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Degradation of Reef Structure, Coral and Fish Communities in the Red Sea by Ship Groundings and Dynamite Fisheries

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DEGRADATION OF REEF STRUCTURE, CORAL AND FISH COMMUNITIES IN THE RED SEA BY SHIP GROUNDINGS AND DYNAMITE FISHERIES

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ABSTRACT

Reef degradation was investigated on 66 Egyptian Red Sea reefs—60 reefs for dynamite damage (using line transects) and six ship grounding sites (using 1 m sample squares). Ship groundings and dynamite fishing caused similar damage, reduction of the reef to rubble (65% of reefs were dynamited, mostly leeward, 58%). Changes in coral (line transect study) and fish communities (point count study) in impacted sites were documented. On impacted reefs, coral cover decreased, bare substratum and rubble increased, and fish dominance shifted away from Pomacentridae. Oceanographic conditions result in a stable pattern of coral communities (windward *Acropora*, leeward *Porites*). Most dynamite damage was on leeward, near-climax *Porites* reef slopes or *Porites* carpets. Most ship groundings were on windward *Acropora* reefs with regeneration periods calculated to be between 100 and 160 yrs. Regeneration time of dynamite damage is expected to be similar because of similar damage. Rehabilitation could speed up recovery but has to be consistent with natural community patterns. Coral transplants should mimic previously existing community structure in order to avoid space preemption by introduced superior competitors. Particularly if *Acropora* were introduced on a large scale into normally *Porites* dominated reef areas, re-establishment of the original community within the desired time-frame could be delayed.

Reports on declining reef health by natural and anthropogenic causes are common in the literature (Eakin et al., 1997; Jackson, 1997; McManus, 1997; Precht, 1998). Natural degrading events like storms, bleaching, predation, lava flows, or disease outbreaks have been well studied (Grigg and Maragos, 1974; Agard et al., 1993; Dollar and Tribble, 1993). Among anthropogenic disturbances, direct impacts such as those caused by ship groundings and destructive fishing techniques have received considerable attention (Alcala and Gomez, 1979, 1987; Galvez and Sadorra, 1988; Pauly et al., 1989; Saila et al., 1993; Cook et al., 1994; McManus, 1997; Salvat, 1987; Precht, 1998; Riegl and Luke, 1998). Much of the literature on groundings is concerned with the permanence of change in the impacted system, as well as regeneration and restoration issues (Hatcher, 1984; Hudson and Diaz, 1988, Gittings et al., 1994; Precht, 1998).

The Red Sea is an area with a relatively small coastal population and extensive reef systems and has been reported to be in generally good shape, but adverse impacts are increasingly widespread (Riegl and Velimirov, 1991; Hawkins and Roberts, 1991, 1994; Jameson et al., 1995; White et al., 1997; Wilkinson, 1998). Some reefs are heavily impacted by destructive fishing methods and ship groundings (Hawkins and Roberts, 1991). With the Straits of Gubal and Tiran, the region possesses two of the world's narrowest and busiest shipping lanes through a coral fringed corridor. Small- and large-scale groundings are frequent.

With the advancement of reef rehabilitation techniques (Clark and Edwards, 1993, 1994, 1995), it is of interest to study the implications of degradation of different communities by different types of impacts. Variability in damage patterns and natural regeneration may have implications for reef management and restoration.

This paper (1) describes characteristics of unimpacted coral and fish communities in the northern Red Sea, (2) investigates damage by ship groundings and dynamite, (3) describes the effects of these impacts on coral and fish community composition, (4) investigates natural recovery, and (5) discusses restoration and management issues.

Materials and Methods

Ship groundings were evaluated on six reefs in the Straits of Tiran/Gulf of Aqaba area (Fig. 1). Damage by dynamite fishing was evaluated on a total of 60 reefs between the Ashrafi reef complex in the Straits of Gubal (27.46°N, 33.42°E) and Ras Banas (23.57°N, 35.47°E). The following ship grounding sites were visited: Maria Schroeder, Waterships-Nabq 1, and Camel-Nabq 2 (the sites Nabq 1 and 2 are immediately adjacent to each other and therefore coded separately), all within the Nabq protected area on the Sinai shoreline of the Straits of Tiran. The Safir and the Belteski Zuri at Ras Nasrani, immediately south of the Straits of Tiran, the Lastovo on Gordon reef, in the Straits of Tiran. The years of groundings are indicated in Table 1.

The study area is characterized by stable meteorological conditions with resultant stable oceanographic conditions. About 80% of the year, dominant wind and swell direction is from NE along the axis of the Gulf of Suez and Red Sea (Riegl and Velimirov, 1994) or, in the Gulf of Aqaba from the NW along the axis of this Gulf. Southerly or westerly storms are rare (see windrose patterns in Figs. 1,3). Therefore it is possible to talk about mostly sheltered (leeward) and mostly exposed (windward) sides of reefs, at least on most off-shore and many fringing reefs. This also results in a stable distribution of different coral communities in windward (exposed) and leeward (sheltered) areas (Riegl and Velimirov, 1994; Riegl and Piller, 1997; Riegl and Luke, 1998).

Dynamite fishing, i.e., the use of explosives to stun or kill fish, is frequently used in the study area. Damage was investigated with the aid of fishermen who had themselves engaged in the activity. In the northern Red Sea it is possible to distinguish dynamite damage from other damage patterns caused by ship groundings, flotsam and debris, or anchoring. Dynamite damage is concentrated on leeward reef areas usually in depths between 2 and 10 m, where fish are easily collected. Windward sides are generally avoided by the fishermen due to currents and because the reef slopes are generally so steep that the explosive charge is lost into deep water. For details on northern Red Sea dynamite fishery, see Riegl and Luke (1998). Ship groundings, floating debris, and anchoring cause damage in shallow reef top and reef edge communities but (unless caused by avalanche effects) not on the reef slope and reef base. Dynamite damage tends to be concentrated on the lower reef slope and fore-reef areas, while the reef edge and upper slope remain intact. Ship grounding sites were known by the local authorities who guided the author to the precise locations.

