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Shifting environmental baselines in the Red Sea

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ABSTRACT

The Red Sea is among the world's top marine biodiversity hotspots. We re-examined coastal ecosystems at sites surveyed during the 1980s using the same methodology. Coral cover increased significantly towards the north, mirroring the reverse pattern for mangroves and other sedimentary ecosystems. Latitudinal patterns are broadly consistent across both surveys and with results from independent studies. Coral cover showed greatest change, declining significantly from a median score of 4 (1000–9999 m^2) to 2 (10–99 m^2) per quadrat in 2010/11. This may partly reflect impact from coastal construction, which was evident at 40% of sites and has significantly increased in magnitude over 30 years. Beach oil has significantly declined, but shore debris has increased significantly. Although substantial, levels are lower than at some remote ocean atolls. While earlier reports have suggested that the Red Sea is generally healthy, shifting environmental baselines are evident from the current study.

1. Introduction

The Red Sea is one of the world's top marine biodiversity hotspots (Roberts et al., 2002). Its coral reefs contain 333 reported coral species (Dubinsky and Stambler, 2011) and endemism is high (Sheppard, 2000). The region's megafauna, including dugong, turtles and other 'Red Listed' species, are also of importance (Sheppard, 2000). Mangroves and seagrass beds are significant sedimentary ecosystems, especially towards the south (Price et al., 1987, 1988). Fisheries, comprising artisanal and industrial sectors, are a resource of longstanding importance (Sheppard, 2000; Jin et al., 2012). Because of the Red Sea's spectacular reefs, and relatively close proximity to Europe, some parts are now a major diving destination and used heavily (Sheppard et al., 1992; Zakai and Chadwick-Furman, 2002; Price and Harris, 2009).

Saudi Arabia's two marine environments, the Red Sea and Arabian/Persian Gulf (or 'Gulf'), are very dissimilar. In comparison with the Gulf, the Red Sea is naturally a less stressful environment, and human disturbances (e.g. coastal infilling, dredging, sedimentation) were also reported to be less prevalent in the Red Sea (Sheppard et al., 1992). Nevertheless, substantial coastal development has occurred (Kotb et al., 2004), particularly in and around the major cities of Rabigh, Yanbu and Jeddah since the 1980s in the case of Saudi Arabia. Overall, the Red Sea has been reported to be relatively unpolluted, apart from localized areas (e.g. Hanna and Muir, 1990; Sheppard et al., 1992; El Nemr et al., 2004). Sewage and oil pollution are problematic in some regions (Medio et al., 2000). The Red Sea has also been subjected to sea surface warming and coral mortality in 1998 (Sheppard, 2003; Kotb et al., 2004), but impact was less than in the Gulf (Rezai et al., 2004).

In general, few large-scale environmental or ecological surveys in the Red Sea have been published based on site-specific data. One exception is an integrated assessment of the abundance of major ecosystems and magnitude of human resource-uses/impacts at 1200 sites along the eastern Red Sea coast during the period 1982–4 (Price et al., 1998). This was a broadscale ecological study, which also identified conservation and coastal management requirements. The same methodology, rapid environmental assessment (REA), has subsequently been used in various parts of the Indian Ocean, including the Gulf, and Atlantic Ocean (reviews; Price, 2004; Price and Harris, 2009). Comparison between the Gulf in 1986 (Price, 1990) and the Red Sea during the mid-1980s using RAE again showed that the Red Sea *was* relatively unimpacted (see also Price, 1999, Appendix 1; Price et al., 1998). Hence, it might be assumed from its past condition that the current status of the Red Sea would be relatively unpolluted or undisturbed.

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Without periodic and/or long-term assessment, however, environmental changes can easily occur, undetected, as one generation replaces another. This phenomenon is known as the shifting baseline syndrome (Pauly, 1995; Sheppard, 1995). It is observable from data of variable resolution (Pinnegar and Engelhard, 2008; Venkatachalam et al., 2009), although human perceptions of change are not always reliable (Papworth et al., 2009).

Here we examine the environmental status of the Red Sea coast of Saudi Arabia using REA. The survey formed part of a recent coastal resources 'baseline' assessment for Red Sea coastal areas of Saudi Arabia (HUTA and emapsite, 2011). The main aims were to (1) characterize overall condition of coastal ecosystems along the Saudi Arabian Red Seas at 137 sites in 2010/11; (2) assess the nature and extent of any major changes, through comparison with data collected at a sub-set of the sites examined in the 1980s and using the same methodology; and (3) discuss findings in the context of shifting environmental baselines and compensable claims for environmental damage from oil spills and ship groundings.

