REPORT

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A coral damage index and its application to diving sites in the Egyptian Red Sea

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Abstract A coral damage index (CDI) is provided, to screen sites to obtain a perspective on the extent and severity of physical damage to coral. Sites are listed as "hot spots" if in any transect the percent of broken coral colonies (BCC) is greater than or equal to 4% or if the percent cover of coral rubble (CR) is greater than or equal to 3%. To demonstrate its utility, the CDI is applied to a real-life management situation off Hurghada and Safaga, Egypt in the Red Sea. The extent of coral damage covered all four diving sites. Forty percent of all the transects were "hot spots" that required management action. Thirty-one percent of the 16 "hot spot" transects were identified by both broken coral and rubble criteria, 25% by only broken coral criterion and 44% by only coral rubble criterion of the CDI, suggesting that past breakage was responsible for most of the observed damage. Sixty-three percent of the "hot spot" transects were at 4 m depth versus 37% at 8 m depth, suggesting that most of the damage was caused by anchors dragging across the reef in shallow water. The severity of coral damage, reflected by CR, was the greatest at Small Giftun in transect 5 at 4 m depth (333% above the CDI). El Fanous experienced the most severe degree of broken coral damage (325% above the CDI) at 8 m depth along transect 2. Estimates of the number of dives per year show diving carrying capacities for El Fanous, Gotta Abu Ramada, Ras Abu Soma and Small Giftun being exceeded by large amounts. The CDI can be used globally to; gauge the severity and extent of damage, focus managers on areas that need mooring buoys and associated dive site management programs, and provide a starting point from which to focus more detailed coral reef assessments and restoration programs.

Key words Coral damage index · Diver and Anchor damage · Carrying capacities · Mooring buoys · Red Sea

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Introduction

As the popularity of recreational scuba diving increases, the physical damage to coral reef organisms caused by anchoring and divers has become a major concern of coral reef managers. In the Red Sea, Riegl and Velimirov (1991) found that off Eilat, Israel and Hurghada, Egypt, breakage of coral by humans was the most common damage category and that it was significantly higher on highly frequented reefs. Damage was most frequent within the first 10 m depth. A significant difference in the amount of corals overgrown by algae was found on the reefs near Hurghada compared with other reefs studied and this was correlated with the occurrence of tissue loss and breakage. In all cases of damage, *Acropora* was the most frequently affected genus while *Millepora dichotoma* was the most affected species. On Red Sea fore-reef slopes, Hawkins and Roberts (1992) also found there were significantly more damaged colonies, loose coral fragments, and partially dead or abraded corals in areas heavily used by divers than in control areas. Hawkins and Roberts

(1993) quantified the effects of trampling on reef-flat communities by divers walking from shore to the reef edge off Sharm el Sheikh, Egypt.

Researchers in other parts of the world have also confirmed diver-related impact as a major management concern within marine parks. Degradation of coral reefs by reef-walkers has been described by Woodland and Hooper (1977), Liddle and Kay (1987), Kay and Liddle (1989), and Neil (1990). Degradation by scuba divers has been documented off Australia by Rouphael and Inglis (1995) and Davis et al. (1995), in the Caribbean by Rogers et al. (1988), Dixon et al. (1993, 1994) and Chadwick-Furman (1996), and off Florida by Tilmant and Schmahl (1982) and Tilmant (1987).

Diver carrying capacities, usually expressed as the number of dives per site per year, is a measure of the number of divers a reef can tolerate without becoming significantly degraded, and also plays an important role in the management of physical damage on a coral reef. Salm (1986a, b) introduced the concept of diver carrying capacity. In the Bonaire Marine Park, Dixon et al. (1994) found that most divers seldom venture further than 300 m in one direction and that there was a decreasing physical impact on reef communities with increasing distance from a mooring buoy. Analyzing coral cover, they estimate that the diver carrying capacity threshold for the Bonaire Marine Park is between 4000 and 6000 dives per site per year. Surveying the percent of damaged coral colonies in the Red Sea Ras Mohammed National Park, Hawkins and Roberts (1997) suggest 5000 to 6000 dives per site per year as a good rule of thumb in the absence of site-specific data. Sampling a suite of invertebrates (hard corals, soft corals, sea fans, branching hydrocorals, and erect sponges), Chadwick-Furman (1996) found the threshold for diving sites in the US Virgin Islands to be only 500 dives per site per year and attributed this significantly lower estimate to the fragility of the various reef organisms in the study area.