For the description of coral and fish communities, random sites in all exposures were chosen and sampled. 10 m line transects (Riegl and Velimirov, 1991, 1994), or photo transects from which we later obtained the line transect information (Riegl et al., 1995) were used. The intercepts of all coral species, benthic invertebrates, and macro-algae were recorded to the nearest centimeter as well as the type of substratum (sand, rock, or rubble) along each transect. In the analysis of ship groundings, 1 m^2 photo quadrats from impact and reference sites were quantitatively evaluated for space coverage by corals, algae, and bare substratum. Space coverage was estimated by superimposing a counting grid (each grid cell representing one %) over the photograph. Regeneration, i.e., growth of new recruits in a previously denuded area was measured the same way.

In order to describe impacts on coral communities, three dynamited sites (Erg Dynamite, Sharm el Arab, Erg Marsa Alam, see Fig. 1) and one ship impact (Safir at Ras Nasrani) were chosen for impact vs reference sampling. The study attempted to compare end-members of damage (totally undamaged, totally damaged), which was necessary, since a satisfactory description of dynamite damage would otherwise have been difficult. Within impacted areas of sufficient size (>100 m in length), random samples were taken. Reference sites were situated on the same reef in the same depth-zone within 100 m adjacent to the impact site.

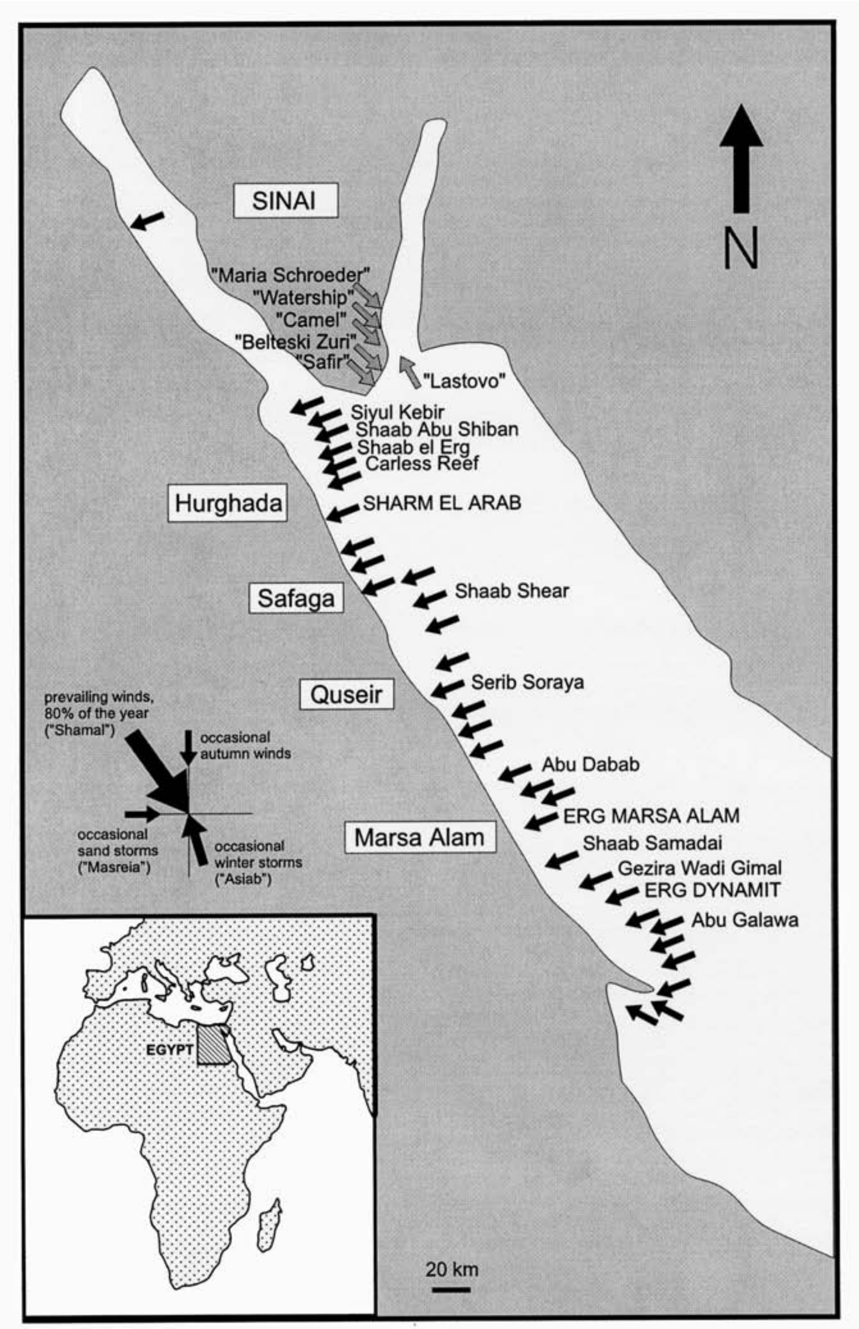

Figure 1. Map of the northern Red Sea showing investigated reefs. Reefs visited during rapid ecological assessment are indicated by an arrow only; impact and reference reefs used for the description of dynamite impacts are named (capitals for coral sites, small caps for fish sites, coral sites were fish sites as well). Ship grounding sites are indicated by gray arrows and the names of the wrecks. A total of 66 sites were visited and sampled, but not all could be shown for reasons of clarity on the graph.

