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Using Reefcheck Monitoring Database to Develop the Coral Reef Index of Biological Integrity

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Abstract: The coral reef indices of biological integrity was constituted based on the reef check monitoring data. Seventy six minimally disturbed sites and 72 maximally disturbed sites in shallow water and 39 minimally disturbed sites and 37 maximally disturbed sites in deep water were classified based on the high-end and low-end percentages and ratios of hard coral, dead coral and fleshy algae. A total of 52 candidate metrics was identified and compiled. Eight and four metrics were finally selected to constitute the shallow and deep water coral reef indices respectively. The rating curve was applied for each metric to identify two lower a_i and upper b_i threshold values. A set of scores 1, 3 and 5 was used to score and narrate individual metric values. Each metric value at a site presented a poor, moderated or good condition of reefs. The index was calculated by averaging all selected metric scores. The overall site classification efficiencies were of 65.97 and 66.13% for shallow and deep waters respectively. Importantly, the strong negative correlation between indices and dynamite fishing -0.286 ($p<0.01$) and number of yacht within 1 km -0.185 ($p<0.05$) in shallow water and with poison fishing -0.279 ($p<0.05$) and coral damaged by other factors -0.283 ($p<0.05$) in deep water indicated that coral reef indices were sensitive responses to stressors and can be capable to use as the coral reef biological monitoring tool.

Key words: Index of biological integrity, coral reef, bioindicator, attribute, metric, minimally, maximally disturbed sites

INTRODUCTION

Coral reefs occupy about 600,000 square miles of the earth's surface (Nybakken, 2001). Reefs are well known as the most complex diverse ecosystems in the world (Clark, 1998), about one third of the world's fish species is said to live on and/or in associated with coral reefs (Clark, 1998; Nybakken, 2001). However, many coral reefs are dying because of destructive and heavy exploitation (Clark, 1998), 11% of the world's reefs have been lost due to human's impacts (Wilkinson, 2000). Since 1997, the Reef Check method, aiming to evaluate human's impact, has been applied at the global scale. Ten types of substrates have been used to classify reef sites and 40 fish and invertebrate species have been selected as the Reef Check bioindicators. The Reef Check bioinicators selected are based on their natural distribution (e.g., regional distribution and/or reef association attribute), economic values and/or ability to respond to overfishing gradient (Hodgson *et al*., 2004).

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Index of Biological Integrity (IBI) is an ecological approach attempting to synthesize diverse biological information of fish and/or invertebrate communities numerically in order to depict impacts on biological structure (Karr, 1981). IBI was first developed in the Midwestern warm water streams (Karr, 1981) and thus it has been conceiving as a stream assessment tool to evaluate the biological integrity (Karr, 1991). Since then, the IBI approach has been commonly applied in streams/rivers, estuaries and wetland. Examples, IBIs in the Maryland coastal and non coastal plains (Stribling *et al*., 1998), in the Rio Paraiba do Sul River in Southeast Brazil (Araujo *et al*., 2003), in the New Zealand Freshwaters (Joy and Death, 2004), in Chesapeake Bay (Weisberg *et al*., 1997), in the Mid-Atlantic United States (Llanso *et al*., 2002) and in the Semiarid Mediterranean Region wetland (Ortega *et al*., 2004). Sensitive responses of fishes and/or invertebrates to the environmental gradients (water pollution levels) have been combined into IBIs that can reflect ecological health at a site. Mean abundances of six Reef Check bioindicators in three oceans, the Indo-Pacific, the Atlantic and the Red Sea, were used to constituted Coral Reef Health Indices (CRHI) (Hodgson, 1999). The CRHIs constituted were not different among these three oceans, although the coral reef condition in the Red Sea is much better than those of that in the Atlantic and Indo-Pacific Oceans. Another index of deterioration (DI), the ratio between mortality and recruitment rates of branching corals, was constituted in the Eilat reefs in the Red Sea (Ben-Tzvi *et al*., 2004). However, the DI did not demonstrate consistent results between disturbed and undisturbed coral communities. A framework for Coral Reef Index of Biological Integrity (CRIBI) development introduced by Jameson *et al*. (2001) orients that the CRIBI development should include community and assemblage structure, taxonomic composition, individual condition and biological processes.

The aim of this study was to develop a global Coral Reef Index of Biological Integrity (CRIBI), which was integrated by several biological and ecological attributes including the natural abundance, reef association and life history of the Reef Check bioindicators. The constituted CRIBI would broadly and sensitively respond to the environmental gradient and can be used as a tool for coral reef monitoring.

MATERIALS AND METHODS

Reef Check Data and Data Extraction

The Reef Check monitoring program has been using ten types of substrates, including Hard Coral (HC), Fleshy Algae (FL), Dead Coral (DC: including rubble and recent killed coral), rocky (RC), sandy (SD), silt (SL), sponge (SP), soft coral (SC) and other (OT), to classify reef habitat conditions. In this study, these ten types of substrates were used to identify minimally disturbed sites (MinDS) or maximally disturbed sites (MaxDS). There are over 40 fish and invertebrate species have been selected as the Reef Check bioindicators (Hodgson *et al*., 2004). Of which, ten species/genus, including butterflyfish (Chaetodontidae), grouper (Serranidae), snapper (Lutjanidae), parrotfish (Scranidae), moray eel (Muraenidae), lobster (Malacostrata), banded coral shrimp (Stenopus hispidus), giant triton (Charonia), diadema and Collector sea urchin (Tripneutes) have been found in all regions/oceans, were used to develop global CRIBI in this study. A total of 3023 Reef Check monitoring sites was surveyed between 1997 and 2004. However, only 246 shallow sites and 170 deep sites, which were fulfilled data of ten substrates and ten bioindicators as mentioned above were extracted and used to develop shallow and deep waters' CRIBIs, respectively. The shallow sites are determined at a depth less than 6 m, while the deep sites are determined at a depth more than 6 m (Hodgson *et al*., 2004).

