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An analysis of fish community responses to coral mining in the Maldives

Alec R. Dawson Shepherd[1], Richard M. Warwick[2], K. Robert Clarke[2] & Barbara E. Brown[1]
[1] *Centre for Tropical Coastal Management Studies, Department of Biology, The University, Newcastle upon Tyne NE1 7RU, UK*
[2] *Plymouth Marine Laboratory, Prospect Place, The Hoe, Plymouth PL1 3DH, UK*

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Synopsis

Coral mining takes place on shallow reef flats at a number of localities in the Maldives, but not on the adjacent deeper reef slopes. A semi-quantitative census method for fish species abundance and biomass is described. Fish community structure is compared on mined and non-mined reef flats and their adjacent slopes using a variety of univariate, graphical/distributional and multivariate statistical techniques. In general, univariate and graphical distributional methods do not indicate significant differences between mined and non-mined localities with respect to the relative abundances and biomasses of species. Multivariate methods (both classification and ordination), however, indicate very clear-cut effects of mining on the reef flats, and also significant effects on reef slopes adjacent to mined flats. The effect was equally clear using non-quantitative (presence/absence) data. The fish species mainly responsible for the differences between mined and non-mined localities are identified, and the differences are explained in terms of the feeding biology of these species.

Introduction

A major cause of environmental degradation in the Maldives is coral mining for use in construction and land-reclamation. Limited coral mining takes place in water depths of 1–2 m on shallow reef flats throughout the islands, but is most severe in North Malé atoll where several reef flats have been stripped almost bare of coral. Brown & Dunne (1988) found that the percentage of living coral cover on unmined reefs varied from 11 to 60%, while the cover on mined sites was less than 5%. The diversity of coral species and genera was also reduced: between 7–16 species were found at mined locations in a survey in 1989, whereas 20–32 species were recorded at unmined sites, the corresponding numbers for genera being 7–11 and 12–18, respectively. Mining does not occur on the adjacent reef slopes or on the reef edges or crests, but is confined to the reef flats where the composition of reef corals is dominated by the massive species suitable for use in the construction industry. Living branching corals which dominate the reef crests and slopes are unsuitable and are not mined. During the course of the present survey, active mining was observed on faroes in North Malé, including locations cited in Brown & Dunne (1988). Mining does result in the production of a sediment plume which could potentially affect adjacent areas of coral reef, but the small scale nature of this activity means that the plume is extremely localised to the vicinity of the mining activity. One important feature of mining activity is the slow recovery of sites once mining has ceased. At some sites in North

Malé, where mining took place over 16 years ago, very little recovery has been noted. This is probably due to the fact that mining activities result in an unconsolidated and rubble covered surface on the reef flat. Any coral settling on the broken rubble surface is rolled over by the waves and strong currents which sweep across the mined area, resulting in poor recruitment.

Reef mining has two principal effects on fish communities. It leads to loss of live coral cover which is reported to reduce both fish abundance (Bell & Galzin 1984, Sano et al. 1984, Bouchon-Navaro et al. 1985), and diversity (Bell & Galzin 1984, Sano et al. 1984). Also, perhaps more importantly, it leads to a reduction in rugosity (topographic diversity) which will also tend to decrease abundance, richness, and species diversity in reef fish communities (Luckhurst & Luckhurst 1978). In this study we assess the changes in the structure of fish communities associated with mined reef flats and their adjacent reef slopes, as compared with non-mined ones.

Methods

Field estimates of abundance and biomass of fish species

A number of methods to estimate the abundance and biomass of coral reef fish have been developed and tested (Sale & Douglas 1981, Brock 1982, Sale & Sharp 1983, Bell et al. 1985, Harmelin-Vivien et al. 1985, Kimmel 1985, Bohnsack & Bannerot 1986, Thresher & Gunn 1986, Fowler 1987, Bellwood & Alcala 1988, Lincoln Smith 1988, Greene & Alevizon 1989). The method adopted here was a version of that developed by the Great Barrier Reef Marine Park Authority of Australia (GBRMPA 1978, 1979), modified to allow an estimate to be made of the numbers and length of species of fish seen per unit area of reef. In this respect it is more quantitative than the GBRMPA method though it still provides a relative, rather than a true, estimate of abundance. In addition the modified counting method, as described below, quickly accounts for abundant species so allowing the observer to concentrate on less abundant species.