Fish communities were assessed by point counts (Bohnsack and Bannerot, 1986) which involved a 10-min search of a 5-m diameter circle. Only fish of selected families were counted, which were regularly encountered on all reefs and therefore considered to be key components of the ecosystem (McClanahan, 1997; Hayward et al., 1997): Serranidae, Anthiinae, Lutjanidae, Lethrinidae, Haemulidae, Sparidae, Mullidae, Mugilidae, Labridae, Scaridae, Acanthuridae, Siganidae, Pomacentridae, Priacanthidae, Pomacanthidae, Dasyatidae, Tetraodontidae, Caesionidae, Balistidae, Chaetodontidae, and Labridae. Since changes in communities are frequently easier to detect at higher taxonomic levels, this approach seems justified (Warwick, 1988; Somerfield and Clarke, 1995). Twelve reefs were used for the comparison of impacted and reference sites. On each reef, five counts were performed, one each at 0, 5, 10, 15, and 20 m depth. Sampling always took place between 10:00. and 16:00 at the same time of day for control and reference sites in order to minimize sampling bias by diurnal abundance changes.

Patterns within the dataset were evaluated by agglomerative hierarchical cluster analysis and multidimensional scaling (MDS; Digby and Kempton, 1984; Agard et al., 1993). MDS is not limited to the description of patterns within the community but has successfully been used to link community structure to environmental variables (Clarke and Ainsworth, 1993; Agard et al., 1993) and to estimate severity of disturbance (Warwick and Clarke, 1993). MDS was preferred over principal components analysis (PCA) because it is better suited for environmental data (continuous data) than species abundances (James and McCulloch, 1990; Clarke and Warwick, 1994). Each of the above statistical methods has specific advantages: cluster analysis is better for delineating very distinct groups, MDS is better for groups with gradations (Field et al., 1982; Kenkel and Orloci, 1986; Warwick et al., 1988). If both analyses provide consistent results, it is likely that they represent natural groupings.

For the comparison of groups (impact vs reference), community characteristics were compared by one-way analysis of similarity (Clarke and Green, 1988). This analysis is built on a non-parametric permutation procedure applied to the same rank similarity matrix underlying the classification or ordination of samples. It is more applicable to the presently used data sets than a multivariate analysis of variance as it does not assume normality of data and allows for the dominance of zero counts in the typical transect data-set. It tests against the null-hypothesis that there are no differences in community composition between samples (Clarke and Green, 1988). Analyses used PRIMER and SPSS software.

Results

Coral and Reef Fish Communities of the Study Area—Reference Areas.—Several coral communities could be differentiated by the cluster analysis shown in Figure 2, including a differentiation into windward *Acropora*-dominated communities, leeward *Porites*-dominated communities, and current-exposed *Millepora*-dominated communities. Two clusters of *Acropora*-dominated transects split shallow reef-edge and reef-crest transects with mainly tabular and small corymbose species (*Acropora hyacinthus, A. secale, A. polystoma*) from deeper areas with more arborescent species (*A. hemprichi*). Also the inner portions of marsas and sharms (local names for embayments with a break in the otherwise continuous fringing reef, generated by occasional flash-floods) were dominated by *Millepora*. Steep, current-exposed reef slopes were characterized by high soft coral frequency (usually *Dendronephthya* spp. and *Litophyton* spp.). Further subdivision of the coral communities on reefs along a depth and hydrodynamic gradient was evident. An overview of the biological characteristics and spatial patterns of scleractinian reef communities in the study area is given in Figure 3. A more complete overview of coral community structure in the study area can be found in Riegl and Velimirov (1994) and Riegl and Piller (1997).

