REEF CHECK DATA REVEAL RAPID RECOVERY FROM CORAL BLEACHING IN THE MAMANUCAS, FIJI

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ABSTRACT

Twenty two fringing reef sites within the Mamanuca Islands, western Fiji were surveyed during 2001 and 2002, using Reef Check methods. A mean increase of 14.3% in hard coral cover was recorded over the 12-month period. This increase in hard coral cover suggests a significant recovery of scleractinian coral colonies that were originally impacted by the 2000 mass bleaching episode in the South Pacific. The event was reported to have caused >80% coral mortality in the southern and eastern regions of Fiji. Between 2001 and 2002 the coral reefs of the Mamanucas progressed from "poor" to "fair" in accordance with the Association of South East Asian Nations (ASEAN) system for describing the health of coral reefs. Our results also show that trained non-specialist volunteers undertaking marine surveys such as Reef Check can competently collect simple, yet important quantitative data regarding the physical health of coral reefs.

Introduction

Fiji is one of the wealthiest countries in the South Pacific. The nation's wealth is partly attributed to its extensive marine resources, which generate significant revenue through tourism and marine resource utilization. For example, Fiji is the world's second largest exporter of live reef products for the aquarium trade, after Indonesia (Sulu *et al.*, 2002). Importantly, Fiji's marine environments are a significant source of protein for local coastal populations, with subsistence catches estimated at

17,000 tons per annum (Spalding *et al.*, 2001). Fiji's reefs support high marine biodiversity (Wilkinson, 2002), with approximately 298 species of coral recorded to date (Veron, 2000; Spalding *et al.*, 2001). The country is made up of approximately 844 volcanic islands, dominated by the Viti Levu and Vanua Levu platforms, which account for 87% of the total land area (Vuki *et al.*, 2000).

Although the coral reefs of Fiji are of vital importance both ecologically and economically, they are under threat through rapid economic and population growth. The country's coral reef ecosystems are being adversely affected by a range of anthropogenic activities including over-fishing, destructive fishing through the use of explosives and poison from the *Derris* root, sedimentation, eutrophication, and pollution (Sulu *et al.*, 2002). Outbreaks of the coral predating crown-of-thorns starfish (*Acanthaster planci*) have been reported annually since 1996 at widely dispersed sites, including the Mamanucas (Sulu *et al.*, 2002). Recent coral bleaching events and storm damage have exacerbated these effects to further reduce reef health (South and Skelton, 2000). Such impacts represent possibly the most substantial threat to the ecological balance and health of reef ecosystems in Fiji on a variety of temporal and spatial scales. With the exception of reefs to the far north of the archipelago, considerable areas of Fiji's reefs were affected by mass coral bleaching in March-April 2000. The presence of elevated temperatures as monitored by the US National Oceanographic and Atmospheric Administration (NOAA) showed progressive warming around the island group (Lovell, 2000). Coral mortality was recorded at 40% for many sites, and >80% for some reefs in southern and eastern Fiji (Sulu *et al.*, 2002; Cumming *et al.*, 2003).