2. Materials and methods

Rapid environmental assessment (REA) was undertaken at 137 coastal sites, distributed at ~10-km intervals (Fig. 1). Sixty-one of these were the same sites examined during the 1980s (Price et al., 1998). Although GPS was not available for the 1980s survey, site locations were determined (e.g. from landmarks, coastal features) and recorded on large-scale maps (1: 50,000) to within an estimated ±500 m of true positions. During the 2010/11 survey, site locations were determined using GPS, thus ensuring good/reasonable concordance of the matched site between surveys. REA sites and data also provided an additional layer of ground-truthing of habitats for a coastal atlas (HUTA and emapsite, 2011). For this and logistical reasons, there are lengths of shoreline where there are no 1980s' records but relatively substantial numbers of new 2010/11 sites. The new sites increase the size of the dataset (N) used for spatial analyses, thereby enhancing the power of statistical tests. Although of lesser significance than examination of temporal changes ('shifting baselines'), spatial analyses permitted comparison with independent studies, and thus one means of validating the robustness of REA as a survey methodology.

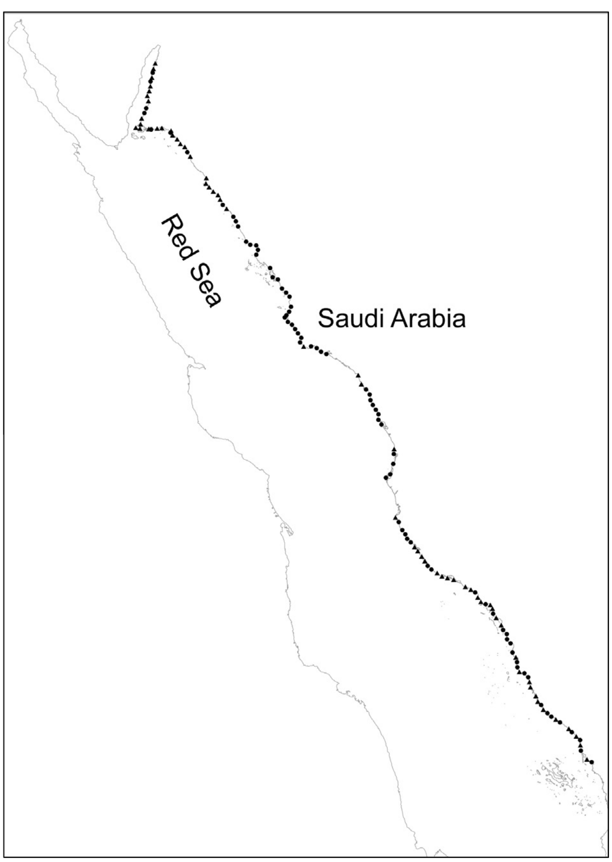

Fig. 1. Map of Red Sea coast of Saudi Arabia showing locations of 137 coastal sites at which rapid environmental assessment was undertaken (solid circles – sites surveys in 2010/11; solid triangles – sites surveyed during mid-1980s and in 2010/11.

Semi-quantitative observations were made on coastal habitats/ecosystems, species groups and resource-uses/impacts pressures (Table 1). Data were collected using a method developed for the Red Sea (Price, 2004; Price et al., 1998) and later used elsewhere (review: Price and Harris, 2009). Observations were made within geographically discrete 'site inspection quadrats' of estimated dimensions 500 m × 500 m (Fig. 2).

The intertidal/land component of the quadrat (500 m × 250 m) was determined from observations while walking. The subtidal component (500 m × 250 m) was examined while snorkelling.

2.1. Abundance of coastal habitats and species groups

Abundance within each quadrat of biological features and magnitude of human use impacts (Table 1), were scored and recorded concurrently. In the case of terrestrial flora, coralline algae (and other marine flora, when present) and coral reefs, scores are based on estimates of areal extent (m^2). For most fauna they reflect the number of individuals, estimated from direct observations, pits or tracks. A score on the logarithmic scale of 0–6 was used for quantifying field estimates of the abundance of biological features; the equivalent arithmetic range in values for each log score is shown in Table 2.