A total of 152 species was selected using a number of criteria and included representatives from three different trophic groups, benthic herbivores, planktivores and omnivores (Hiatt & Strasburg 1960, Hobson 1974), fish of importance to the aquarium industry (A.J. Edwards personal communication), species regularly reported from the line fishery, fish used in the baitfishery, and fish of aesthetic significance. Cryptic, shy and secretive fish were not counted. During a counting session the observer swam in zig-zag fashion through a 200 by 15 m area on the reef flat. The process was repeated in a 200 by 15 m area marked on the adjacent reef slope. Except for one site all counts

Table 1. Locations of sampling sites A-W, indicating whether they are mined (+) or non-mined (−). Fr. reef = Fringing reef. Abbreviated locations: e.g. N ring reef W Gulhi = northern site on ring reef west of the island of Gulhi.

Site	Location	Mined	Site	Location	Mined
A	Fr. reef Hulule airport W	+	M	S ring reef WSW Dhiggiri	−
B	Fr. reef Malé anchorage NW	+	N	N ring reef WSW Dhiggiri	−
C	Fr. reef Villingili W	+	O	Rim of reef S Muli	−
D	Fr. reef Kurumba NW	−	P	Rim inner sth of Muli	−
E	Fr. reef Malé NW	+	Q	N ring reef SW Bandidhoo	−
F	Fr. reef Malé anchorage SE	+	R	S ring reef SW Bandidhoo	−
G	Fr. reef Education I W	+	S	N ring reef NE Himandhoo	−
H	Fr. reef Education I E	+	T	S ring reef NE Himandhoo	−
I	N ring reef W Gulhi	−	U	N ring reef NE Fesdu	−
J	S ring reef W Gulhi	−	V	S ring reef E Kuda Bandos	+
K	S ring reef NE Giraavaru	+	W	S ring reef W Bandos	+
L	N ring reef NE Giraavaru	+			

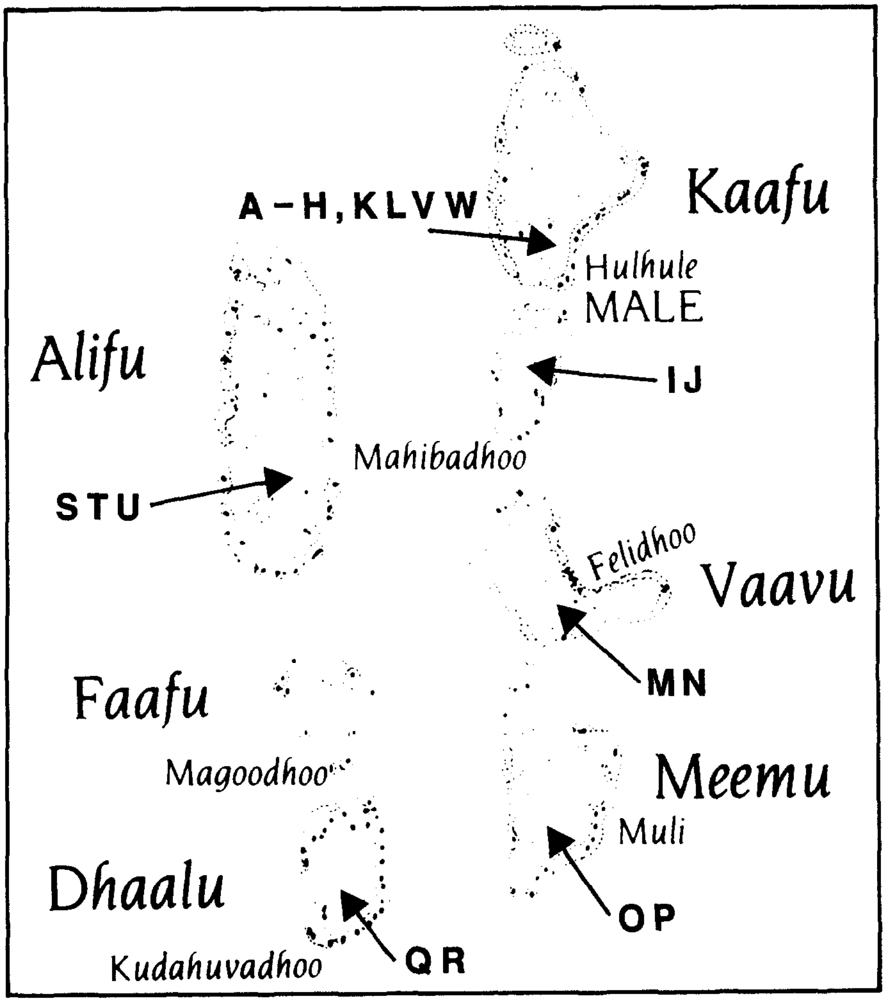

Fig. 1. Map of the central group of atolls in the Maldives chain, indicating the allocation of sampling sites A-W to each atoll.