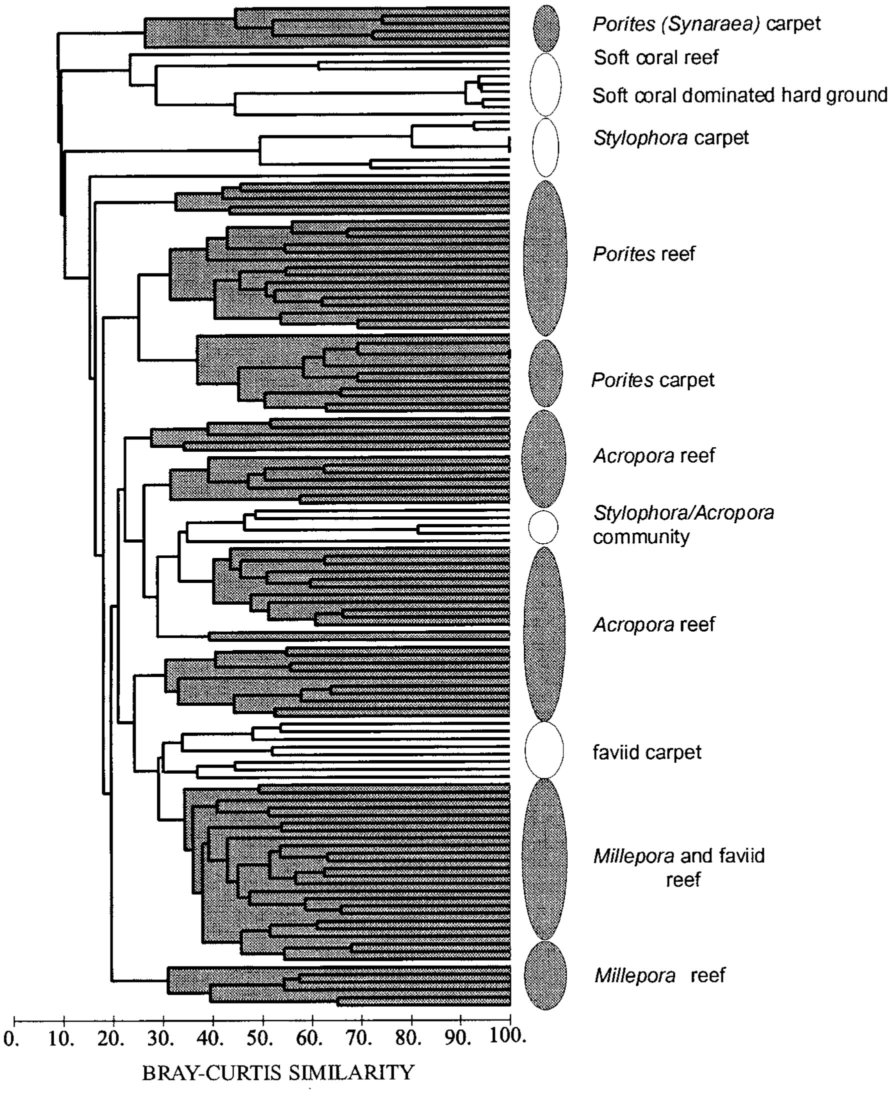

Figure 2. Classification of coral transects. Linkage is group average, distance measure is the Bray-Curtis similarity index. The sites used for the description of impacts by ship groundings and dynamite are not included in this analysis. Clusters are dependent on space cover of the dominant species. Further analysis of the samples contained in the clusters, which correspond to zonation patterns on the reefs, is presented in Figure 3.

Three types of coral carpets (non-reef frameworks, Reiss and Hottinger, 1984; Riegl and Piller, 1999) were found (*Porites* carpet, *Porites* (*Synaraea*) carpet, faviid carpet). They occurred in areas of flat-bottom topography in depths between 5 and 40 m. Soft-coral-dominated hardgrounds were widely distributed (*Sarcophyton* dominance off Hurghada and in Safaga Bay between 10 and 30 m, *Lobophytum* dominance at South Queisum island, mixed *Lobophytum/Sarcophyton* dominance in Foul Bay between 1 and

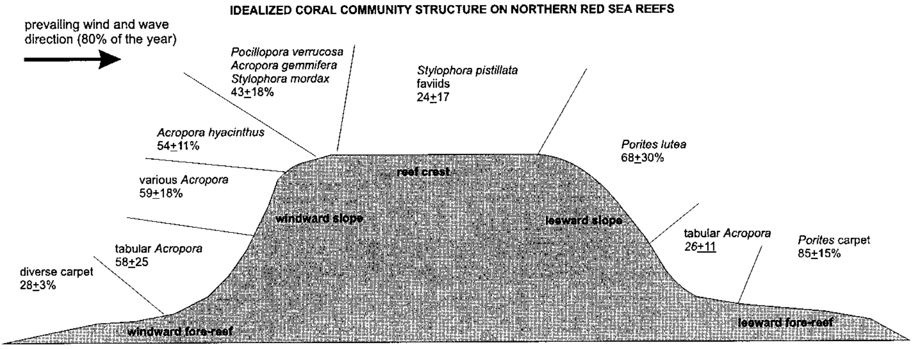

Figure 3. Typical coral community differentiation on northern Red Sea reefs (based on this study and Riegl and Velimirov, 1994; Riegl and Piller, 1997). The dominant taxa in each community type are given, as well as the average living coral coverage of the substratum.

10 m). Xeniid soft corals were widespread and dominated particularly in greater water depths (>20 m).

Fish communities followed the differentiation of coral communities into windward, leeward, and current-exposed communities (Figure 4). Counts from damaged areas (dynamite and ship groundings) formed clusters, which indicated distinct community structure. Exposed sites differed in community composition but not in averages of abundance and diversity from sheltered sites (t-tests, $P > 0.05$). The sites with the lowest fish abundances were *Porites* carpets and damaged areas. Typical families of windward reefs were Pomacentridae and Serranidae (including *Anthias*), while current-exposed sites were characterized primarily by *Anthias*. Leeward and deep sites had fewer fish, were also frequently dominated by Pomacentridae, but had a higher percentage of other families.

Dynamite and Ship Groundings—Impacted Areas.—From 60 sampled reefs, 39 (65%) had signs of dynamite damage; 58% of dynamite scars were found on leeward reefs. Due to the stable pattern of windward-leeward coral community differentiation, most damage occurs on *Porites*-dominated communities (Fig. 4). Analysis of samples from Erg Dynamite, Sharm el Arab, Erg Wadi Gimal, and the Safir grounding site (Fig. 1) grouped impact and reference sites into distinct clusters, indicating differences in community structure (Fig. 5). Some degree of overlap existed in the cluster analysis with two impact transects grouping with the reference sites. Such overlaps can be expected, since some impacted sites still retained patches of good coral cover. Overall, the separation of groups was very clear (Fig. 5). One-way ANOSIM confirmed significant differences in community structure of dynamited and reference sites ($R = 0.626$, $P < 0.001$). Coral cover decreased significantly in all pairs, as did proportion of rock, while proportion of rubble increased significantly (two-way ANOVA, $P < 0.01$). This analysis also showed that damage by dynamiting and ship grounding was similar, since the impacted samples grouped together, i.e., severe to total reduction of coral cover.