Coral reef diver carrying capacities are usually very sensitive political and economic subjects because sport diver volume directly impacts local and regional tourist economies, and because understanding of this subject by scientists, managers and politicians is still very limited. Diver carrying capacities are rarely considered "up-front" by planners and developers. As a result, coral reef managers in many areas have to fight uphill battles to convince authorities to limit sport diving volume. In areas where new development is being planned (i.e., the South Coast Tourist Area off Aqaba, Jordan), diving carrying capacities can be used to effectively design the size and configuration of the tourist development so it is in balance with potential diver-related economic revenues. Effective diver education programs can allow coral reef managers to increase carrying capacities (Medio et al. 1997). Mooring buoys and the management of the number of vessels using mooring buoys with respect to time and location are other effective tools coral reef managers use in reducing the anchor and diver damage to coral reefs. By requiring vessels to use mooring buoys and limiting the number of buoys and boats using the buoys, coral reef managers can effectively implement carrying capacity programs.

Hotel/resort and other development along the coast of Egypt is proceeding rapidly, and threatening valuable coral reef ecosystems (Jameson et al. 1995). Effective coral reef management programs are critical to sustainable tourism strategies for the Red Sea (Reeve et al. 1998). Although Egypt's coastal zone management program is still in the process of development, a number of marine protected areas have been designated and are being administered by the Egyptian Environmental Affairs Agency's (EEAA) Department of Protectorates. Since the late 1980s, and with the support of the European Union, Egypt initiated active management programs in the world-renowned Ras Mohamed National Park and, more recently, in the Nabq and Abu Galum Managed Resource Protected Areas of South Sinai. By inaugurating the South Sinai Protected Areas Program simultaneously with the rapid increase of hotel development, it has been possible to manage the development process with a measurable degree of effectiveness. However, even with these efforts, the number of tourists visiting the Ras Mohammed National Park now exceeds 500 000 visitors per year and individual dive-boat moorings are estimated to experience up to 20 000 dives per year (Medio et al. 1997). Hawkins and Roberts (1992) expressed concern over the future rapid expansion of divers using reefs off Sharma el Sheikh, Egypt and predicted that such levels would be unsustainable and cause serious reef degradation. Damage due to divers is now the main cause of coral mortality at the most heavily used sites of the Ras Mohammed National Park (Medio et al. 1997) and qualitative studies have demonstrated differences in live coral cover between heavily used and unused areas.

Unlike the Sinai, tourism development on the 1000 km western coast of the Egyptian Red Sea (Fig. 1) has proceeded without an active marine management system in place. The Elba Protectorate (designated in 1986 and amended in 1995) includes a large land mass in the southeastern section of Egypt, 22 Red Sea Islands, and all mangrove stands along the western Red Sea coast. For many years before the designation of the Elba Protectorate and until 1997 (when a ranger enforcement unit was established out of Hurghada by EEAA with support from the United States Agency for International Development), management of diving and anchoring at dive sites along the western Red Sea coast was non-existent. As a result, the large number of diving vessels (estimated at about 60–100 full-time operators, with seasonal variation) and active dive centers (about 80) operating in the Hurghada area have had