were taken on reef profiles characterised by a reef flat in 1–2 m water with a reef slope extending steeply down to at least 15 m. The reef flat count area for the one site was in 3 m of water. The observer worked down the standard species list, which was photocopied onto waterproof writing film, considering each species in sequence. For 38 species (predominantly food fish like grouper and snapper), all fish seen during the count period were noted. For the remaining 114 species (57 species of large reef-fish such as parrotfish, surgeonfish, angelfish and butterflyfish and 57 smaller reef-fish including wrasse and damselfish) the observer entered the time taken to see up to ten individuals of each species, the number seen, and the time taken to cover the 3000 m^2 area. Counting of a particular species stopped when ten individuals had been seen. The observer then had time to concentrate on the remaining species on the list and not on species that were very abundant. If more than ten individuals of a given species were seen within a five minute period it may have been that the population of this species was heterogeneous over the count area. In this case an abundance estimate based on a single count may have been misleading. For such cases five replicate counts were carried out in separate parts of the count area. The average abundance was calculated from the time taken to see ten individuals, if it took less than five minutes, or the number seen, if less than ten individuals were seen

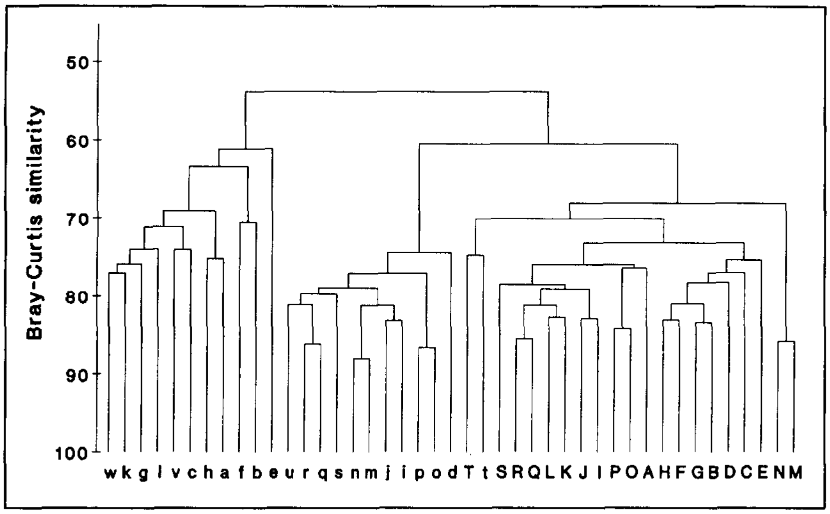

Fig. 2. Dendogram from Bray-Curtis similarity matrix of √√ transformed species abundance data with group-average linking. Reef flat sites A-W designated by lower case letters, slope sites by upper case.

in five minutes. The time taken to see the specified number of individuals, and the time to cover the known counting area, was used to calculate the numbers of each species of fish per unit area. All surveys were carried out in daylight hours, generally between 0900 and 1600 h.

Biomass was calculated for each species in one of two ways. Number and estimated length (± 5 cm) of all fish seen during each counting session were noted for the 38 species of food-fish. Estimated length was then used to generate biomass using known length/weight regression coefficients obtained from fish collected in the line fishery. A mean biomass estimate for each of the remaining 114 species was used to calculate biomass per unit area from numbers per unit area.

A qualitative assessment of the degree of mining impact was used, the sites being designated simply as mined or non-mined (Table 1). Mined reef flats were characteristically stripped almost bare of coral and were only observed in the southern end of North Malé atoll. Non-mined reef flats showed no evidence of mining though at certain locations there was evidence of reef degradation within the last few years due to other factors. These factors may have included coral bleaching and crown of thorns infestations, the latter being reported to have an effect on reef fish community structure (Williams 1986). Counts were undertaken on 11 mined reef flat sites and 9 adjacent slopes, and 12 non-mined reef flats and 11 adjacent slopes, the locations of which are shown in Fig. 1. Eight of the sampling locations were sited on fringing reefs adjacent to islands in North Malé atoll, thirteen on ring reefs or faroes in various atolls, and two on fringing reefs adjacent to an island in Meemu atoll.