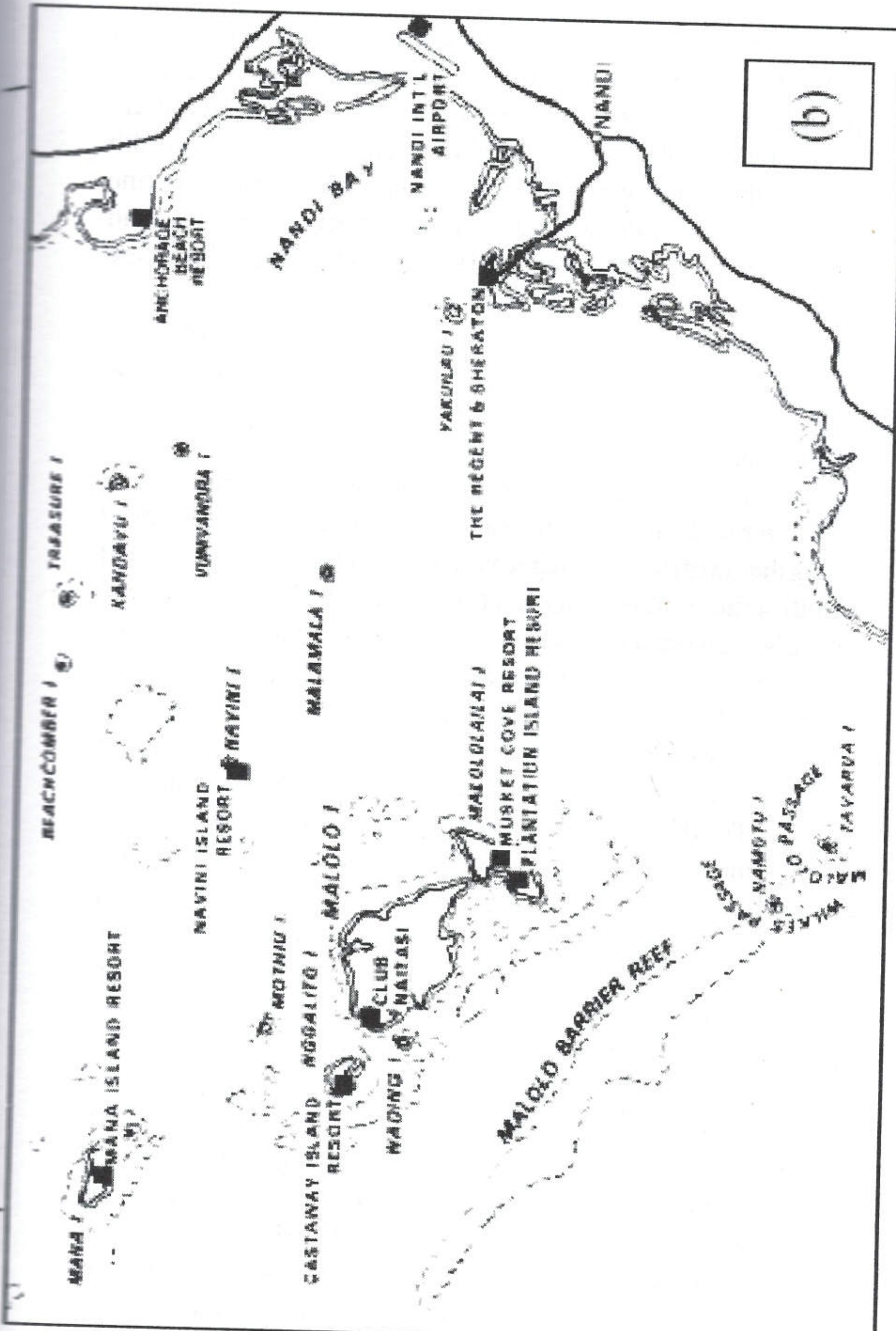
If left unchecked, the current suite of impacts will ultimately lead to reduced financial returns for coastal communities and other stakeholders who rely on fishing and marine-based tourism for their livelihoods. The 2000 mass bleaching event catalyzed the first major Global Coral Reef Monitoring Network (GCRMN) activity in the region where eight independent research groups collaborated to assess bleaching at 19 sites throughout Fiji (Wilkinson, 2002; Cumming *et al.*, 2003). Since 1996, the GCRMN has assisted with the Seawater Temperature Monitoring Programme at the University of the South Pacific (USP) to record temperatures throughout Fiji. Data from approximately 100 Fijian reefs have been collected by researchers, reef-based tourist operations, such as the Fiji Dive Operators Association (FDOA), and non-governmental organizations (NGOs), namely Coral Cay Conservation (CCC), Greenforce, and the International Marine life Alliance (IMA).

Study Area and Methods.