Minimally and Maximally Disturbed Sites' Criteria

High-end and low-end percentages of HC and DC and/or FL frequencies, the ratios (FL+DC)/(FL+DC+HC) and HC/(DC+FL) at a site were used to identify the MinDS and MaxDS sites in this study. A site consisting a high-end percentage of frequency of HC, a high ratio HC/(DC+FL) and a low ratio of (FL+DC)/(FL+DC+HC) was determined as minimally disturbed reef. While a site consisting a high-end percentage of frequency of DC and/or FL, low ratio HC/DC+FL and a high ratio of (FL+DC)/(FL+DC+HC) was determined as maximally disturbed reef. In this study, the minimal percentage of the high-end HC frequency was determined at 35% and the maximal percentage of the high-end of DC+ FL <35% for the MinDS site. While the minimal percentage of the low-end of DC+FL >50% for the MaxDS site. The ratio of HC/DC+FL requested to be greater than 2 at a given MinDS site and smaller than 1 at a given MaxDS site. The ratio HC/DC+FL >2 or HC/DC+FL<1 indicate a consistent difference between MinDS and MaxDS conditions. Low distribution of HC in the Atlantic Ocean naturally caused the low threshold (35%) of the high-end percentage of HC frequency in MinDS and MaxDS sites criteria. Only few Reef Check monitoring sites in the Atlantic Ocean consist 60% of HC frequency, while 40% of sites in the Indo-Pacific Ocean consist from 60 to 90% of HC. The criteria of MinDS and MaxDs sites are summarized as below:

Minimally disturbed site (MinDs)

- High-end percentage of hard coral frequency of occurrences >35%
- Low-end percentage of {(FL+DC)/(FL+DC+HC)}<35% and
- HC/(FL+DC) ≥ 2

Maximally disturbed site (MaxDS)

- Low-end percentage of hard coral frequency of occurrences <30%
- High-end percentage of {(FL+DC)/(FL+DC+HC)}>50% and
- HC/(FL+DC) ≤ 1

Candidate Metric Compilation and Calculation

Methods of candidate metric compilation and identification were based on the guidance from previous IBI development (Karr, 1981; Weisberg *et al*., 1997; Stribling *et al*., 1998; Llanso *et al*., 2002; Joy and Death, 2004) and the framework of coral reef index development (Jameson *et al*., 2001). Metrics of (1) species taxonomic richness and (2) species composition were basically compiled from individual species abundances or composition at a given Reef Check site/transect. Metrics presenting ecological and/or biological attributes, in particular living environment, habitat tendencies, trophic level, food consumption, length, natural mortality, age at the first maturity, lifespan and resilience, were compiled and identified by information extracted from FishBase database. The ecological and/or biological ranks of an individual species in each environmental gradient or life history attribute are the base to identify and compile these metrics. (3) Metrics of living environment were based on attribute of true brackish water or marine species; (4) Metrics of habitat tendencies were based on reef associated attribute; (5) Metrics of food consumption were based on feeding items (e.g. detritus, herbivore, omnivore and predation/nekton), found in stomach of each species; (6) Metrics of trophic levels were based on the trophic calculation that presented in FishBase database. The scientific norm to compile a biological metrics, including (7) length/size; (8) natural mortality; (9) age at the first maturity; (10) life span and (11) resilience, were based on the k and r life histories. Basically, the more abundance of k species (e.g., bigger size and longer life) is the more health reefs. The data of these attributes for each k or r species are available in the FishBase database. Basically, a larger number of species within a genus in the higher rank of reef association and/or reef health reflection was given a higher score. Metric's value at a given site was basically calculated from species abundances at that site. The summaries of metric compilation and identification are shown in Table 1. A total of 52 candidate metrics compiled at each shallow or deep water, these metrics were used to develop CRIBI development. Metric description is presented in Table 4.

Table 1: Metric identification based on nine ecological attributes of reefcheck bioindicators obtained from the fishbase database

Ecological attribute and its description		Scoring and narrative ratting			
		Very low	Low	Medium	High
Ecology (% of number of species of a genus living in a environment)	Criteria		Marine, Brackish and Fresh	Marine and Brackish	Marine
	Score		(0.5)	(1)	(1.5)
Habitat (% of number of species of a genus being reef-associated)	Criteria		Less than 50%	50-90%	Over 90%
	Score		(1)	(3)	(5)
Food consumption (% of number of species of a genus having different volumes of these food item categories in stomach)	Criteria	Mainly plant (Herbivore)	High zoobenthos, low plant (Omnivore)	Medium nekton and zoobenthos (Carnivore)	High nekton, low zoobenthos (Piscivore)
	Score	(1)	(2)	(3)	(4)
Trophic level (% of number of species of a genus ranked in different trophic levels)	Criteria		2-<3 (low)	3-3.5 (medium)	>3.5 (high)
	Score		(1)	(3)	(5)
Length/size (cm) (% of number of species of a genus having Lmax in each category)	Criteria	≤20 (small)	21-40 (medium)	41-60 (large)	>60 (very large)
	Score	(1)	(2)	(3)	(4)
Natural mortality (% of number of species of a genus having different % of mortality per year)	Criteria		> 1 (high)	0.5-1.0 (medium)	<0.5 (low)
	Score		(1)	(3)	(5)
Age at the first maturity (year)	Criteria	<1 (soon)	1-≤2 (medium)	2-3 (late)	>3 (very late)
	Score	(1)	(2)	(3)	(4)
Life span (year)	Criteria	<3 (short)	4-10 (medium)	11-30 (long)	>30 (very long)
	Score	(1)	(2)	(3)	(4)
Resilience (based on highest % from categories)	Criteria	>90% (high) (High)	70-90% (med) (Medium)	50-<70% (med)+ (low) (Low)	>50% (low) (Very low)
	Score	(1)	(2)	(3)	(4)