Seven of the eight ship groundings had occurred on windward reef slopes. All impacted the upper reef slopes and at least part of the reef flat. Damage correlated well with ship speed and angle of impact. This information was derived from measurement of the impact scars on the reefs and aerial photographs of the groundings. The least damage was done by ships hitting the reef head-on, which limited the impact area more or less to the

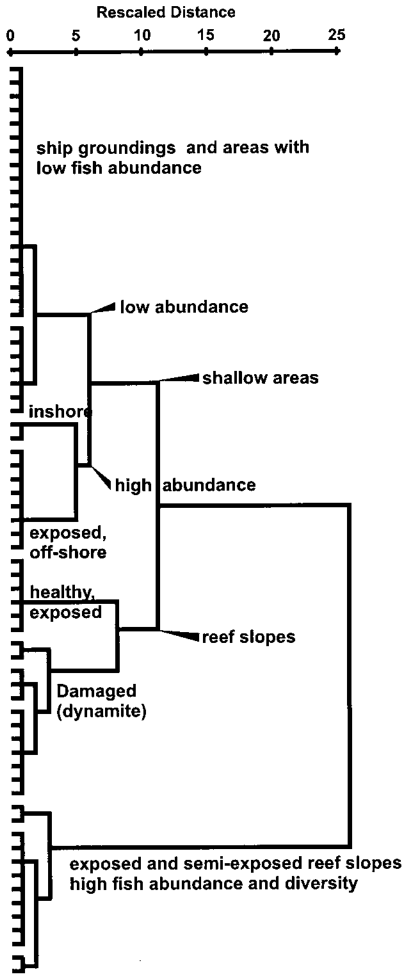

Figure 4. Fish community structure: Classification of point counts. Clustering algorithm is Ward's method with squared Euclidian distance as measure. Damaged sites form distinct clusters, which suggests changes in community structure.

width of the hull (three cases). The largest scale damage was caused by vessels hitting sideways (four cases). In one case (MARIA SCHROEDER), the vessel never actually hit the reef but was transferred onto the reef flat by a freak wave.

Natural regeneration appeared to be slow. A linear correlation ($r^2 = 80.1$, $P < 0.01$) was observed between the observed regeneration percentages (i.e., the coral cover inside the impact area expressed as the percentage of coverage in the reference area) and time (Fig. 6). An exponential regression fitted to the same data had lower significance ($P < 0.05$). While the assumption that regeneration proceeds in a linear way is almost certainly an over-simplification, it could in the present study be used to roughly estimate regeneration times. In the present example from the northern Red Sea, the time necessary for a windward upper reef slope coral community to re-grow to pre-impact coverage values is mostly in the range of 100–150 yrs (Table 1).

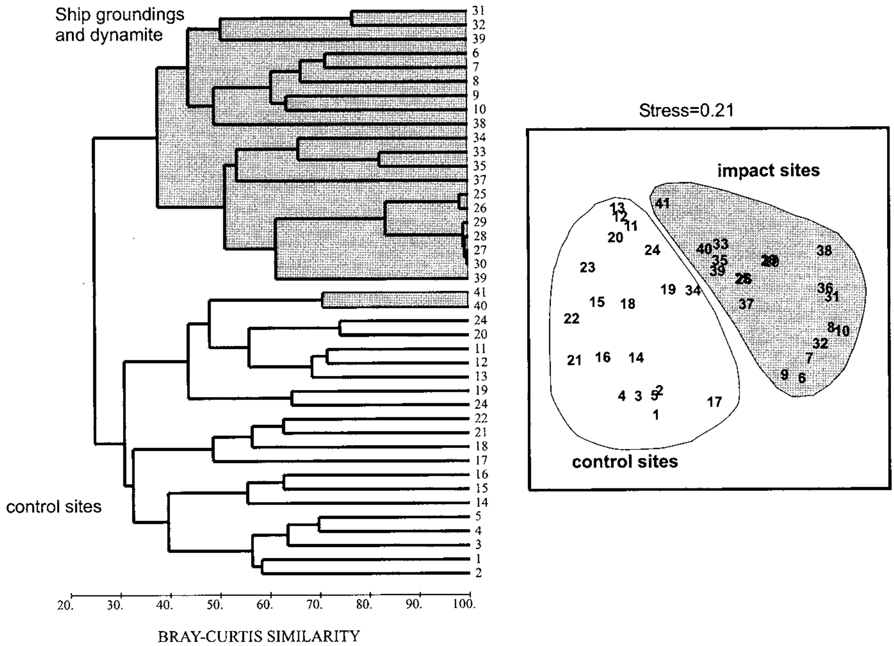

Figure 5. Differences in community structure between impacted and reference reefs. Both analyses (cluster analysis and MDS) use the same distance matrix but different grouping algorithms. The differences in community structure between impact and reference sites are very clear. The low number of outliers supports the significance of the separation. Ship grounding impact samples group with dynamite impact samples, which indicates similarity of the damage. Cluster analysis uses group average as linkage, distance measure is the Bray-Curtis similarity index.

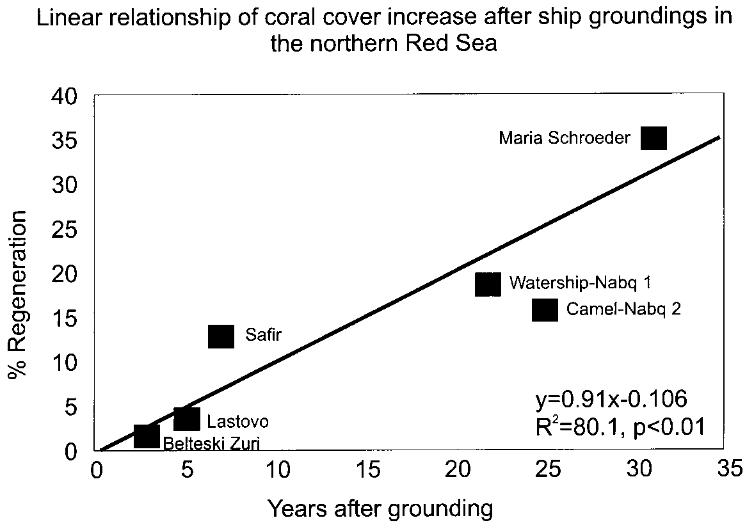

Figure 6. Relationship between coral cover in the impact site and the time passed since the impact. Only ship groundings were used in the analysis since age estimation of dynamite impacts was dubious. The best fit relationship was linear (0.01 significance level). Also an exponential model could have been fitted, but with lower significance (0.05).