Data were entered into a microcomputer using a specially developed program written in dBase III+. Numbers and biomass per 1000 m^2 were calculated for each species using these data and specially prepared software.

Data analysis

Analysis involved a comparison of the abundance and biomass of 152 species between mined and non-mined sites, between reef-flats and reef-slopes, and by location. A variety of univariate and multivariate statistical techniques has been used to compare the structure of reef fish communities (Gladfelter & Gladfelter 1978, Luckhurst & Luckhurst 1978, Gladfelter et al. 1980, Bell 1983, Williams & Hatcher 1983, Bell & Galzin 1984, Sano et al. 1984, Bouchon-Navaro et al. 1985, Williams 1986, Galzin 1987, Samoilys 1988). We have chosen

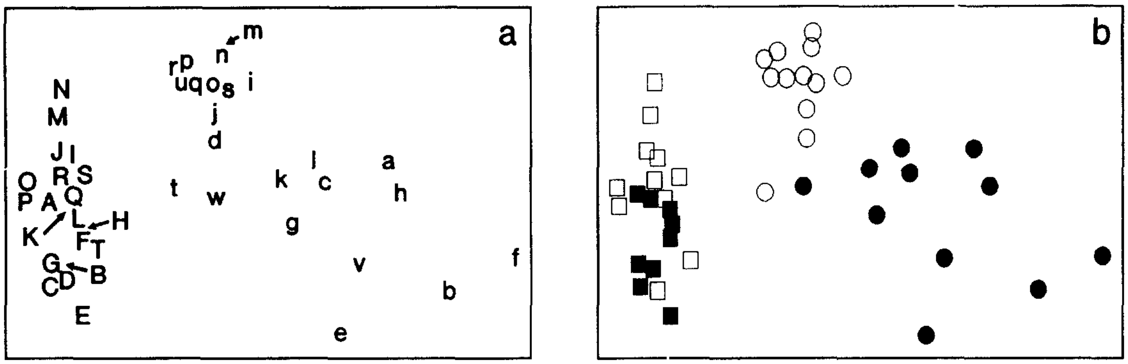

Fig. 3. MDS ordination of Bray-Curtis similarity matrix of √√ transformed species abundance data: a – Reef flat sites A-W designated by lower case letters, slope sites by upper case, b – Letters replaced by open symbols = non-mined and solid symbols = mined (circles for reef flats, squares for slopes).

to adopt the following suite of analytical procedures, the rationale for which, together with more details of the methodology, are described elsewhere (Warwick et al. 1990):

(1) The univariate indices of number of species, species richness (Margalef's D), Shannon diversity (H′) and evenness (Pielou's J) were calculated, using logarithms to the base *e* throughout. The significance of differences between mined/non-mined and flat/slope sites was tested by two-way ANOVA.

(2) Graphical descriptors in the form of *k*-dom-

Table 2. Percentage contribution by the top twenty species to the Bray-Curtis dissimilarity in species abundances (SIMPER analysis) between mined and non-mined reef flats, by trophic grouping. + denotes non-mined abundance > mined, – denotes non-mined < mined.

Species		Planktivore	Benthic herbivore	Omnivore
Sufflamen chrysoptera	–			2.27
Chromis atripectoralis	+	2.05		
Halichoeres hoeveni	+			2.03
Acanthurus leucosternon	+		1.94	
Plectroglyphidodon lacrymatus	+		1.90	
Amblyglyphidodon leucogaster	+	1.87		
Plectroglyphidodon dickii	+	1.73		
Labrichthys unilineatus	+			1.70
*Oxymonacanthus longirostris**	+			1.51
Stegastes nigricans	+		1.48	
*Chaetodon triangulum**	+			1.46
Chaetodon kleinii	–			1.45
Pomacentrus trichourus	–	1.41		
Ctenochaetus striatus	+		1.36	
Zebrasoma scopas	+		1.34	
Meiacanthus smithii	+			1.32
Scarus scaber	+		1.28	
Parapercis hexophthalma	–			1.28
Myripristis violacea	+	1.23		
Thalassoma hardwickii	+			1.18
Total	+ = 16	8.29	9.30	14.20

* obligate corallivores.