Metric Evaluation, Scoring and Index Calculation

The first step-metric evaluation: each of 52 candidate metrics was evaluated by employing two non-parametric statistical tests, Mann-Whitney U and Kolmogorov-Smirnov. These two statistical tests, in order, aim to identify difference of means and distribution patterns of metric values between MinDS and MaxDS sites. Metric evaluation was separate for shallow and deep waters. Metrics, which passed these two statistical tests ($p<0.05$), were preliminarily selected. If there are several metrics within an ecological or biological attribute group having same values (r^2 and P) of statistical tests, an alternative selection was given to common and simple metrics. An IBI consisting simple and common metrics is more reliable and easier to apply (Stribling *et al*., 1998). The second step-sensitive responses of metric to HC and stressors (DC and FL): the Spearman correlation was applied to evaluate the sensitive responses of preliminarily selected metrics to HC and DC and/or FL conditions. Metrics having strong correlations with HC or DC and/or FL ($p<0.05$) were alternatively selected. A negative or positive Spearman correlation between an individual metric and HC or DC and/or FL was significant to support metric scoring and narration in the next step. The third step-metric's threshold value identification, scoring and narration: in this step, a rating curve, where all values of a given selected metric were projected ascending, was applied to identify two lower a_i and upper b_i threshold values. These two threshold values divide metric values into three different groups, each group consists a number of sites presenting similar reef condition. Metric values between a_i and b_i were assigned a score of 3 and their associated sites were narrated as moderated condition. In case, metric having positive correlation with HC and negative correlations with DC and FL, metric values smaller than a_i

Table 2: Criteria of metric scoring and narration and site classification efficiency

	Metrics had positive correlation with HC and negative correlation with FL and DC				Metrics had negative correlation with HC and positive correlation with FL and DC			
Score	Metric value (P)	Narration	Original site condition	Classification efficiency	Metric value (P)	Narration	Original site condition	Classification efficiency
1	$P<a_i$	Maximally disturbed	Minimally disturbed	Incorrectly	$P>b_i$	Maximally disturbed	Minimally disturbed	Incorrectly
			Maximally disturbed	Correctly			Maximally disturbed	Correctly
3	$a_i \le P \le b_i$	Minimally disturbed	Minimally disturbed	Correctly	$a_i \le P \le b_i$	Minimally disturbed	Minimally disturbed	Correctly
5	$P>b_i$		Maximally disturbed	Incorrectly	$P<a_i$		Maximally disturbed	Incorrectly

or bigger than b_i were assigned scores of 1 or 5, respectively. On another hand, metric having negative correlation with HC and positive correlations with DC and FL, metric values smaller than a_i or bigger than b_i were assigned scores of 5 or 1, respectively. A site, where its metric value assigned a score of 1, was narrated as poor condition. While a site, where its metric value assigned a score of 5, was narrated as good condition. Metric scoring and narration methods are presented in Table 2. The fourth step-metric redundancy: this step aims at avoiding a domination of some metrics from a given ecological or biological attribute to ensure a broadly sensitive of the index. In this step the Pearson correlation was employed for each pair of selected metrics. Once metric having higher r^2 (>0.75) of the Pearson test and lower p-value of the Mann-Whitney U test (in the first step) was rejected (Stribling *et al*., 1998; Llanso *et al*., 2002). The fifth step-Site classification efficiency: this step calculates a number of sites that were correctly classified by using these selected metrics. A MinDS site evaluated as good condition, or a MaxDS site evaluated as poor condition was taken into account correct classification. While a MinDS site evaluated as poor condition, or a MaxDS site evaluated as good condition was taken into account incorrect classification. The summaries of site classification are presented in Table 2.

The sixth step-index calculation: IBI score at a given site was calculated by averaging all selected metrics' scores at that site as the followings: IBI Score = (Score of metric1 + Score of metric 2 +…+ Score of metric n)/n metrics (Stribling *et al*., 1998). The IBI scores ranged from 1 to 5 indicate from MaxDS to MinDS conditions. Finally, the seventh step-index validation. The sensitive responses of constituted CRIBI to anthropogenic disturbances were explored by employing the Spearman correlation. The anthropogenic disturbances, included destructive fishing activities such as dynamic and poison, aquarium fishing and invertebrate collection, tourist activities (e.g., coral damaged by anchor and number of yacht within 1 km), were recorded by the Reef Check monitoring program.

RESULTS

Minimally and Maximally Disturbed Sites and Their Substrate and Bioindicator Composition

By the criteria of reef classification as mentioned in the Method section, 76 MinDS and 72 MaxDS sites in shallow water and 39 MinDS and 37 MaxDS sites in deep water were identified. Substrate compositions of MinDS or MaxDS sites in shallow and deep waters are presented in Fig. 1. A MinDS site did consist of 40-60% of HC frequencies and less than 20% of both FL and DC frequencies. In contrast, a MaxDS site did consist less than 20% of HC frequencies and more than 20% of FL or DC frequencies. Frequencies of DC and FL in the MaxDS sites in shallow water were higher than that of in deep water.