Table 1. Characterization of investigated ship groundings in the northern Red Sea.

Wreck	Year of grounding	% coral cover – reference	% coral cover – impact	% regeneration	Estimated regeneration period (years) – linear model
Watership (Nabq 1)	1974	50.8 ± 27.1	9.1 ± 8.3	18%	123.5
Camel (Nabq 2)	1971	65.2 ± 19.7	10.1 ± 9.2	15%	161.3
Maria Schroeder (Nabq 3)	1965	19.5 ± 11.7	6.8 ± 3.5	3%	89
Lastovo	1991	36.1 ± 11.1	1.1 ± 0.8	3%	156
Safir	1989	20.9 ± 16.1	2.7 ± 3.7	13%	54.3
Belteski Zuri	1993	63.8 ± 26.1	0.3 ± 0.5	0.5%	600

In the case of the wrecks at Nabq 1 (WATERSHIP), coral cover was also measured on the steel hull of the wreck itself which was 33.5 ± 19.1%, while cover in the impact area was only 9.1 ± 8.3%. If coral increase was linear, it would only take 34 yrs for coral cover on the hull to reach the same value as on the reference site. On the impacted reef, however, regeneration time was calculated (assumption of linear increase) as 123.5 yrs.

Dense algal lawns, mainly made up by *Laurencia* spp. were encountered on the BELTESKI ZURI grounding site.

IMPACTS ON FISH COMMUNITIES.—For pattern detection between impact and reference sites, different localities were used than for the description of community patterns. Classification of fish counts from 12 impact vs reference sites did not clearly separate samples into two clusters, but impacted sites did form separate groupings within each of the major clusters. MDS failed to clearly separate the impact from the reference samples. However, one-way ANOSIM showed that significant differences existed when pooled data from impact and reference sites were tested against each other (global $R = 0.138$, $P < 0.001$), indicating a change in community structure. In impacted sites, fish frequency was reduced ($t = 2.36$, $df = 24$, $P < 0.027$). Particularly Pomacentridae were reduced in frequency, but differences among sites were not significant due to high variability.

DISCUSSION

This study showed that ship groundings and dynamite fishing have similar effects in the northern Red Sea—mainly the removal of a large proportion or the entirety of the impacted coral community and the production of unstable substratum in the form of impact-generated boulders and rubble.

The results for coral and fish communities clearly show the marked windward-leeward community differentiation. Effects of impacts vary in respect to their position on the reef. While windward sides harbor the higher abundance and diversity of coral and fish, the taxonomic composition and different life history strategies of constituent species suggests differences in impact severity. Windward sides are populated by faster-growing communities, while leeward sides by slow-growing communities (Riegl and Velimirov, 1994; Riegl and Piller, 1997, 1999). Most ship groundings occur in the area of faster-growing windward reefs, while most dynamiting impacts are on leeward sides (Fig. 4). These differences lead to several important implications for regeneration. Intergranular cementation, which is necessary for sediment lithification and, in this case, the re-establishment of firm substratum from impact-generated rubble, is highest in areas of high water flux at the sediment-water interface (MacIntyre, 1977; Purser and Schroeder, 1986; Scoffin, 1992; Grammer et al., 1999), and can therefore be high in windward areas but slow in leeward settings. In the study area, no cemented rubble was found. It can be expected that unstable substratum, with all its negative implications for coral re-establishment, will persist for long periods of time. The oldest investigated, and still uncemented, rubble was from the grounding of the CARNATIC on windward Shaab Abu Nuhas in 1869.

Leeward shallow northern Red Sea reefs are characterized by a high *Porites* dominance (Head, 1984; Riegl and Velimirov, 1994; Riegl and Piller, 1997, 1999). In the study area, they were primarily affected by dynamiting and not by ship groundings. The problems associated with damage in these communities are similar to those created by ship-groundings on windward slopes but they are aggravated by the biological characteristics of their coral communities, i.e., the slow linear extension rate of *Porites* (6.17 mm yr^{-1} in the Gulf of Aqaba to 6.42 mm yr^{-1} in southern Egypt; Heiss, 1994). This may have several implications for regeneration. Slower linear coral growth can mean slower regrowth and therefore also slower regeneration of the coral community. Also, leeward reefs experience lower current velocities which may result in slower formation of submarine cement (MacIntyre, 1977; Purser and Schroeder, 1986; Grammer et al., 1999) which would be necessary for rubble binding. This may hinder rubble binding and therewith the regeneration of stable substratum.

The absence of stable substratum is a key factor hindering coral regeneration on grounding sites, as was observed in the case of the MV WELLWOOD and other groundings reported by Gittings et al. (1988), Hudson and Diaz (1988), and Gittings et al. (1994). The low recovery rates of the two wrecks at Nabq in over 20 yrs clearly indicate the importance of the availability of stable substratum for coral settlement.