The Mamanuca Islands in the west of Fiji (Fig. 1) have been the focus of tourism development from at least the mid-1960s. Similar to other Fijian island groups, coastal zone management in the Mamanucas has been relatively nascent (Comley *et al.*, 2003), but the tourism industry in Fiji is very much aware of the value of conserving the coral reefs and fostering sustainable development (Walker *et al.*, 2002). The Fiji Coral Reef Conservation Project (FCRCP), a collaboration between the UK-based NGO Coral Cay Conservation (CCC) and the Fijian Ministry of Tourism, Culture, Heritage and Civil Aviation, has been operating in the Mamanucas since 2002 (Comley *et al.*, 2003). The full project was preceded by a three-month pilot program, the Mamanuca Coral Reef Conservation Project – Fiji 2001 (MCRCP) in the previous year (Harborne *et al.*, 2001).

In an effort to collect baseline resource data to be used in coastal management plan, the MCRCP undertook a rapid assessment of the coral reefs of the region with the use of trained, self-financing volunteer divers. One component of the work undertaken was an assessment of reef health using the "Reef

Figure 1. a) The Fiji islands, showing the project area (dashed line) for the MCRCP and FCRCP. *Source:* Fiji Visitors Bureau. (b) Major islands with the Mamanucas.


(b)
NANDI
NANDI INT'L AIRPORT
NANDI BAY
ANCHORAGE BEACH RESORT
THE REGENT & SHERATON
TREASURE I
KANDAVU I
BEACHCOMBER I
NAVINI I
NAVINI ISLAND RESORT
MALAMALA I
MALOLO I
MALOLOLAILAI I
MUSKET COVE RESORT
PLANTATION ISLAND RESORT
MANA ISLAND RESORT
MANA I
CLUB NAITASI
CASTAWAY ISLAND RESORT
MALOLO BARRIER REEF
NAMOTU I
TAVARUA I

Check" methodology. Reef Check is the largest international coral reef monitoring program and is designed for non-professional divers. Reef Check surveys generate relatively simple but useful quantitative information on general reef health through the abundance of indicator mobile and sedentary marine organisms, benthic structure, anthropogenic impacts, and abundance of commercially harvested species.(See www.reefcheck.org for further details).

The standard Reef Check survey protocol utilizes transects at two depth bands of approximately 3 and 10 m. During the MCRCP/FCRCP survey, the vast majority of transects were carried out between 2 and 10 m.

A 100 m transect was deployed at each depth at each site. Four replicate transects, each 20 m in length, were surveyed along the 100 m line. The replicate transects followed the designated depth contour in sequence but the start and end point of each 20 m replicate were separated by a 5 m space. Therefore the distance between the start of the first transect and end of the last transect was 20 + 5 + 20 + 5 + 20 + 5 + 20 = 95 m.

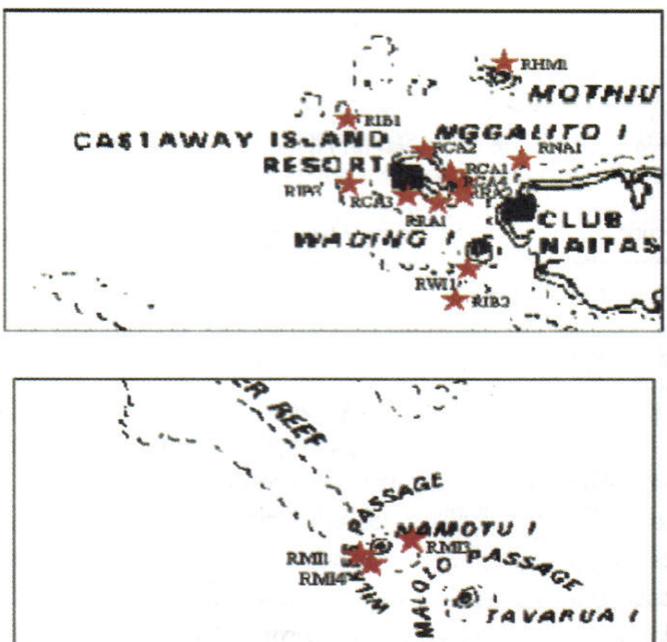
The four 20 m long transects were point sampled at 0.5 m intervals to determine the substratum types and benthic community present. The divers noted down the substratum type directly under each point. The standard Reef Check protocol splits the benthic substratum into 10 basic categories (hard coral, soft coral, recently killed coral, nutrient indicator algae, sponge, rock, rubble, sand, silt/clay, and others). Definitions are provided in Hodgson *et al.* (2003). However, for this study, hard corals were further divided into the categories *Acropora* and non-*Acropora*, and silt/clay was omitted due to its infrequent abundance.