2.2. Magnitude of resource-uses/impacts

The same 0–6 scale (Table 2) was also used to score the relative magnitude of coastal uses and environmental pressures. For construction and oil pollution, scores represent estimates of the total area of either construction (jetties, roads, houses, etc.) or oil (tar on the beach and/or in the sea). For solid waste and wood litter, scores represent the estimated number of items, irrespective of their size (with notes made on the dominant items, e.g. plastic bottles or cans, in the case of solid waste). Estimating fishing/collecting pressure by rapid assessment is not straightforward (Price et al., 1998). In the absence of direct evidence of boats or fishers, fishing was determined indirectly from various indicators, including nets and equipment, seemingly in recent or current use. Here, scores for fishing/collecting simply reflect the estimated magnitude of one or more indicators, using an ordinal (0–6) ranked scale of increasing magnitude. Additionally, physical coastal features recorded included details of the shore profile and substratum type, and photographs of each site were taken.

2.3. Data analysis

Non-parametric statistical methods were used, as REA utilizes ranked i.e. ordinal data. Wilcoxon's matched pairs test (Z score) was used to discern temporal trends, given that the locations of the comparison sites were closely matched in 1982–84 and 2010/11. Strength of latitudinal association was assessed using Spearman's rank correlation (R_s).

Table 1
Habitats/ecosystems, species groups, uses and impacts examined along the Saudi Red Sea coast by REA during 2010/11.

Ecosystems/species groups		Resource-use/impacts
Flora	*Fauna*	
Seagrasses	Reefs/corals	Oil
Algae	Birds	Human litter (plastics, metals, other solid waste and pollution)
Mangroves	Mammals	Driftwood and wood litter
Freshwater vegetation	Turtles	Construction/development
Halophytes	Fish	Fishing
	Invertebrates	

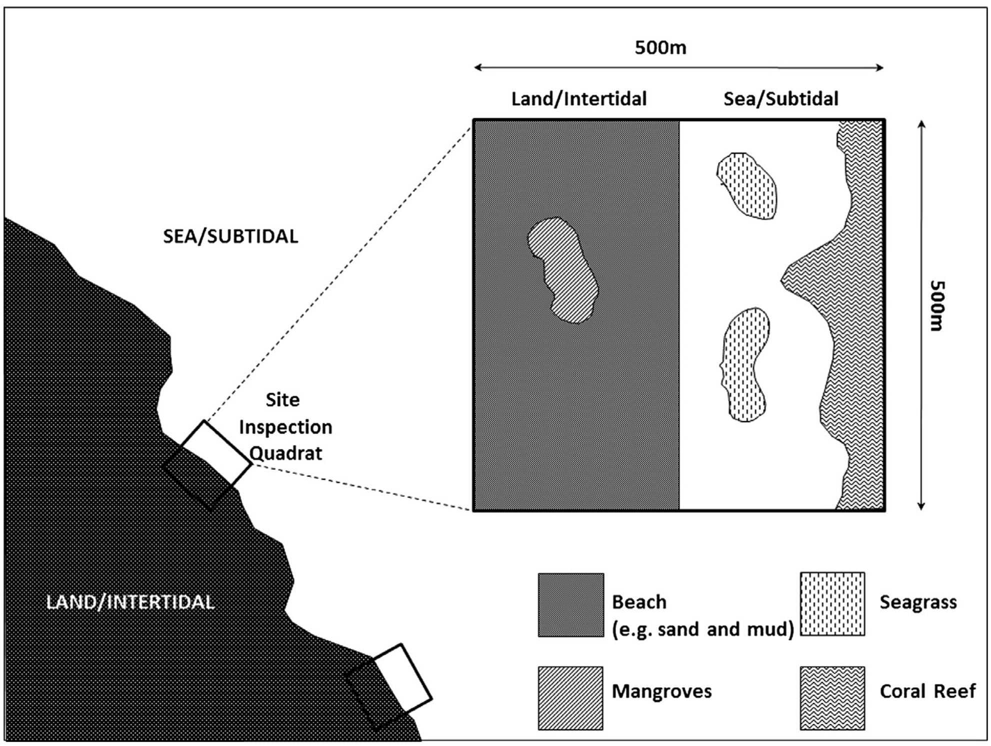

Fig. 2. Schematic diagram showing configuration and dimensions of REA site inspection quadrat.

Table 2
Scores on the logarithmic ordinal scale and arithmetic equivalents used in REA.