Regeneration rates in the northern Red Sea appear to be slow in comparison to data from other areas in the literature. However, the regeneration rates presented in this paper are less than those estimated by Hawkins and Roberts (1991) in the Straits of Tiran. In Florida, Gittings et al. (1988) reported regeneration of 13% of the original cover 27 mo after the grounding of the MV WELLWOOD. This would be equivalent to total regeneration within 17 yrs, which is faster than recovery estimates from the Red Sea (Fig. 6, Table 1). However, Aronson and Swanson (1997) report that transects from the WELLWOOD grounding site are more similar to hardgrounds than to nearby reef reference sites, which indicates that regeneration was not as fast as might have been expected according to Gittings et al. (1988). Smith (1985) reported coral regeneration rates of 25 $cm^2\,m^{-2}y^{-1}$ after ship groundings in Bermuda, whereas Cook et al. (1994) quote 80–160 yrs regeneration time for that area, a rate comparable to that from the northern Red Sea. In a study on storm disturbance in Hawaii, which had similar effects as the dynamite and ship groundings in the case presented here, Dollar and Tribble (1993) calculated recovery times of 40 yrs (assuming exponential increase in coral cover) to 70 yrs (assuming linear increase of coral cover) for coral communities to regain pre-disturbance cover. This ties in well with the 50 yrs estimated by Grigg and Maragos (1974) to be necessary for reefs to regain peak abundance after lava flows. However, due to frequently recurring storm disturbances, Dollar and Tribble (1993) found that regeneration was effectively halted. Over a 13-yr period from 1980 to 1993, they observed zero net recovery of the coral community. It is

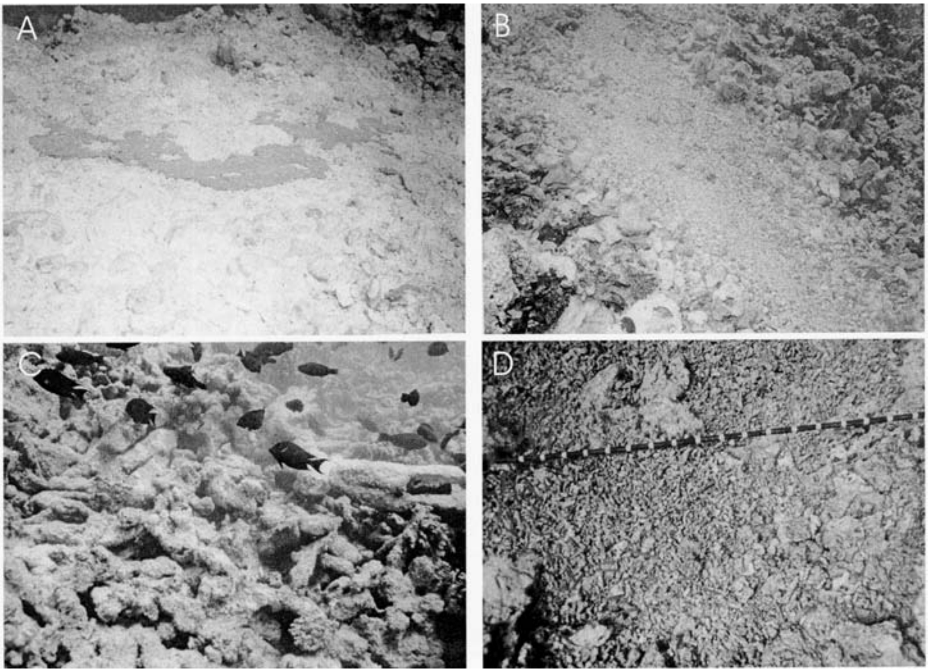

Figure 7. (A) Grounding site of the ROYAL VIKING SUN on Tiran Island. This grounding was not studied for the present paper. The vessel's hull etched a terrace out of the reef. The reef edge was completely annihilated to a depth of approximately three meters. Hull paint can be seen in the center. (B) Same grounding site, the deposits of an avalanche mostly made up of fine rubble are seen overlying the coarse rubble blocks which cover the entire reef slope. Most of the reef slope to a depth of 30 m was covered by rubble. (C) Dynamite damage in a columnar *Porites* community. The *Porites* framework is broken up into coarse blocks. Sharm Tachtani. (D) Dynamite damage in a branching coral community. The *Acropora* framework is broken up into fine rubble.

possible that the low recovery values on some exposed northern Red Sea sites (for example the WATERSHIP-Nabq 1 and the CAMEL-Nabq 2) are also caused by recurrent disturbances by storms. Since much of the reef slope is covered by unstable rubble, this could be easily moved by storm waves, damage new coral communities, and repeatedly set back any recolonization to zero. In the Maldives, Brown and Dunne (1988) found virtually no recovery 16 yrs after coral mining had ceased. This again corresponds well with the regeneration observed on the Red Sea ship grounding sites (Fig. 7). In both areas, the substratum is similar, namely unstabilized rubble and sand.

An interesting case is the high coral settlement on the hull of the wreck of the CAMEL-Nabq 2. Coral cover on the hull was almost four times higher than on the impacted reef. Although not quantified, a similar situation was observed on most other wrecks where the hull was still present. This situation is not fully understood. One of the reasons may be the large amount of unstable substratum on the impacted reef in contrast to the stable substratum offered by the wreck. The elevated position on the ship hulls may keep the coral recruits away from sediment and unstable substratum. Another explanation could be the presence of weak electrical currents possibly created by electrolysis. This is known to increase the settlement of coral larvae (Schuhmacher, 1994; Schuhmacher and Schillak, 1994; Goreau and Hilberts, 1996).