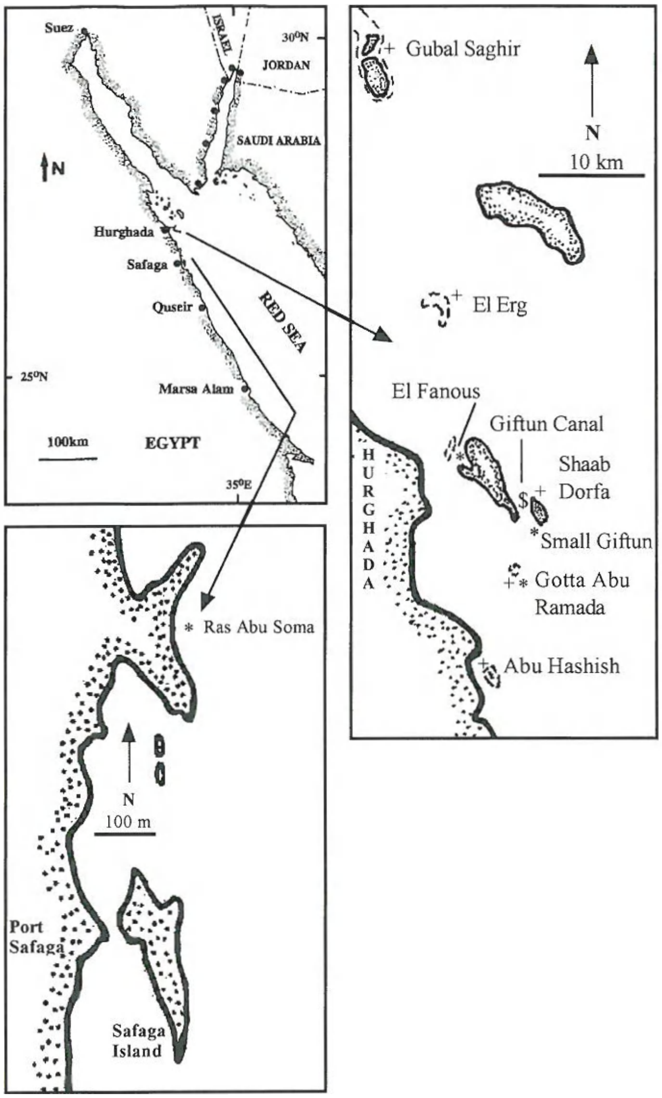

Fig. 1 Location of diving sites off Hurghada and Safaga, Egypt in the Red Sea. * = 1996 transect site. $ = control site, + = 1987 Riegl and Velkimerov (1991, 1994) transect site

free reign to operate unsupervised in the Protectorate. This has caused considerable physical damage to coral reefs (Jameson and Smith 1997, Jameson et al. 1997).

Information for accurately evaluating the condition of diving sites is critical for effective management. To be useful, monitoring programs must be designed with scientific and management questions in mind, and their development and implementation must involve managers and user groups to the maximum extent possible. A particular need is the ability to quickly and accurately assess the condition of ecosystems and the level of environmental threats (Eakin et al. 1997). Coral reef bioindicators lag far behind freshwater and estuarine marine biomonitoring programs, many of which have undergone extensive calibration and have been developed into multi-metric indexes of biotic integrity with well-defined interpretive frameworks. Many of these indexes result in the calculation of a simple numerical "score" for a particular site, which can then be compared over time or with other sites. Such rankings have an intuitive appeal to resource managers and users, and can be an effective means of galvanizing political willpower towards pollution prevention and conservation activities (Jameson et al. 1998).

The purpose of this study is to provide coral reef managers with a tool, a coral damage index (CDI, Table 1), to screen large numbers of diving sites to obtain a perspective on the extent and severity of physical damage to coral (not the cause of damage). To demonstrate its utility, the CDI is applied to a real-life management situation in the Red Sea. The CDI also provides managers with an understanding of which sites need mooring buoys and associated dive site management programs, and provides a starting point from which to focus more detailed coral reef assessments and restoration programs. The criteria for the CDI are supported by best available data from the Red Sea and Caribbean. The CDI can be useful to coral reef managers world-wide and can also be a meaningful addition to multi-metric indexes for coral reef ecosystem assessment.

Methods

The coral damage index

Broken coral and coral rubble are the life forms used for the CDI (Tables 1 and 2) because they best represent past (rubble) and more recent (broken coral) physical damage to coral on reefs.

Coral damage index criteria justifications

The CDI criteria are justified using data from the Red Sea and Caribbean (Table 3 and Fig. 2). Data from minimally impaired sites, collected in 1987 by Riegl and Velimirov (1991, 1994), provided a baseline perspective for breakage and rubble formation that was minimally affected by anthropogenic impacts or natural disasters (Table 3). At these sites, diving and anchoring activity was very low, for 1987 standards, because these sites are located further from Hurghada and are not suitable for anchoring in stormy seas (Riegl and Velimirov 1991). Coral disease and *Acanthaster* impacts were minor (Riegl and Velimirov 1991, 1994). Hurricane damage was not a factor because Egypt is not subject to cyclonic storms (Hawkins and Roberts 1997).

Table 1 Coral damage index. Sites are listed as "hot spots" (candidates for further monitoring, assessment and/or restoration) if they fail any one of the criteria for any transect

Coral damage index
The percent of broken coral colonies is greater than or equal to 4%, or the percent cover of coral rubble is greater than or equal to 3%.

Table 2 Life form categories used in the coral damage index and sampled for at five diving sites in the Egyptian Red Sea

Life form category	Characteristics
Broken Coral. Expressed as percent broken coral colonies (BCC). By using percentages rather than numbers we factor out the potential confounding effects caused by differences in coral cover which exist among sites (Hawkins and Roberts 1997).	Broken (any part) or overturned live coral colony with no extensive regeneration or callus formation. Non-attached but otherwise live colonies were classified as broken if there was visible evidence that the stem had been broken off (Riegl and Velimirov 1991, Hawkins and Roberts 1997).
Coral Rubble (CR). Expressed as percent cover of coral rubble.	Unconsolidated dead coral fragments (English et al. 1997).