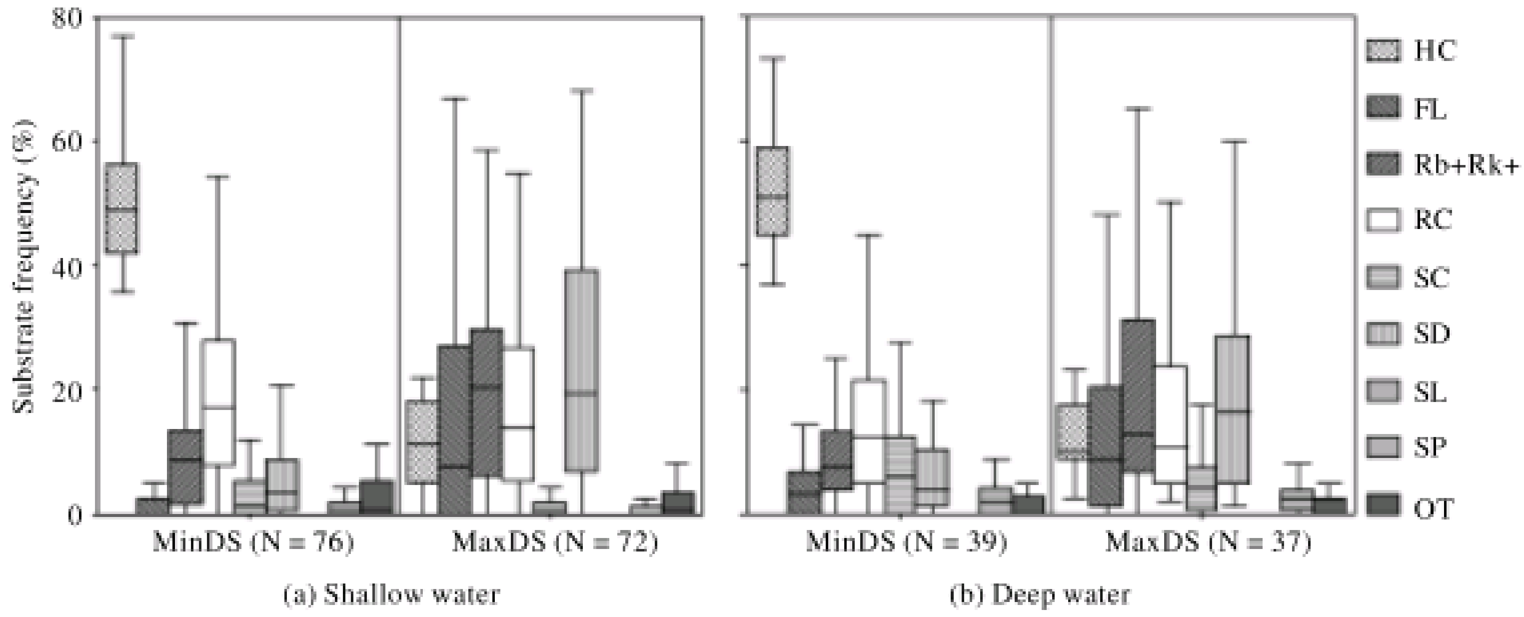

Fig. 1: Substrate composition of the minimally and maximally disturbed sites (MinDs and MaxDS) in the (a) shallow and (b) deep waters. N is number of sites. The lower and upper bars indicate the minimal and maximal values respectively. The box, interquartile range (IQR), indicates the distance between the 25th and 75th percentiles, the bar in box indicates median value

Table 3: Minimally and maximally disturbed sites's species composition (mean abundance) of the shallow and deep waters

	Shallow water		Deep water	
Species	Maximally disturbed site	Maximally disturbed site	Maximally disturbed site	Maximally disturbed site
Butterflyfish	24.97	11.28	28.10	16.76
Snapper	7.39	2.79	32.28	28.10
Moray eel	0.42	0.26	0.26	1.16
Parrotfish	13.45	22.64	16.08	17.57
Grouper	1.00	0.61	1.85	1.35
Banded coral shrimp	0.93	0.67	0.92	2.57
Lobster	0.08	0.10	0.26	0.03
Triton	0.04	0.17	0.26	0.00
Diadema	42.87	83.97	32.05	26.32
Collector sea urchin	0.37	9.49	0.10	0.89

Compositions of 10 involved Reef Check bioindicators at MinDS or MaxDS sites in shallow and deep waters are presented in Table 3. Diadema, parrotfish, butterflyfish and snapper, in order, were the four most abundant species among sites. There was not much different diadema abundance between minimally and maximally disturbed sites in the deep. Parrotfish was more abundance at the MaxDS sites in the shallow water. In both shallow and deep waters, there was more abundance of Butterflyfish at MinDS sites than at MaxDS sites. Snapper was more abundant in deep water than in shallow water. Other six remaining species found very low abundance at almost all of sites.

Metric Evaluation

Of 52 candidate metrics, 23 metrics of shallow water and 11 metrics of deep water passed the two statistical Kolmogorov-Smirnov and Man-Whiteney U tests. However, only 15 and 6 common and simple metrics, highlighted in the Table 4, were preliminarily selected for the shallow and deep waters respectively. The Shannon-Wiener Index did not pass these two statistical tests. The Spearman correlation explored 11 and 4 metrics of shallow and deep waters respectively having strong correlations with HC or DC and/or FL. Moreover, the metric redundancy step indicated three metrics,