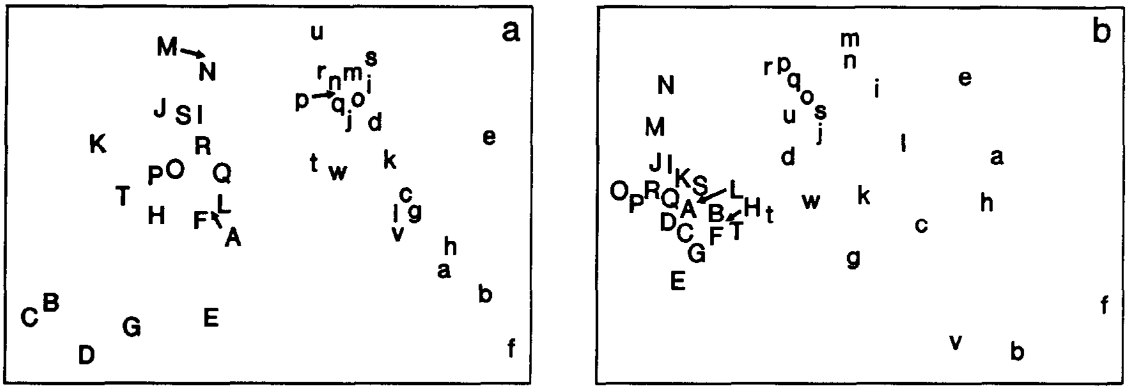

Fig. 4. MDS ordinations of species abundance data (as Fig. 3a): a – non-transformed, b – presence-absence.

inance curves have been plotted for both the species abundance and biomass data. The significance of differences in both shape and mean elevation of curves from different 'treatments' (mined/non-mined, flat/slope) have been tested using the computer program DOMSIG (Clarke 1990).

(3) Hierarchical agglomerative clustering was performed on a Bray-Curtis similarity matrix based on double square root transformed species abundance or biomass data and using group-average linking.

(4) Multidimensional Scaling Ordination (MDS) was performed on the same similarity matrix. The effects of varying transformations on the species

Table 3. Percentage contribution by the top twenty species to the Bray-Curtis dissimilarity in species biomasses (SIMPER analysis) between mined and non-mined reef flats, by trophic grouping. + denotes non-mined biomass > mined, – denotes non-mined < mined.

Species		Planktivore	Benthic herbivore	Omnivore
Sufflamen chrysoptera	–			3.20
Acanthurus leucosternon	+		2.30	
Cetoscarus bicolor	+		2.26	
Monotaxis grandoculis	+			1.81
Sargocentron spiniferum	+			1.79
Ctenochaetus striatus	+		1.62	
Amblyglyphidodon leucogaster	+	1.57		
Acanthurus nigricauda	–		1.52	
Scarus scaber	+		1.51	
*Chaetodon triangulum**	+			1.45
Chaetodon kleinii	–			1.43
Plectorhinchus orientalis	+			1.43
Caranx spp.	–			1.41
Scarus frenatus	+		1.34	
Zebrasoma scopas	+		1.33	
Siganus stellatus	+			1.30
Melichthys indicus	–			1.30
Cheilinus fasciatus	+			1.29
Lethrinus xanthochilus	–			1.24
Myripristis violacea	+	1.22		
Total	+ = 14	2.79	11.88	17.65

* obligate corallivore.

abundance data have also been explored, in particular the use of presence/absence data to test whether less quantitative (and hence less time-consuming) census methods might produce useful results.

(5) The ANOSIM test was used to assess the significance of differences between pre-defined groups of sample sites in the multivariate analyses.

(6) The species mainly responsible for the Bray-Curtis *dissimilarity* between site groups were determined using the computer program SIMPER.

Results

The cluster analysis shows a clear separation of mined reef-flats from non-mined reef flats and reef slopes (Fig. 2). Non-mined reef flats separate out from reef slopes except for site t which is situated on a ring reef in Ari atoll. It is the only site in which the reef flat count was made in slightly deeper water (3 m) which probably explains why its community structure is more similar to that of the reef slopes. This analysis shows no clear separation of slopes adjacent to mined reef flats from those adjacent to non-mined reef flats.