Ranked abundance/ magnitude score (*log scale*)	Areal extent (m^2): flora and reefs or no. of individuals: other fauna (*equivalent arithmetic range*)
0	0
1	1–9
2	10–99
3	100–999
4	1000–9999
5	10,000–99,999
6	100,000 +

3. Results

3.1. Summary statistics

The overall status of the coastal and marine environment of the Saudi Arabian Red Sea is summarized in Table 3. Of the key marine ecosystems, mangroves were present at nearly one-quarter of the sites, although generally not in high abundance. Seagrasses and coral/reefs were more prevalent and occurred in higher abundance. Of the mobile fauna, the prevalence and abundance of fish and invertebrates were relatively high. Birds, turtles and mammals

Table 3
Summary environmental data for 137 coastal sites along the Red Sea coast of Saudi Arabia during 2010/11. Data shown are scores for abundance of ecosystems and magnitude of resource-uses/impacts using ordinal data (0–6 scale) determined from REA.

Attribute	*N*	Range	Prevalence (%)	Mn
Ecosystems/habitats and species				
Mangroves	137	0–5	21	0
Seagrasses	136	0–6	62	2
Halophytes	137	0–6	76	2
Algae	136	0–6	97	3
Freshwater vegetation	135	0–3	10	0
Coral/reefs	137	0–5	55	2
Birds	137	0–5	80	1
Turtles	137	0–1	12	0
Mammals	137	0–3	4	0
Fish	136	0–6	97	3
Invertebrates	136	0–6	96	3
Resource-uses/impacts				
Construction	137	0–5	40	0
Fishing	131	0–3	18	0
Human litter	137	1–6	100	3
Wood litter	108	0–5	65	1
Oil	89	0–1	1	0

were less abundant, although birds were recorded at most of the sites.

Most sites were oil-free and devoid of fishing, i.e. occurrence was low. However, solid waste/human litter was recorded at every site, sometimes in very high quantities; the median score was 3, equating to 100–999 items per quadrat (500 m × 500 m, i.e. 250,000 m^2), i.e. per 500 m of beach. Although construction was evident at 40% of the sites, it was extensive at relatively few sites, and the median score for all sites was 0.

3.2. Spatial analysis

Apart from freshwater-dependent vegetation, coastal vegetation increased in abundance towards the southern Red Sea, significantly for mangroves and halophytes, as did bird abundance (Table 4). Coral/reef and invertebrate abundance increased significantly towards the northern Red Sea. Of the resource-uses/impacts, magnitude of fishing increased significantly towards the northern Red Sea, whereas the magnitude of human litter/solid waste and wood litter increased significantly towards the south.

3.3. Temporal analysis: comparison of 2010/11 and 1980s data

Changes in the Red Sea environment over a 30-y period are shown in Table 5. Most environmental features have not changed markedly. Of the biological features, coral abundance has declined significantly. In the 1980s, median coral abundance was 4 (1000–9999 m^2 per quadrat), but only 2 (10–99 m^2 per quadrat) during 2010/11.

The magnitude of several resource-use/impacts has changed significantly (Table 5). While the median score for magnitude of construction (roads, corniches, jetties, etc.) at the comparison sites examined has not changed between the 1980s and 2010/11, the maximum value recorded has increased from 4 to 5. This, together with the greater percentage of sites at which construction was encountered (i.e. magnitude score $\geqslant 1$) in 2010/11 than 1982–4 Table 6. Data on magnitude of construction at 60 comparison sites during 1980s survey and present (2010/11) study (see also Table 6), probably accounts for the observed significant increase in magnitude of construction. Other significant changes in resource-uses/impacts include a decrease in oil and increase in human litter/solid waste.

Table 4
Correlations between latitude and abundance/magnitude of habitats/ecosystems, species groups, resource-uses/impacts in the Saudi Arabian Red Sea using Spearman's rank correlation coefficient (R_s): N = number of sites; p = level of significance; NS = not significant. Statistics are based on scores for abundance of ecosystems and magnitude of human uses/impacts using ordinal data (0–6 scale).