Table 4: Candidate metric definition and two non-parametric statistical tests

		Shallow water		Deep water	
Code	Candidate metrics and their attribute groups	MannW	Kol_Smir	MannW	Kol_Smir
	Species richness attribute				
Bt	Abundance of Butterflyfish	0.000*	0.001*(s)	0.008*	0.028*(s)
Sn	Abundance of Snapper	0.000*	0.001*(s)	0.018*	0.134
Mo	Abundance of Moray Eel	0.932	0.999	0.216	0.963
Pa	Abundance of Parrotfish	0.396	0.310	0.219	0.190
Gr	Abundance of Grouper	0.273	0.922	0.300	0.875
Bd	Abundance of Banded Coral Shrimp	.042*	0.595	0.117	0.357
Lo	Abundance of Lobster	0.688	1.000	0.016*	0.584
Tr	Abundance of Giant Triton	0.128	1.000	0.025*	0.914
Dia	Abundance of Diadema	0.007*	0.006*(s)	0.830	0.609
Col	Abundance of Collector sea urchin	0.002*	0.163	0.578	1.000
NuS	Number of species per 800 m^2 of transect	0.775	0.912	0.128	0.812
S.W	Shannon-Wiener Index	0.578	0.434	0.685	0.650
	Species composition attribute				
Tot	Total individual of bioindicators per transect	0.434	0.453	0.618	0.847
CBt	Proportion of Butterflyfish	0.000*	0.000*(s)	0.009*	0.047*(s)
CSn	Proportion of Snapper	0.000*	0.001*(s)	0.030*	0.047*(s)
CMo	Proportion of Moray Eel	0.985	0.977	0.160	0.871
CPa	Proportion of Parrotfish	0.211	0.402	0.405	0.472
CGr	Proportion of Grouper	0.379	0.402	0.337	0.859
CBd	Proportion of Banded Coral Shrimp	0.050*	0.460	0.022*	0.099
CLo	Proportion of Lobster	0.679	1.000	0.019*	0.584
CTr	Proportion of Giant Triton	0.117	0.994	0.025*	0.914
CDi	Proportion of Diadem	0.000*	0.001*(s)	0.388	0.162
CCo	Proportion of Collector sea urchin	0.002*	0.163	0.586	1.000
	Ecology/environment attribute				
Ema	Marine environment species	0.000*	0.000*(s)	0.000*	0.001*(s)
Emb	Marine and brackish water environment species	0.000*	0.000*(ov)	0.009*	0.047*(ov)
Embf	Marin, brackish and freshwater environment species	0.005*	0.043*(s)	0.101	0.414
	Habitat/reef associated attribute				
HR1	50-90% species within family is reef associate	0.003*	0.001*(s)	0.081	0.249
HR2	More than 90% species within family is reef associate	0.003*	0.001*(s)	0.108	0.249
	Trophic group attribute				
Phe	Mainly herbivorous	0.036*	0.099	0.154	0.311
Pom	Partly benthivorous and herbivorous	0.872	0.481	0.530	0.745
Pca	Partly benthivorous and nektivorous	0.004*	0.015*(s)	0.546	0.929
Ppi	Mainly nektivorous	0.379	0.402	0.337	0.859
	Trophic level attribute				
Tro1	Low: trophic level between 2-3	0.000*	0.000*(s)	0.000*	0.001*(s)
Tro2	Medium: trophic level between 3-3.5	0.000*	0.000*(s)	0.004*	0.025*(s)
Tro3	High: trophic level higher than 3.5	0.005*	0.043*(ov)	0.401	0.414
	Maximum length attribute				
Len1	Maximal length less than 20 cm	0.000*	0.000*(s)	0.058	0.093
Len3	Maximal length less between 20 and 40 cm	0.205	0.414	0.470	0.655
Len4	Maximal length more than 60 cm	0.005*	0.043*(ov)	0.101	0.414
	Natural mortality attribute				
Mor1	High: natural mortality higher than 1	0.000*	0.000*(ov)	0.009*	0.047*(ov)
Mor2	Medium: natural mortality between 0.5 and 1	0.226	0.229	0.732	0.816
Mor3	Low: natural mortality lower than 0.5	0.379	0.402	0.337	0.859
	First age of maturity attribute				
Mat1	Soon: first maturity in the first year of age	0.959	0.603	0.963	0.993
Mat2	Moderate: First maturity in the second year of age	0.211	0.402	0.405	0.472
Mat3	Late: first maturity in the third year of age	0.000*	0.001*(ov)	0.030*	0.047*(ov)
Mat4	Very late: first maturity later than three year of age	0.450	0.551	0.149	0.356
	Life span attribute				
Lif1	Short: life span less than 3 years	0.000*	0.000*(ov)	0.056	0.093
Lif2	Medium: life span between 4-10 years	0.000*	0.002*(s)	0.212	0.270
Lif3	Long: life span between 10-30 years	0.907	0.522	0.080	0.230

Table 4: Continued

		Shallow water		Deep water	
Code	Candidate metrics and their attribute groups	MannW	Kol_Smir	MannW	Kol_Smir
	Resilience attribute				
Res1	High: over 90% of species within family is in high resilience category	0.000*	0.000*(ov)	0.009*	0.047*(ov)
Res2	Medium: 70-90% of species within family in medium resilience category	0.211	0.402	0.405	0.472
Res3	Low: 50-70% of species within family in medium and low resilience categories	0.000*	0.001*(ov)	0.030*	0.047*(ov)
Res4	Very low: more than 50% of species within family in low resilience category	0.379	0.402	0.337	0.850

Mann_W: Mann-Whitney U test; Kol_Smir: Kolmogorov-Smirnov test. The numbers in the Table 3 are the r-value of two motioned statistical tests. *Indicates significant p<0.05. The bolded numbers with (s) indicate the metrics were preliminarily selected, (ov) indicate that those metric were not selected according to the criteria of metric selection

Table 5: Metrics' threshold, value, score and site classification efficiency

			Score and threshold values		
Metric and measurement units	Tiles (%)	CE (%)	1	3	5
Shallow water					
1. Abundance of butterflyfish (count)	55-80	65.5	<12.95	12.95-30	>30
2. Abundance of snapper (count)	55-80	65.5	<2	2-6	>6
3. Abundance of diadema (count)	25-55	62.2	>12	1-12	<1
4. Proportion of butterflyfish (%)	50-70	71.6	<21.65	21.65-43.2	>43.2
5. Proportion of snapper (%)	47-70	64.9	<0.53	0.53-8.1	>8.1
6. Proportion of diadema (%)	30-50	64.9	>18.5	4.02-18.5	<4.02
7. Trophic level between 3 and 3.5 (%)	47-70	70.3	<20.02	20.02-44.85	>44.85
8. Maximal length less than 20 cm (%)	50-70	71.6	<21.95	21.95-46.7	>46.7
Overall site classification efficiency		65.97			
Deep water					
1. Abundance of butterflyfish (count)	37-70	67.1	<7.98	7.98-32.8	>32.8
2. Proportion of butterflyfish (%)	47-70	65.8	<22.25	22.25-44.12	>44.12
3. Proportion of snapper (%)	47-70	65.8	<4.35	4.35-16.58	>16.58
4. Trophic level between 3 and 3.5 (%)	47-70	65.8	<25	25-45.38	>45.38
Overall site classification efficiency		66.13			