Table 3 Means and standard errors of percent broken coral colonies (BCC) and percent cover of coral rubble (CR) from surveys conducted in 1987 at five minimally impaired sites off Hurghada, Egypt by Riegl and Velimirov (1991, 1994). Transect length was 10 m. Transect depths are in 1 m depth intervals (i.e., if there are 12 transects they are continuous from 1 m to 12 m depth). The 29 transects from the Shaab Abu Rimathi (alias Gotta Abu Ramada) are three series from 1–10 m depth. n = number of transects

Diving site	n	BCC (SE)	CR (SE)
Shaab Dorfa	11	6.1(4)	1.9(1.9)
Abu Hashish	12	3.2(2)	0.8(0.5)
Shaab Abu Rimathi	29	0(0)	0(0)
Gubal Saghir	17	0.23(0.2)	0(0)
El Erg	12	2.6(1.7)	0(0)
Pooled Mean	81	1.7(0.7)	0.4(0.3)

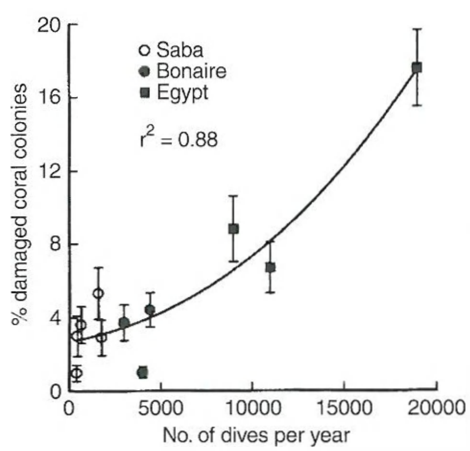

Fig. 2 Effects of scuba diving on coral damage levels in Egypt, Bonaire and Saba. Increases in diver use result in an exponentially increasing level of damage. Figures show the mean and standard error for measures of damage at each dive site in each location. n = 214 samples. From Hawkins and Roberts (1997)

For diving sites in 10–15 m depths off Saba, Bonaire and Egypt, Hawkins and Roberts (1997) found that there was exponentially increasing levels of coral damage beyond the point where dives per year exceeded 5000–6000 and where damaged coral colonies exceeded 4% (Fig. 2).

The following logic was used in determining the final values for the criteria:

1. *Percent of broken coral colonies greater than or equal to* 4%. More weight was given to the Hawkins and Roberts (1997) data when determining this criterion value. The 4% value also fell within the range of broken colony data from 1987 presented in Table 3 (Riegl and Velimirov 1991, 1994). Using our Giftun Canal control site as a check, the criterion value was 1% above the highest percentage of broken coral colonies recorded at this minimally impaired site.

2. *Percent of coral rubble value of greater than or equal to* 3%. Since rubble reference data was more limited geographically than broken colony data, more weight was given to the highest rubble value (1.9%) recorded in the 1987 reference sites listed in Table 3. One percent was added to this value to allow for a certain degree of sampling error/variability and it was rounded off to the nearest percent (3%). Using our Giftun Canal control site as a check, the final criterion value was 1% above the highest percentage of broken coral colonies recorded at this minimally impaired site.

Red Sea dive site survey methods

Four sites were selected in areas frequented by diving vessels in the Hurghada (Gotta Abu Ramada, Small Giftun, El Fanous) and Safaga (Ras Abu Soma) areas (Table 4). The Global Coral Reef Monitoring line intercept transect method (English et al. 1997) was used to sample the damage in 1996. At each site, five 20 m long replicate transects were placed haphazardly along the reef slope at 4 and 8 m depth. A 10 m transect length was determined as adequate using a species-transect length curve. However, a 20 m transect length was actually used to be consistent with Global Coral Reef Monitoring Network protocols (English et al. 1997). All beginning and end points of transects were marked with steel rods. For easy identification and relocation, yellow tags denoting "Park Study Site" were attached to transect rods and white cable ties were attached to the substrate near the rod. Giftun Canal, a minimally impaired site that is relatively unknown by divers, was used as the control. Because of the extensive amount of diving occurring in the study area, it was impossible to find a perfect control site with no impacts occurring. While *on station (from approximately* 0900 *to* 1600 *LT)*, daily observations were made of the number of boats, number of anchors on the reef, number of divers and number of snorkelers (Table 5).