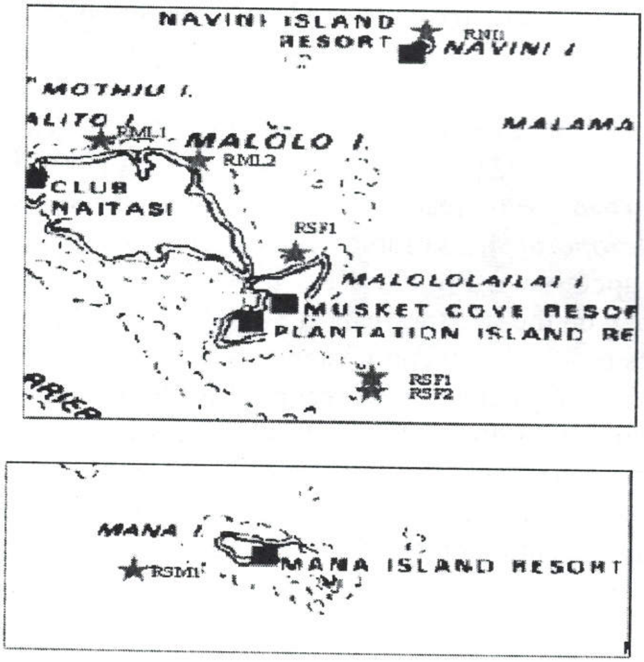
Furthermore, the presence of coral recruits, defined as colonies < 5 cm in diameter, was recorded along each transect line. This enabled recovery to be recorded both as the presence of healthy existing coral colonies, which may have partially bleached in the 2000 event and the recruitment of new hard coral colonies on stable non-living substrata (reef rock and dead coral).

Table 1. (Continued)

Site code	Site name / General location	Depth (m)
RML 1	Malolo Island	7
RML 2	Malolo Island	4
RML 3	Malolo Lailai	6
RNA 1	Nayanu Levu	3
RNI 1	Navini Island	5
RRA 1	Raviniake (close to CCC base)	3
RRA 2	Raviniake (close to CCC base)	4
RSF 1	Sunflower	14
RSF2	Sunflower	4
RSM 1	Supermarket	8
RWI 1	Waidigi Island	6

Figure 2. Location of Reef Check sites (red stars) completed during the pilot phase of the MCRCP (July/August 2001), and subsequently during the Fiji Reef Conservation Project in June/July 2002. (Key to codes in Table 1)





Results

An overall increase in hard (scleractinian) coral cover for the 22 transects was recorded, from 13% mean total cover in 2001, to 27.3% mean total cover in 2002 (Figure 3). Hard coral cover included all living colonies of scleractinian corals whether they were large established colonies or recent recruits over the twelve-month period. Statistically the increase was significant (paired t-test; $p < 0.01$, Table 2). A significant increase in coral recruits recorded along the transects was also found between 2001 and 2002 (Mann-Whitney test; $p = 0.025$, $n = 20$). In 2002 Haycock (pers. obs.) noted that coral recruits were generally more prevalent at Navini (RNI1), Honeymoon (RHM1), and Sunflower (RSF1/RSF2). Conversely, at the Malolo Island and Castaway sites, recovery of large coral colonies was more prominent than the recruitment of juvenile corals (Walker, D., pers. obs.).