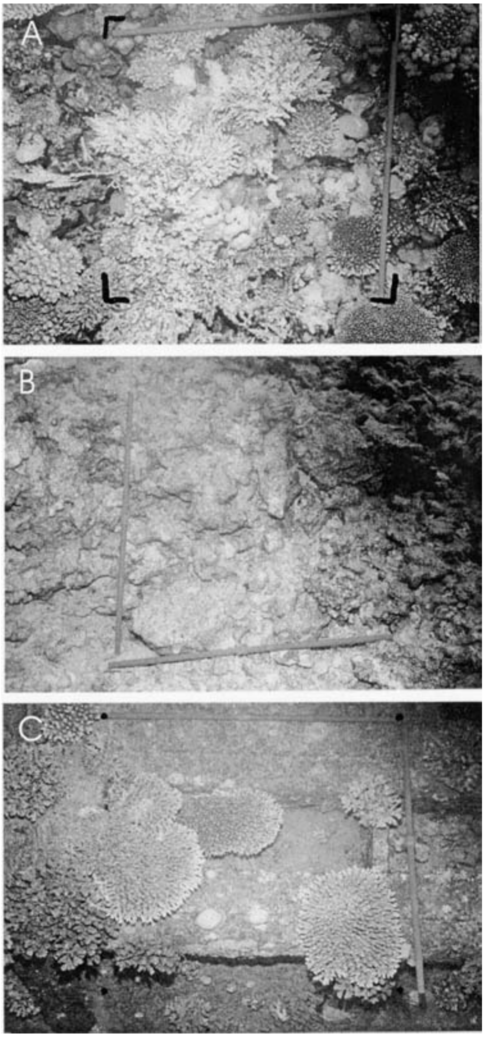

Figure 8. (A) Reference site near the grounding site of the CAMEL-Nabq 2 in the Straits of Tiran. The coral community is dominated by *Acropora* spp. (B) The grounding site 25 yrs after the impact. Overall regeneration was 15%. (C) Coral growth on the hull of the wreck. Coral cover was almost four times higher than on the grounding site.

Hatcher (1984) provides evidence of algal-dominated stable states in areas where corals were damaged by ship groundings. Dollar (1982) observed a comparable sequence of algal settlement on reefs damaged by storm waves in Hawaii as was seen on the northern Red Sea ship grounding sites. While in Hawaii, the algae had disappeared from the reef after 3 mo, in some Red Sea grounding sites (BELTESKI ZURI) dense lawns of fleshy red algae were still present 3 yrs after the grounding. It is likely that the presence of Pomacentrids and other territorial grazers could lead to a reduction of algal blooms, however, our study indicated that Pomacentrid frequency in particular was reduced in the impact sites. These fish could be aided by transplanting corals or any structure which can serve as refuge or territory into the denuded areas (Sano et al., 1984, 1987). In order to achieve near-natural coral larvae settlement rates, at least some key components of the fish community may have to be initially re-established (Bohnsack, 1993), since their activities could play an important role in priming the damaged reef for re-settlement.

Recovery periods are difficult to estimate and depend on the definition of recovery. If Pearson's (1981) definition of "restoration of a coral assemblage to a degree comparable to its original state" or Gittings et al.'s (1994) "replenishment of populations as well as the restoration of age-class structure" are used, Red Sea reefs impacted by ship groundings and dynamite may stand a low chance of natural recovery at a scale of decades or even centuries. This is particularly true for the leeward, slower growing communities. Also on dynamited sites, remarkably little regeneration was observed in our study. The likelihood and rate of regeneration is probably a function of scale. While small-scale impacts (individual blasts) are on the scale of a localized episodic event that does not alter the system (or the community), large-scale impacts (a ship grounding or several densely spaced dynamite blasts over large portions of a reef) can totally alter ecological and even environmental parameters and thereby make natural regeneration almost impossible. Therefore, rehabilitation by transplantation is a promising option (Clark and Edwards, 1993, 1994, 1995). However, rehabilitation efforts should be consistent with the original zonation patterns. If leeward sides were artificially recolonized primarily by rapidly growing, aggressive corals, such as *Acropora* (Thomason and Brown, 1986), the slow-growing, competitively weak *Porites* would be disadvantaged from the onset and regeneration of the original community could be difficult. Clark and Edwards (1995) showed that *Porites* exhibit high survival rates after transplantation into damaged sites. This indicates that restoration of such late-successional stage *Porites* communities (Riegl and Piller, 1997, 1999; Riegl and Luke, 1998) is possible. Transplantation of a sufficient number of large specimens may, coupled with the high survival rate (Clark and Edwards, 1995) and capabilities of asexual reproduction (Highsmith, 1980, 1982), significantly speed up the artificial re-installation of a *Porites*-dominated reef. An advantage in transplanting large *Porites* colonies is that they can be directly placed onto impact-generated coral rubble. However, care would have to be taken that the coral removal from the donor site does not compromise the donor community and that transplants are big enough to avoid easy dislodgment in the recipient area during storms. On windward slopes the success of rehabilitation efforts will largely depend on the ability to stabilize the substratum or removal of the rubble (Gittings et al., 1994). This is of special importance since the growth form and attachment mode of *Acropora* requires stable substratum and attachment.

This study has implications for management. Since most impacts, and therefore the heaviest degradation, was encountered on leeward sides with slow-growing and slowly regenerating communities that are hard to restore, emphasis should be put on protecting these areas. Management plans that take special consideration of these vulnerable areas should be encouraged. In Red Sea protected areas, presently most emphasis is put on the study of the effects of ship groundings and the impacts of tourism. The effects of dynamiting and the concomitant loss of an important part of the reef ecosystem need to be urgently addressed.

Conclusions

1. In the northern Red Sea, dynamite damage is a more common cause of reef degradation than ship groundings.

2. Ship groundings affect mainly windward reefs; dynamite damage mainly leeward reefs.

3. Damage caused by ship grounding and dynamiting is similar—in the most serious cases, coral cover was reduced to zero and the reef broken into rubble.

4. Regeneration on ship grounding sites was relatively slow. The time taken for re-establishment of a coral community similar to pre-impact conditions on windward reefs was estimated between 100 and 160 yrs.

5. After some ship groundings, coral settlement on the hulls was faster than on the denuded reef.

6. Fish communities degraded similar to coral communities (loss of abundance and diversity).

7. Dynamited coral communities (leeward climax *Porites* communities) have a low chance of natural recovery.

8. Restoration has to be consistent with natural community patterns (windward *Acropora*, leeward *Porites*) in order to allow re-establishment of nature-like reef communities.

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