Attribute	N	R_s	p
Ecosystems/habitats and species			
Mangroves	137	−0.28	$\leqslant$0.001
Seagrasses	136	−0.11	NS
Halophytes	137	−0.30	$\leqslant$0.001
Algae	136	−0.10	NS
Freshwater vegetation	135	0.05	NS
Coral/reefs	137	0.49	$\leqslant$0.001
Birds	137	−0.64	$\leqslant$0.001
Turtles	137	−0.15	NS
Mammals	137	−0.08	NS
Fish	136	0.02	NS
Invertebrates	136	0.22	$\leqslant$0.01
Resource-uses/impacts			
Construction	137	0.04	NS
Fishing	131	0.30	$\leqslant$0.001
Human litter	137	−0.09	$\leqslant$0.05
Wood litter	108	−0.21	$\leqslant$0.05
Oil	89	−0.15	NS

4. Discussion

4.1. Critique of methodology

Quantitative survey methods and semi-quantitative techniques, utilizing lower-resolution data, carry advantages and disadvantages; tradeoffs are inevitable. REA as a methodology has been critiqued in the literature (e.g. Price, 1990, 2004; Price et al., 1998; Price and Harris, 2009). The latter study revealed significant decadal changes in coral fish abundance and in fishing/collecting in Chagos (British Indian Ocean Territory). The ability of the methodology to detect significant environmental changes, following the massive 1991 the Gulf War oil spill, has also been reported (Price et al., 1993). These and other works (e.g. Price, 1990, 1999; Price et al., 1988) have demonstrated the robustness of REA as a methodology.

As noted by Price et al. (1998), transformations were made to 14.6% of the Red Sea data entries from the 1980s, resulting in a more extensive quantitative dataset. This facilitated statistical analysis, and allows more direct comparison between the Red Sea in 1982–84 and other regions or studies using REA – including the present (2010/11) survey of the Red Sea.

In the present study, re-survey at all 1200 sites examined during the 1980s, although desirable, was not logistically feasible. The total number of sites surveyed in 2010/11 was 137, and less for the temporal assessments, inevitably reducing statistical power. The limited number of comparison sites, coupled with the lower statistical power of non-parametric tests required for analysis of ranked/ordinal data as used for REA is arguably a limitation of the methodology. However, a notable feature of REA, in contrast to most detailed surveys, is the capture of a wider range of types of information on ecosystems and disturbances concurrently, within the same site inspection quadrat and using the same log(0–6) assessment scale (see also Price and Harris, 2009). REA is seen as complementary to rather than an alternative to detailed investigations in monitoring and other assessments (Price, 1990). It is concluded that overall REA has provided adequate approximation of current environmental conditions in the Red Sea, and of major changes over a 30-y period. Biological patterns observed are broadly consistent across both surveys, and also accord with distributions determined from independent surveys (e.g. corals and mangroves; Sheppard et al., 1992). This also points towards robustness of the REA methodology and low-resolution data against potential differences in observer experience/skill.

As noted, in some instances significant environmental changes in the Red Sea were discernible between 1982–84 and 2010/11, based on the Wilcoxon test, even when no difference in median abundance/magnitude values was evident. Similar observations have been made elsewhere using REA (Price and Harris, 2009), suggesting that median values alone may provide an incomplete metric of environmental change. Further statistical analysis, such as ranking, cluster analysis and principal component analysis could perhaps help clarify what additional factors might be contributing to observed environmental differences in the condition of Red Sea coastal ecosystems.

4.2. Interpretation of results

High ecosystem diversity along the Red Sea coast was evident in both the present study (Table 3) and earlier survey (Price et al., 1998), with saltmarsh halophytes the most prevalent ecosystem and freshwater dependent vegetation the least. Coral reef abundance increased significantly towards the north, mirroring the reverse pattern shown significantly (halophytes, mangroves) or qualitatively, (seagrasses) by soft-substrate ecosystems. These

Table 5
Summarized environmental data from sites along Saudi Arabian Red Sea coast during 2010/11 (this study) and comparison with data obtained at same site in 1980s (Price et al., 1998) using the same REA methodology. Statistics are based on scores for abundance of habitats/ecosystems/species groups and magnitude of resource-uses/impacts using ordinal data (0–6 scale) analyzed by Wilcoxon's matched pairs test (*Z* score): *N* = number of sites; *p* = level of significance; *NS* = not significant.