An increase in hard coral cover was also shown by both non-*Acropora* and *Acropora* corals over the period of a year; non-*Acropora* increased from 9.8% in 2001 to 19.3% in 2002 (p <0.01), whilst *Acropora* cover more than doubled from 3.3% in 2001 to 8.0% in 2002 (p <0.05). All sites surveyed in 2002 (with the exception of RCA4, RNI1 and RRA2) had greater recorded cover of non-*Acropora* corals than *Acropora* corals (Table 2) (mean cover of 19.2% and 8% respectively, Fig. 3). The highest coral cover was recorded on the two transects at Sunflower reef (Table 2). Counts of 82 and 79 and means of 49.4% and 51.3% for total hard coral cover were recorded for RSF1 and RSF2 respectively. Both Sunflower transects also recorded the highest coral cover in 2001. The increase in hard coral cover was generally recorded across the sites in the Mamanucas, with the exception of RCA2 and RRA2 (Table 2).

The 2002 surveys showed a similar amount of algal cover to the 2001 surveys (27.8% and 24.6% respectively). Sponges and soft corals were rarely seen on the transect lines (both had mean coverage of <2%). The only other benthic class to show a significant change over time was that of rock, decreasing in cover (p <0.01).

Figure 3. (Next page) Temporal changes in benthic cover (%) between 2001 and 2002 across the 22 survey sites.

Notes: RKC = Recently killed coral.

Significant increases occurred in the percent cover of *Acropora*, Non-*Acropora*, total coral and Other (OT) categories (t-test, *P*< 0.05). There was also a significant decrease in the % cover of rock (RC) between 2001 and 2002.

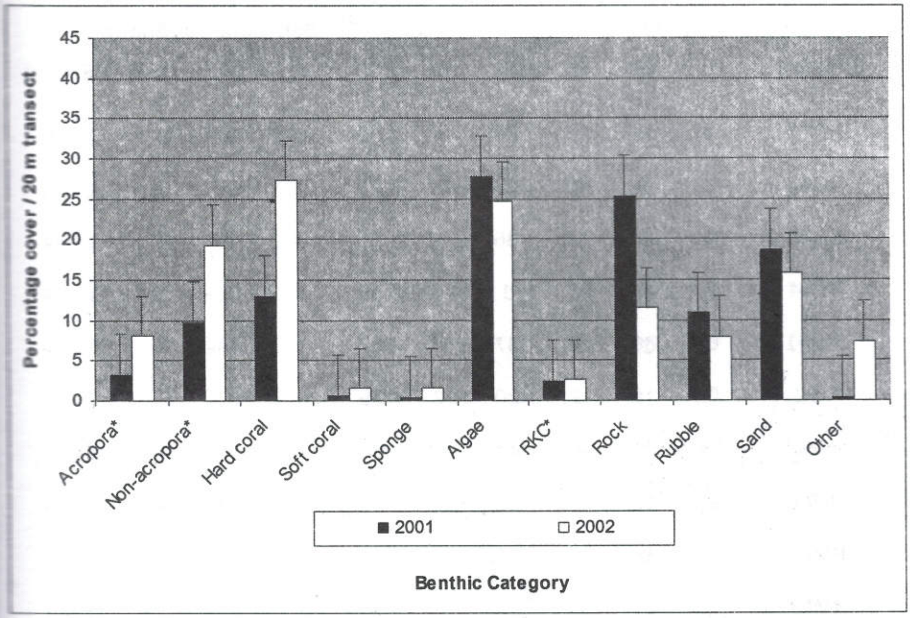


Table 2. (Following pages) Total transect substrate counts for the 22 repeat surveys (2001-2002). Results of paired t-tests display differences between in total cover for each substrate type across the Mamanucas. *RKC = Recently killed coral.