% tile is percentiles at the lower and upper metric value thresholds; CE is site classification efficiency, which indicates the percent of correct site classified by using the selected metrics in relative reference and degraded sties applied for individual metrics and overall of the shallow and deep waters separately

including, i) Marine, brackish and freshwater environment species (Embf); ii) More than 90% of species within family was reef associated (HR2) and iii) Partly benthivorous and nektivorous (Pca), in shallow water had high r-value of the Pearson correlation tests and lower p-values of the Mann-Whitney U tests. Henceforth, only eight metrics of shallow water and four metrics of deep water (Table 5) were finally selected to combine shallow and deep coral reef indices respectively.

Threshold Percentiles, Metric Values and Scores

The results of lower a_i and upper b_i threshold percentiles and values, site score and site classification efficiencies of each metric are shown in Table 5. The lower and upper threshold percentiles were very different from metric to metric. Site classification efficiency of an individual metric was not high (from 62.2 to 71.6%), resulting in low overall site classification efficiencies (65.97 and 66.13%) in both shallow and deep waters (Table 5). The results of the Spearman correlation showed that six metrics of shallow water, including species richness and composition of butterflyfish and snapper, trophic level between 3 and 3.5 and maximal length less than 20 cm, were positively correlated to HC and negatively correlated to DC and/or FL. While the two remaining metrics, species richness and composition of diadema, were negatively correlated to HC and positively correlated to

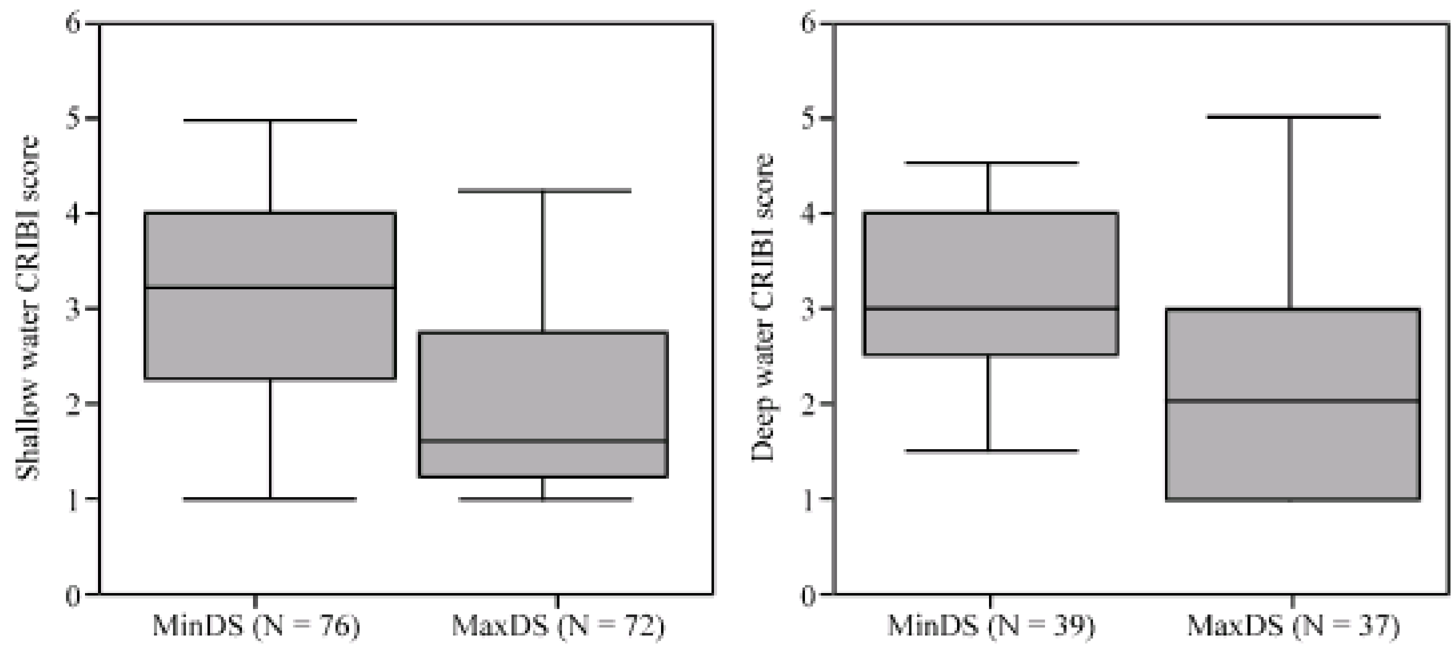

Fig. 2: Shallow and deep CRIBI scores. Noticeably, the lower and upper bars are the minimal and maximal values. The box, interquartile range (IQR), indicates the distance between the 25th and 75th percentiles, the bar in box is median value

FL and DC. In the deep water, all four selected metrics were positively correlated to HC and negatively correlated to FL and DC. The results of metrics' scoring and narration are presented in Table 5. Threshold values of snapper richness metric in deep water were higher than that of in shallow water (Table 5). Site classification efficiencies of shallow water were more variation from metric to metric, the highest was 71.6% and the lowest one was 62.2%. In deep water, site classification efficiencies were not much different among four metrics (Table 5).

