA) of each Alcyonacea genus and mean Generic Richness (GR). ●: RA - 1, ○: RA - 0.5 such that ●: one or few, ●●: uncommon, ●●●: common,●●●●●: abundant, ●●●●●: dominant. Please refer to 'Study Sites' section of article for explanations of how environmental parameters were measured. Shall: shallow, Mod.: moderate, Shelt.: sheltered, Exp.: exposed, Turb.: turbid.

	Cluster 1					Cluster 2						Outliers			
	S11	S12	S5	S2	S14	S6	S8	S1	S13	S7	S9	S10	S15	S3	S4
Anthelia												●	●●●●		
Dendronephthya			●							○		●	●		
Heteroxenia									○					●●	●●
Lemnalia													●		
Litophyton										○		●○			
Lobophytum				●					○	○	●	○			
Rhytisma						●●	●●	●●	●○	●	●●	●○	●●○	●	●●○
Sarcophyton	●●●	●●	●●●	●●●●	●●●●	●●●	●●●	●●	●●●○	●	●●●	●○	●	●	●
Sinularia	●●●●	●●●	●●●●	●●●	●●●	●●●●	●●●●	●●●	●●●○	●●○	●●●	●●	●●●	●	●●○
Tubipora											●		○	●	
Xenia								●	●●	○	●●			●●	●●○
Gorgonian				●					○		●	●			
Mean GR (S.D.)	2 (0)	2 (0)	3.8 (0.6)	4 (0)	3 (1)	4 (1)	3 (0)	4 (0)	4.5 (0.7)	4 (0)	7 (0)	4.5 (0.7)	5.5 (0.7)	6 (0)	4.8 (1.7)
Maximum Depth	Shall.	Mod.	Shall.	Mod.	Mod.	Shall.	Mod.	Mod.	Shall.	Shall.	Mod.	Deep	Deep	Shall.	Shall.
Exposure	Mod.	Mod.	Mod.	Mod.	Mod.	Shelt.	Shelt.	Mod.	Shelt.	Mod.	Exp.	Exp.	Exp.	Shelt.	Shelt.
Water Clarity	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Clear	Mod.	Mod.	Mod.	Mod.	Clear	Clear	Turb.	Turb.

hard corals and a high percentage cover of sediment (Table 1). Under more moderate environmental conditions, Alcyonacea assemblages tended to be relatively similar to one another: less diverse and often characterised by an abundance of *Sinularia* and *Sarcophyton* (Table 2).

It is not surprising that Alcyonacea would benefit from the high exposure and water clarity at Sites 10 and 15; these conditions aid passive suspension feeding (Fabricius et al. 1995, Fabricius and De'ath 1997), removal of sediments (Riegl 1995) and phototrophy (Fabricius and De'ath 1997, Fabricius and McCorry 2006). However, Alcyonacea appear to have had some alternative competitive advantage over hard corals at Site 4. Fabricius (1998) reported that alcyonarian dominance in inshore waters is often attributed to disturbance such as sedimentation or physical damage. Others suggest an advantage could stem from a higher tolerance of sediment loading (van Katwijk et al. 1993), or from nutrient enrichment, low light availability and reduced predation in shallow inshore waters (Alino et al. 1992).

RECOMMENDATIONS FOR ANTSIRANANA BAY.

Alcyonacea constitute an important part of stable coral reef communities. However, they are capable of monopolising vast areas of the benthos (over 50 % cover), particularly on shallow, wave-protected fringing reefs and on disturbed reefs (Fabricius 1998). High abundance alone is not considered an indicator of poor reef health, but disturbance-related dominance of species-poor stands may be detrimental to the recruitment and survival of hard corals (Fabricius 1998). At present, the contribution of Alcyonacea to the shallow-water reef benthos in northwest Antsiranana Bay is comparable to recent records from other parts of Madagascar (Webster and McMahon 2002, Nadon et al. 2007, Harding and Randriamanantsoa 2008) and also from other geographic regions (e.g., Great Barrier Reef, Fabricius 1997 and Caribbean, Tratalos and Austin 2001). Disturbance-related abundance was only observed at Site 9 during this study, but the reefs there supported the highest alcyonacean diversity in general. Future monitoring would allow identification of potential phase-shifts towards Alcyonacea-dominated communities. However, at present, we believe that the Alcyonacea of Antsiranana Bay are ecologically important and thus should be conserved along with the other ecosystem components. Furthermore, they may hold potential economic value should the usage of Antsiranana Bay change in the future; for example if ecotourism or alternative livelihoods, based on alcyonacean resource use, were to be developed.

Marine protected areas (MPAs) have become central to the ecosystem approach to coral reef management (Mascia 2001). Motivations for their establishment include economic benefits to tourism as well as the conservation of ecosystems and their sustainable use (Agardy 1994). If the establishment of MPAs is considered in Antsiranana Bay in the future, it is essential that information about all reef taxa be taken into account in the design process. There is general consensus amongst the scientific community that MPAs should be located in high quality habitats, preferably where there is exposure to ocean currents for effective dispersal (Mascia 2001). On this basis, in Antsiranana Bay we would expect that Sites 10 and 15 would be selected for protection because of their high coral cover (>40 %), proximity to the mouth of the bay, and exposure to wind and wave energy. However, it is also suggested that MPAs should protect representative habitats (Kelleher et al. 1995); Table 2 indicates that the alcyonacean components of the habitats in Sites 10 and 15 were not representative of the northwest of Antsiranana Bay. While these sites were amongst the most diverse parts of the bay studied, containing ten Alcyonacea genera, two genera (*Heteroxenia* and *Xenia*) were absent. This is potentially important since both have been shown to contain useful bioactive compounds for medicine (Duh et al. 2002, Radwan et al. 2002).

We recommend that this survey of the Alcyonacea on the shallow reefs in the northwest of Antsiranana Bay should be extended to include the rest of the bay, particularly the shallow coral reefs observed in the northeast, and also deeper non-reef habitats. These analyses should also be built upon with similar studies of other reef taxa. Further studies would help to increase the amount of empirical data to address the lack of information from this part of the western Indian Ocean, and would provide the baseline knowledge and understanding necessary to inform sound future management plans and implementation for the area.

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SUPPLEMETARY MATERIAL.

AVAILABLE ONLINE ONLY.

TABLE S1. Location and characteristic environmental conditions of each study site. Please refer to 'Study Sites' section of article for explanations of how parameters were measured.
TABLE S2. Sampling effort of study sites during 2008 field survey. LIT: Line Intercept Transect methodology, REA: Rapid Ecological Assessment methodology.
FIGURE S1. Dendrogram using average linkage (within groups) cluster method and Pearson correlation measure, indicating similarity of sites in terms of Alcyonacea community composition, i.e. median Relative Abundance (RA) of each Alcyonacea genus and mean Generic Richness (GR).