Site/Year	Acropora		Non-Acropora		Total Hard Coral		Soft Coral		Sponge	
	01	02	01	02	01	02	01	02	01	02
RCA1	1	1	9	49	10	50	0	0	0	0
RCA2	1	0	26	23	27	23	2	0	0	1
RCA3	0	0	10	36	10	36	0	0	0	1
RCA4	2	9	2	1	4	10	3	0	1	1
RHM1	6	30	9	37	15	67	2	4	2	1
RIB1	0	19	2	20	2	39	0	0	0	2
RIB2	13	20	24	44	37	64	1	5	0	3
RIB3	8	10	7	12	15	22	0	0	0	0
RMI1	0	0	27	21	27	21	6	11	6	0
RMI3	4	6	27	32	31	38	3	0	0	13
RMI4	0	1	33	36	33	37	5	19	7	8
RML1	0	23	11	41	11	64	0	4	1	0
RML2	0	1	19	49	19	50	0	0	0	3
RML3	1	0	36	23	37	23	0	0	0	3
RNA1	11	31	16	33	27	64	0	2	0	5
RNI1	6	34	18	30	24	64	1	11	0	3
RRA1	0	1	4	23	4	24	0	0	1	2
RRA2	4	7	15	3	19	10	1	0	0	1
RSF1	14	21	57	58	71	79	1	1	1	0
RSF2	34	39	11	43	45	82	1	3	2	0
RSM1	0	0	11	37	11	37	0	1	0	2
RWI1	1	4	1	10	2	14	0	0	0	3
t-test(42)	-2.12		-3.01		-3.35		-1.44		-1.83	
P	<0.05		<0.01		<0.01		>0.05		>0.05	

	Algae		RKC*		Rock		Rubble		Sand		Other	
Site/Year	01	02	01	02	01	02	01	02	01	02	01	02
RCA1	54	34	0	0	28	4	30	25	38	46	0	1
RCA2	57	15	2	3	26	16	14	18	32	35	0	49
RCA3	60	70	5	0	18	15	31	13	36	22	0	3
RCA4	40	61	3	1	42	19	21	23	45	39	1	6
RHM1	58	44	2	0	64	18	4	0	10	0	3	26
RIB1	82	31	1	2	26	33	8	4	41	46	0	3
RIB2	10	41	12	7	88	33	10	5	1	0	1	2
RIB3	77	22	2	42	6	5	8	4	52	65	0	0
RMI1	63	35	0	0	36	5	3	0	9	0	10	8
RMI3	39	30	11	1	55	37	3	0	18	35	0	6
RMI4	39	81	4	2	57	7	8	0	7	1	0	5
RML1	24	16	0	0	17	17	18	6	89	31	0	22
RML2	70	51	2	2	27	2	18	15	21	23	3	14
RML3	44	4	5	0	15	45	41	16	18	13	0	13
RNA1	60	20	1	7	25	43	25	3	20	16	2	0
RNI1	34	34	3	8	70	13	12	2	14	3	2	22
RRA1	37	56	2	1	36	16	28	14	52	46	0	1
RRA2	35	52	9	3	34	16	28	44	34	33	0	1
RSF1	22	38	12	0	32	0	15	12	5	0	1	30
RSF2	60	4	3	2	22	24	14	4	11	16	2	25
RSM1	12	63	2	0	116	35	1	0	18	13	0	9
RWI1	21	26	5	1	24	14	52	60	56	33	0	9
t-test(42)	1.25		0.0884		3.23		1.31		0.83		-3.84	
P	>0.05		>0.05		<0.01		>0.05		>0.05		<0.001	

Discussion

The most striking difference between 2001 and 2002 data sets is the increase in both *Acropora* and non-*Acropora* and therefore, total scleractinian coral cover at almost all of the study sites. The significant decrease in the total recorded cover of rock across the survey sites suggests that the available space was becoming occupied by coral recruits during the period between the surveys. The significant increase in the number of recruits recorded between the two sampling times verifies this suggestion. Survey sites spanned the complete range of geomorphological reef types present in the Mamanucas region at widely dispersed localities. The increase in hard coral cover can generally be viewed as extremely encouraging.

The Association of South East Asian Nations (ASEAN) system for describing the health of coral reefs (Chou *et al.*, 1984) states that coral reefs with hard coral cover of less than 25% are described as being in 'poor' health, whilst those of cover in excess of 25% are described as 'fair.' Therefore, the reefs in the region appear to have doubled in live hard coral cover in one year, thus increased their ASEAN health rating from poor to fair.