IBI Scores and Coral Reef Condition Classification

CRIBI scores at MinDS and MaxDS sites of both shallow and deep waters are presented in Fig. 2. In both shallow and deep waters, the MinDS sites' CRIBI median scores (the lines in boxes) was much higher than the MaxDs sites' ones. The CRIBI scores between 25 and 75 percentiles of MinDS sites rank between 2 and 4, with the median values reached 3.3 and 3.0 scores. Noticeably, the median value of 3 was threshold delineating the minimally and maximally disturbed condition. These low median scores indicate that many MinDS sites have very low CRIBI scores. At the MaxDS sites, the median values were lower than 2 and CRIBI scores at 25-75 percentiles ranked from 1 to 3 in both the shallow and deep waters. In the shallow water, 35.5% of the MinDS sites and 22.2% of the MaxDS were incorrectly classified. In the deep water, 33.3% of the MinDS sites and 35.1% of the MaxDS sites were incorrectly classified.

The inter-correlation of CRIBI, individual metrics and the ratio of (F+D)/(F+D+H) of shallow sites is projected on the Grabiel biplot (Fig. 3). The results showed that the sites having higher CRIBI scores locate near and between the metrics of butterflysfish and snapper. While the sites having lower CRIBI scores locate near metrics of diadema and the ratio of (F+D)/(F+D+H).

Responses of CRIBI to Disturbances

The responses of CRIBI to the anthropogenic disturbances are shown in Table 5. The CRIBI in the shallow water is strongly negatively correlated to the impacts of dynamic fishing ($p<0.01$) and number of yacht within 1 km ($p<0.05$). The CRIBI in the deep water is strongly negatively correlated to poison fishing and coral damaged by other factors ($p<0.05$). Both the shallow and deep water CRIBI are strongly positively correlated to HC ($p<0.01$) and negatively correlated to FL and DC ($p<0.05$ or 0.01).

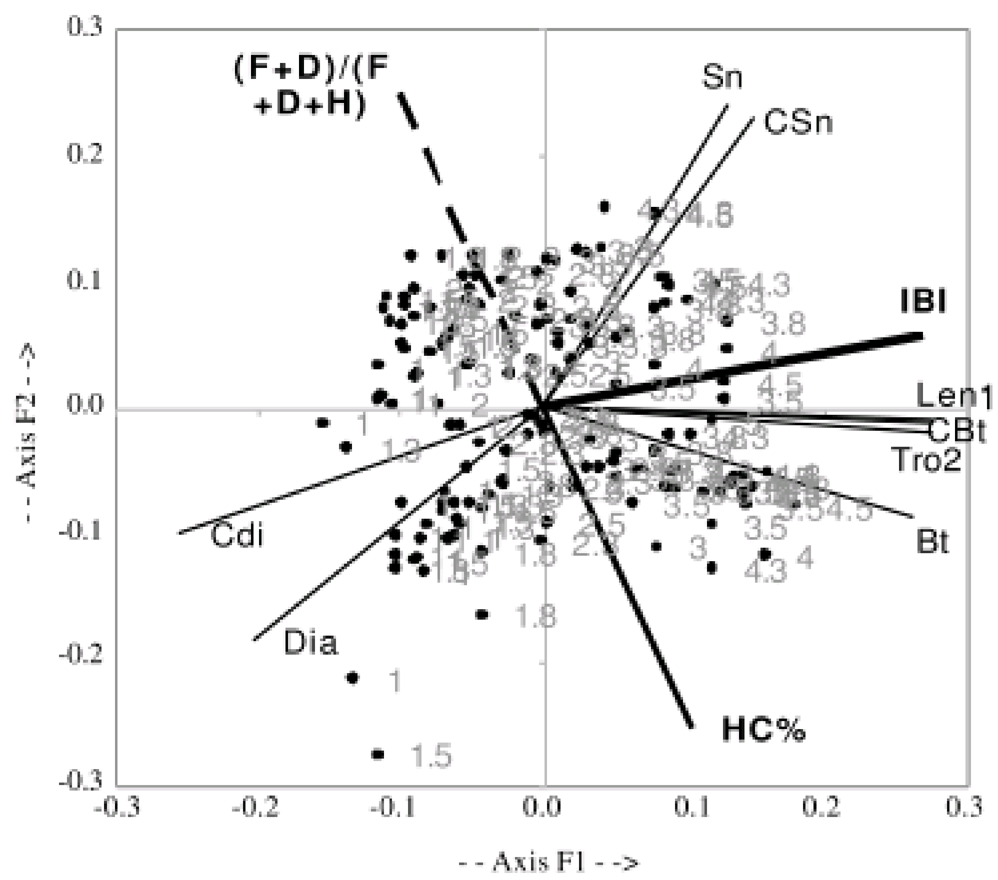

Fig. 3: The Grabiel Biplot of CRIBI, metrics and the ratio of (F+D)/(F+D+H) by the sites of the shallow water. IBI = Coral reef index of biological integrity, (F+D)/(F+D+H) = (Fleshy algae+Dead coral)/((Fleshy algae+Dead coral+Hard coral). The dots are the site; the number nearby the dot is the CRIBI score of that site

Table 6: Response CRIBI to disturbances in both shallow and deep waters

		Shallow water		Deep water	
Code	Anthropogenic impact and substrate	IBI	Hard coral	IBI	Hard coral
Anthropogenic impact					
FiD	Dynamic fishing (scale level)	-0.279**	-0.386**	-0.015	0.125
FiP	Poison fishing (scale level)	-0.032	-0.168*	-0.279*	-0.182
NuY	Number of yacht within 1 km (scale level)	-0.185*	-0.210**	-0.150	0.008
OtD	Coral damaged by other factors (count)	0.105	0.112	-0.283*	-0.209
Substrate					
FL	Fleshy algae (%)	-0.233**	-0.316**	-0.368**	-0.312**
HC	Hard coral (%)	0.433**		0.372**	
FlRbRk	Fleshy algae, rubble and recently killed coral (%)	-0.333**	-0.618**	-0.287*	-0.459**