Results

Table 4 Extent of coral damage at diving sites in the Egyptian Red Sea expressed as percent of broken coral colonies (BCC) and percent cover of coral rubble (CR).Transects were located at 4 and 8 m depths. T = transect number, CS = control site, * = "hot spot" (i.e. BCC values of 4% or greater, CR values of 3% or greater)

Dive Site/Location	T1 BCC/CR	T2 BCC/CR	T3 BCC/CR	T4 BCC/CR	T5 BCC/CR
El Fanous/27°16.06'N, 33° 53.20'E					
4 m	0/0	0/5*	0/0	0/0	4*/7*
8 m	0/0	17*/0	5*/1	0/0	0/0
Gotta Abu Ramada/27°09.26'N, 33° 57.90'E					
4 m	3/4*	0/8*	0/0	0/0	0/0
8 m	3/0	0/0	0/0	0/0	0/0
Ras Abu Soma/26°50.29'N, 33° 59.80'E					
4 m	2/9*	0/0	2/2	4*/2	2/6*
8 m	0/0	0/0	0/0	4*/4*	1/8*
Small Giftun/27°10.15'N, 33° 50.85'E					
4 m	0/0	0/0	8*/10*	7*/0	8*/13*
8 m	0/0	0/0	3/6*	0/0	4*/5*
CS Giftun Canal/27°10.02'N, 33° 50.07'E					
4 m	0/0	3/2	0/0	0/0	0/0
8 m	0/0	0/0	0/0	3/2	0/0

Table 5 Number of daily observations, from approximately 0900–1600 LT, with means (SE), of number of boats (Boats), number of anchors on the reef (Anchors), number of divers (Divers)/estimated dives per year (DPY – assuming two dives per diver and diving 300 days per year), and number of snorkelers (Snorkelers) for the five sites surveyed off Hurghada and Safaga, Egypt, Red Sea. CS = control site, * = Hawkins and Roberts (1997) recommended carrying capacity of 6000 dives per year exceeded

Dive site/date	Boats	Anchors	Divers/DPY	Snorkelers
El Fanous				
03 Oct. 1996	7	14	57	30
11 Oct. 1996	9	18	87	45
Means(SE)	8(1)	16(2)	72(15)/43,200*	37.5(7.5)
Gotta Abu Ramada				
12 Sept. 1996	7	10	35	15
13 Sept. 1996	3	6	8	8
Mean (SE)	5(2)	8(2)	21.5(13.5)/12,900*	11.5(3.5)
Ras Abu Soma				
5 Nov. 1996	6	12	72	30
6 Nov. 1996	6	12	80	35
Mean(SE)	6(0)	12(0)	76(4)/45,600*	32.5(2.5)
Small Giftun				
15 Sept. 1996	7	14	74	38
16 Sept. 1996	27	54	330	160
Mean(SE)	17(10)	34(20)	202(128)/121,200*	99(61)
CS Giftun Canal				
15 Oct. 1996	2	4	14	0
16 Oct. 1996	1	0	2	0
17 Oct. 1996	1	2	2	0
Mean(SE)	1.3(0.5)	2.7(1.9)	6(5.7)/3,600	0(0)

Discussion

Using the CDI as a management tool

The CDI can be used globally to gauge the severity and extent (but not exact cause) of coral damage (diver, anchor, dynamite, fish trap, chronic coral disease, *Acanthaster* infestation, and/or hurricane-related) because:

1. The CDI uses baseline data from Red Sea reefs that have been minimally impaired by these impacts (Table 3); and

2. The CDI is based on data from minimally impaired coral reefs at different locations around the world (Table 3 and Fig. 2).

The extent of damage can be measured by the number of diving sites with "hot spots", the percent of transects with "hot spots", the percentage of "hot spots" identified by the two CDI criteria (singly and in combination) and the percentage of "hot spots" at various depths. The severity of damage can be measured as the percentage above the CDI criteria values with respect to location and depth.

The resolving power of the CDI is dependent on the size of the area selected for reference. Therefore, the purpose of the damage assessment will determine the focus area of the CDI. In this study, individual transect lines provided the right amount of resolution for the identification of damaged areas within diving sites and provided managers with the information needed to locate mooring buoys and plan restoration work. If transect data had been pooled in this study, the resolution of the CDI would have been reduced and not as effective in identifying appropriate "hot spots" for the needs of management.