Acropora coral, normally known for its susceptibility to bleaching (Brown, 1987; Lovell, 2000) also recovered significantly with branching *Acropora* coral cover in areas such as Sunflower reef (to the south of Malolo Lailai) recording high levels of abundance. *Acropora* corals are biologically designed to recover quickly from physical damage (Brown and Howard, 1985). They are adapted for life in high-energy shallow environments (i.e. reef crests) and are amongst the fastest growing corals with high fecundities. This life history strategy as a disturbance-adapted ruderal (*r*-selected traits) enables them to recover more quickly from population crashes than slower-growing *K*-selected (competitors) or *S*-selected (stress-tolerators) corals

(Goodman, 1974; Pianka, 1972 but see also Edinger and Risk, 2000). Lovell (2000) also states that a high survival rate of corals at depth or inshore ensures a high level of recruits to stock recovering bleached colonies on some of Fiji's reefs.

As no permanent markers of the transects were used, two sources of error are apparent when comparing the 2002 data with that of 2001. GPS points were taken over the start and end points in 2001, and in 2002 when the sites were revisited using these GPS readings. Dive teams were dropped in as close to the original points as possible.

However, due to several factors, including adverse weather conditions and currents, accurate positioning of survey divers was only possible to within about 10-15 meters in some cases. It would be very difficult to drop divers in on the same point that was used as the start point from the year before, unless the start and end points were permanently marked underwater. Similarly, it would be difficult to know exactly how the measuring tape was originally laid in 2001, and that the bearing of the line may be slightly different without submerged markers. As a result, all transects will have probably been taken along a slightly different line in 2002 to that swum in 2001. In light of these factors it is highly likely that the data collected will be valid only for gross temporal comparison in benthic cover and faunal abundance rather than specific changes at individual sites. Data were collected along the same depth contours at all sites in both years, and trends in increased coral cover existed at over 80 % of the sites visited.

Cumming *et al.* (2003) state that an estimated 10-40% of coral colonies died from bleaching within four months of the onset of bleaching in 2000. The Mamanucas were not as badly affected as reefs in southern and eastern regions of Fiji, commonly displaying >80% mortality rates. Sea surface temperature (SST) in the Mamanucas exceeded expected summertime maxima for 5 months and peaked at 30-31°C prior to bleaching between March and early April 2000 (Walker *et al.*, 2002). The watershed point at which corals start to bleach is generally regarded as 30°C (Brown, 1997) whilst the bleaching threshold in Fiji appears to be in the range of 29.5-30°C (Cumming *et al.*, 2003).

Our results suggest that a significant degree of recovery from bleaching by scleractinian corals has occurred across the Mamanucas island group. The increase in hard coral cover can be attributed to a combination of recruitment of new corals on available reef rock and the recovery of previously partially bleached colonies. An increase in recruitment was recorded along transect lines over the time period of the study. Lang *et al.* (1992) and McField (1999) state that bleached colonies are able to begin recovery within 3.5-4 months of a bleaching event in some cases. Bleached colonies in 2000 may have been recorded as non-recoverable (see Cumming *et al.*, 2003) only to begin recovering after four months in the bleached state. The results presented here also support the idea that the Mamanucas region is of national importance in Fiji as it shows demonstrable capacity to recover from bleaching events and storm episodes (Cumming *et al.*, 2003).

Conclusion

Our results indicate a significant recovery from bleaching by scleractinian corals in the Mamanucas region of Fiji and further support the argument that trained non-specialist volunteers can be invaluable for the collection of reliable biological, quantitative data sets for coral reefs as part of a well-coordinated survey or monitoring program (Mumby *et al.*, 1995; Darwall and Dulvy, 1996; Harding *et al.*, 2000; and Evans *et al.*, 2001). Adequately trained volunteers can be a cost effective substitute to qualified marine biologists, where the use of such professional personnel would be unfeasibly expensive or logistically impossible due to time constraints. Reef Check is perhaps the most ambitious and successful reef-monitoring program which uses volunteer divers. Reef Check has gained considerable momentum since it was launched in 1997. The recent five-year report contained data collected by over 5,000 people from 1,500 reefs in more than half of the coral reef countries of the world (Hodgson and Leibeler, 2002). Despite the information collected being data in their simplest form, our results show that these data can reveal spatial trends and impacts over short timescales that are important for many coastal management decision-making processes.

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