*, **Indicate the statistical significant p<0.05 and p<0.01, respectively, - : Indicates the negative r-values of Spearman correlation. Scale level means the categories of heavy, moderated, low and none of reef damages. Count means the frequency of occurrence (see Reef Check manual for detail)

DISCUSSION

The strongly positive correlations between the constituted CRIBIs and hard coral in both the shallow and deep waters indicate that the CRIBI developed in this study are capable to apply to assess and monitor healthy reef. While the strongly negative correlations between CRIBIs and dead coral and or fleshy algae indicate that the constituted CRIBIs are able to use to evaluate and monitor the degraded reef condition. Moreover, the strongly negative correlations between CRIBIs and dynamic fishing, poison fishing, number of yacht within 1 km and other damaging factors (Table 6), indicate that the constituted CRIBIs are sensitive to respond to the anthropogenic disturbances. In the context of using destructive fishing activities and increasing sea/beach tourist development in recent decades, the sensitive responses of the shallow water CRIBI to dynamic fishing and number of yacht with 1 km are important information indicating the negative affects of these activities on reefs. The CRIBI development in this study are largely based on paradigms from previous freshwater and estuarine IBI (Weisberg *et al*., 1997; Stribling *et al*., 1998; Llanso *et al*., 2002; Araujo *et al*., 2003; Joy and Death, 2004). However, the CRIBI scores are low, the CRIBI scores between 25th and 75th percentiles ranking from 2 to 4 and median values reaching 3, especially in the MinDS sites (Fig. 2). The coastal and non-coastal plain IBI indices in Maryland streams showed the benthic IBI score between 25th and 75th percentiles ranking from 3 to 4.5 and median values reaching above 3.5 (Stribling *et al*., 1998). Additionally, the results of site classification efficiencies are low (60-70%). Similarly, there were low site classification efficiencies in estuarine benthic IBIs in Chesapeake Bay (Weisberg *et al*., 1997) and Mid-Alantic Region (Llanso *et al*., 2002). Site classification efficiencies of the Maryland coastal and non-coastal plain benthic IBI were higher than 88% (Stribling *et al*., 1998). The low site classification efficiency in estuarine IBI development was supposed that this is due to the influences of various natural stresses on the structures and attributes of benthic community composition in estuarine habitats (Llanso *et al*., 2002). In the framework for coral reef IBI development, Jameson *et al*. (2001) also hypothesized that the continuum biological condition of reef system, the marginal distribution of substrates varying from near pristine to severely degrade and the fine scale degradation of reefs would influence the sensitivity and efficiency of CRIBI. In this study, the low site classification efficiency of CRIBI development is assumed because of the influence of the minimally and maximally disturbed sites' criteria, where the minimal percentage of the high-end HC frequency was cut of at 35% for the MinDS sites.

Among ten Reef Check bioindicators involved in CRIBI development in this study, butterflyfish, snapper and diadema play more roles in reflecting coral reef condition and responding to the anthropogenic disturbances. Especially, butterflyfish is a reef associated species (Sano *et al*., 1984; Ohman *et al*., 1998; Froese and Pauly, 2004). In this study, we found that the abundance of butterflyfish less than 12.95 or 7.98 individuals/800 m^2 (a Reef Check transect) in shallow or deep water respectively indicates the more disturbed reef status. While more than 12.9 or 10.8 individuals (per 800 m^2) indicates less disturbed status (Table 5). Present findings are similar to Ohman *et al*. (1998) results, where he found that less than 5 or more than 10 butterflyfishes per 500 m^2 indicate the unhealthy or healthy reef conditions respectively. Diadema is critical important role in maintaining natural balance between algae and coral (Nybakken, 2001). We found out the densities of diadema between 1< and >12 individuals m^{-2} in shallow water are correlated to reef degraded conditions. Similarly, the low diadema population density (<5 individuals m^{-2}) correlated to the low (<10%) hard coral in Jamaica ocean (Edmunds and Carpenter, 2001). On another hand, reefs would be bioeroded by over grazing if the density of diadema >12 individuals m^{-2} (Ogden and Carpenter, 1987). However, our study did not find these indications in deep water, no metric relating to diadema contributed to the deep water CRIBI (Table 5). This may be due to lack of the distinct differences of diadema densities between MinDS and MaxDS sites. Parrotfish is a second abundant species (after diadema) at the monitoring sites. However, this species did not strongly involve in reflecting reef health condition. In shallow water, although the abundance of parrotfish at MinDS sites is more than at MaxDS sites, this different abundance is not strong enough to classify good or poor reef condition. The proportions of snapper, which can capably reflect reef condition, are very different from shallow water to deep water, much higher required in the deep water comparing to the shallow water (Table 5). This difference may be due to natural habitat preference, snapper distributes in deeper water. Grouper, moray eel, lobster and giant triton are bigger body size species having important role at the higher level of energy flow/food chain. The presence of metric trophic level between 3 and 3.5 in the final constituted CRIBIs indicates that these species also contribute in reflecting reef condition. The roles of these species in the CRIBI development are not clearly like the role of snapper, another big body size species. This is because of very low densities of these species at the monitoring sites that is a consequence of overfishing in the recent decades.

This constituted CRIBI is the new for marine environment, particularly coral reef ecosystems. The sensitive responses of the CRIBI to the anthropogenic disturbances strongly indicate the reliability of CRIBI applicability. The scientists, practitioners and managers would use CRIBI as the biological monitoring tool for coral reef management. However, in this study, the CRIBI constituted at the global scale, this may cause less sensitive of CRIBI in different regions/oceans. The next research should better constitute separate CRIBI by the oceans. Adjusting criteria of the minimally disturbed sites' determination, in particular high-end percentage of HC, this may help to improve the sensitivity of the CRIBI and site classification efficiencies.

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