It should be emphasized that this exercise in developing a bioindicator for coral reef ecosystem assessment demonstrates the critical value of historical data from minimally impaired coral reefs. The CDI could have been better refined if more historical data from minimally impaired Red Sea sites – or other minimally impaired sites without hurricane damage – was available. Too often, monitoring and marine protected area management is focused on impaired or threatened sites. As a result, critical baseline data from minimally impaired sites is very limited, although essential for scientists and managers trying to understand the causes and meaning of change on coral reefs.

Red Sea diving sites

The focus of this study was on gauging the extent and severity of physical coral damage at diving sites. There was no way to accurately determine the exact cause(s) of the physical coral damage. In this study, results may be confounded by natural physical damage i.e., breakage by other marine organisms, predation, natural disease, or bioerosion. Riegl and Velimirov (1991) mentioned the problem of accurately interpreting the causes for observed physical damage and found it difficult in many cases to differentiate between natural and man-made damage. More recently, dynamite-related damage patterns in the Red Sea were described by Riegl and Luke (1998) who showed that specific types of user damage created distinct damage patterns, which allowed them to extrapolate to causes. Quantitative surveys by team members (Tables 4 and 5) as well as qualitative observations by experienced divers and boat skippers operating in the study area since 1985 strongly suggest the damage described in this paper is overwhelmingly anchor and diver-related.

The extent of coral damage covered all four diving sites. Forty percent of all the transects were "hot spots" that required management action. Ras Abu Soma and Small Giftun were the most damaged sites (five "hot spots" each), followed by El Fanous (four "hot spots"), and Gotta Abu Ramada (two "hot spots"). Thirty-one percent of the 16 "hot spot" transects were identified by both broken coral and rubble criteria, 25% by only broken coral criterion and 44% by only coral rubble criterion of the CDI. This suggests that past breakage was responsible for most of the observed damage. Sixty-three percent of the "hot spot" transects were at 4 m depth versus 37% at 8 m depth, suggesting that most of the damage was caused by anchors dragging across the reef in shallow water (Table 4).

The severity of coral damage (Table 6), reflected by CR, was the greatest at Small Giftun in transect 5 at 4 m depth (333% over the CDI criterion value). Transect 3 at Small Giftun in 4 m depth also experienced considerable damage reflected by a CR value of 233%. El Fanous experienced a severe degree of broken coral damage (BCC value 325% over the CDI criterion value) at 8 m depth along transect 2. Damage percentages, relative to CDI values, for other "hot spots" are shown in Table 6.

While the estimates of the number of dives per year in Table 5, showing diving carrying capacities for El Fanous, Gotta Abu Ramada, Ras Abu Soma and Small Giftun being exceeded by large amounts (and this does not include the damage caused by snorkelers), is an estimate based on limited sampling, it should never-the-less be of major concern to coral reef managers.

Management action

In early 1997, using the results of this study, the Hurghada Environmental Protection and Conservation

Table 6 Severity of coral damage in "hot spots" represented as the percentage increase of broken coral colonies (BCC) and coral rubble (CR) over the CDI criteria values of 4% (BCC) and 3% (CR) for diving sites in the Egyptian Red Sea. Transects were located at 4 and 8 m depths. T = transect number, * = "hot spot"

Dive site	T1 BCC/CR	T2 BCC/CR	T3 BCC/CR	T4 BCC/CR	T5 BCC/CR
El Fanous					
4 m	0/0	0/67*	0/0	0/0	1*/133*
8 m	0/0	325*/0	25*/1	0/0	0/0
Gotta Abu Ramada					
4 m	3/33*	0/167*	0/0	0/0	0/0
8 m	3/0	0/0	0/0	0/0	0/0
Ras Abu Soma					
4 m	2/200*	0/0	2/2	1*/2	2/100*
8 m	0/0	0/0	0/0	1*/33*	1/167*
Small Giftun					
4 m	0/0	0/0	100*/233*	75*/0	100*/333*
8 m	0/0	0/0	3/100*	0/0	1*/67*

Association (HEPCA) with financial assistance from the United States Agency for International Development and with the participation of EEAA's Protectorates Division, installed over 250 mooring buoys (including reef top pins) at popular local diving sites within the Hurghada/Safaga area. More mooring buoys are planned for installation south of Hurghada/Safaga. HEPCA is also responsible for maintaining these buoys/pins.

More rangers have been assigned to the area, and work is underway to establish a zoning and dive site management plan.

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