Attribute	Median		*Z*	*N*	*P*
	1980s (Price et al., 1998)	2010/11 (This study)			
Ecosystems/habitats and species					
Mangroves	0	0	−0.907	61	NS
Seagrasses	2	2	0.152	55	NS
Halophytes	2	2	−1.832	56	NS
Algae	4	3	0.738	37	NS
Freshwater vegetation	0	0	0.549	58	NS
Coral/reefs	4	2	−2.71	55	⩽0.01
Birds	1	1	1.093	54	NS
Turtles	0	0	1.732	60	NS
Mammals	0	0	1.633	50	NS
Fish	1.5	3	1.617	12	NS
Invertebrates	3	2	−0.764	33	NS
Resource-uses/impacts					
Construction	0	0	2.351	60	⩽0.05
Fishing	0	0	−1.498	56	NS
Oil	1	0	−3.975	28	⩽0.01
Human litter	2	3	4.012	49	⩽0.01
Wood litter	1.5	1	−1.081	40	NS

Table 6
Data on magnitude of construction at 60 comparison sites during 1980s survey and present (2010/11) study (see also Table 5).

Magnitude (0–6)	Frequency/no. of sites	
	1982–84	2010–11
0	51	33
1	1	19
2	1	2
3	5	3
4	2	0
5	0	3
6	0	0
N	60	60

patterns are explained by the broader shelf and more sedimentary conditions towards the southern Red Sea (Price et al., 1988; Sheppard et al., 1992). It is speculated that the high productivity of these systems (Price et al., 1998) might also be influencing the significantly greater bird abundance towards the south observed in both studies.

While oil pollution was both uncommon and of low magnitude (*mn* score = 0), other human-use/impacts were moderately prevalent but of low magnitude (construction, fishing), or widespread and of moderate magnitude (human litter) (Table 3). Similar patterns were generally evident during the 1980s (Price et al., 1998).

Several statistically significant environmental changes were observed (Table 5). The marked coral (cover) decline is likely a reflection of increased construction, which typically involves coastal infilling and sedimentation. This is a known stressor for coral reefs (e.g. Medio et al., 2000), but not the only one. The significant increase in magnitude of construction contributed to by a relatively small number of sites is consistent with this. Coral bleaching, especially following the 1998 El-Nino event (Sheppard, 2003), was also harmful but only in the southern Red Sea (Kotb et al., 2004). Other potential factors include localized nutrient enrichment from effluent discharges (Sheppard, 2000; Kotb et al., 2004). In the Saudi Arabian Red Sea, the status of coral reefs and coral communities has been reported to be generally good, with high living coral cover averaging 50% (Kotb et al., 2004). Reduced coral cover and environmental disturbance are localized, although Medio et al. (2000) note extensive damage to coral reefs in areas lacking sewage treatment.

Quantities of solid waste/human litter along the Red Sea coast of Saudi Arabia have significantly increased, but current densities (100–999 items per 500 m of beach) are not unprecedented. The (REA) method does not determine size categories or weight; most items observed were a few cm in size or less (and one plastic bottle generates a dozen fragments, decreasing eventually to countless plankton-sized particles). Even higher densities of shore debris have been recorded using the same methodology in Chagos, a remote and uninhabited group of atolls in the Indian Ocean (Price and Harris, 2009). The authors noted that high concentrations of debris are also found in remote Pacific atolls, where ocean current gyres are the main transport vector. Along the Red Sea coast, most items originate from land-based sources.

Although only small quantities of beach oil were encountered, and levels have actually decreased at sites examined (Table 5), the Red Sea is subjected to periodic oil spills (Sheppard, 2000; Sheppard et al., 1992), with potential for severe damage to coral reefs (Medio et al., 2000). Oil pollution incidents and ship groundings, from which spillages can also follow, are compensable through environmental damage claims by Red Sea States (PME, 2001; PERSGA, 2009).

While extensive areas of the Red Sea and its coral reefs have been reported to be in generally good condition (Kotb et al., 2004), this study has revealed discernible environmental changes at the same sites over 30 years. It provides yet further evidence of shifting baselines across the world (e.g. Saenz-Arroyo et al., 2005; Venkatachalam et al., 2009), and that the Red Sea is no longer uniformly pristine. Knowledge of ambient ecosystem health is an important consideration in the development environmental damage claims for compensable incidents and accidents, such as (traceable) oil spills and ship groundings on coral reefs. This is also important for assessing other impacts, including environmental damage from anthropogenic climate change. The present REA study, and associated Red Sea habitat atlases derived from classification of >450,000 polygons from QuickBird satellite imagery and ground-truthing (HUTA and emapsite, 2011), has set a benchmark for current ecosystem distribution and environmental health in the eastern Red Sea. For future monitoring over decadal or other time scales, REA is likely to remain a valuable broadscale assessment tool, in conjunction with more quantitative studies and other approaches, such as modeling, ranking, and multivariate analysis, depending on the precise objectives of investigations.

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