The MDS configuration with the lowest stress value of 0.092 indicates a reasonable representation of the between-site similarities in a two dimensional picture (Fig. 3a, b). The distinction between flat and slope sites is again very clear cut, as is the distinction between mined and non-mined reef flats. The distinction between reef slopes adjacent to mined and non-mined reef flats is less clear cut but is suggested. The ANOSIM test confirms these trends. Not surprisingly, there is a significant difference between mined and non-mined reef flat sites $R = 0.74$ ($p = 0.1\%$), but this test also confirms a significant difference between reef slopes adjacent to mined and non-mined reef flats $R = 0.36$ ($p = 0.1\%$)

The MDS configuration for species *biomass* is more or less identical to the species *abundance* MDS shown in Fig. 3, and is therefore not presented here. Experiments using different transforma-

Table 4. Percentage contribution by the top twenty species to the Bray-Curtis dissimilarity in species abundances (SIMPER analysis) between non-mined reef flats and non-mined slopes, by trophic grouping. + denotes non-mined flats > slopes, − denotes non-mined flats < slopes.

Species		Planktivore	Benthic herbivore	Omnivore
Chromis ternatensis	−	3.45		
Stegastes fasciolatus	−	2.70		
Chrysiptera unimaculata	+	2.30		
Anthias evansi	−	2.17		
Chromis dimidiata	−	2.08		
Chromis agilis	−	2.06		
Stegastes nigricans	+		1.93	
Anthias squamipinnis	−	1.91		
Pomacentrus pavo	−	1.72		
Ctenochaetus striatus	+		1.68	
Amplyglyphidodon leucogaster	−	1.64		
Caesio sp. 1	−	1.47		
Apogon sp. 1	−	1.41		
Apogon sp. 2	−	1.39		
Plectroglyphidodon leucozona	+	1.35		
Acanthurus leucosternon	+		1.32	
Plectroglyphidodon dickii	+	1.27		
Thalassoma hardwickii	−			1.26
Halichoeres marginatus	+			1.25
Hemitaurichthys zoster	−	1.24		
Total	+ = 7	28.16	4.93	2.51

tions of the abundance data show very little difference in discriminating power between the two extremes of no transformation (Fig. 4a) and presence/absence (Fig. 4b). The same separation of flat/slope and mined/non-mined sites is clearly evident.

SIMPER was used to determine the twenty species making the largest contributions to the dissimilarity in abundance and biomass between: (1) mined and non-mined reef flats; (2) non-mined reef flats and non-mined reef slopes; (3) reef slopes adjacent to mined and non-mined reef flats (Tables 2–7). Contributions are grouped according to whether the fish are planktivores, benthic herbivores, or omnivores.

Comparison of mined and non-mined reef flats shows that for 16 of the twenty species contributing most to the dissimilarity, the abundance is lower on mined reef flats (Table 2) and for 14 of the twenty species the biomass is lower (Table 3). The effect is reflected across all three trophic groups.

A similar comparison of non-mined reef flats and non-mined reef slopes (Tables 4, 5) shows that the abundance and biomass of the majority of species are greater on reef slopes. Planktivores appear to contribute to the higher abundance found on reef slopes despite the fact that herbivores tend to be more abundant on non-mined reef flats. The difference in the abundance versus biomass contributions across trophic groups reflects the higher mean weight of onmivores versus planktivores.

Interestingly, the abundance and biomass of the majority of species is greater on slopes adjacent to mined reef flats than to non-mined reef flats (Tables 6, 7). Much of the difference in abundance is due to planktivores though the higher mean weight of onmivores is reflected in a higher contribution to the difference in biomass by this trophic group.

Mean values for various univariate indices of community structure are given in Table 8. There are no significant differences in Shannon Diversity or Evenness between mined and non-mined sites, or between reef flats and slopes. For the total number of species and Species Richness, there is no

Table 5. Percentage contribution by the top twenty species to the Bray-Curtis dissimilarity in species biomasses (SIMPER analysis) between non-mined reef flats and non-mined slopes by trophic grouping. + denotes non-mined flats > slopes, − denotes non-mined flats < slopes.

Species		Planktivore	Benthic herbivore	Omnivore
Ctenochaetus striatus	+		2.07	
Chromis ternatensis	−	2.01		
Aethaloperca rogaa	−			1.92
Lethrinus mahsena	−			1.80
Cephalopholis miniata	−			1.68
Aphareus furcatus	−			1.68
Caranx spp.	−			1.64
Acanthurus leucosternon	+		1.63	
Stegastes fasciolatus	−	1.58		
Stegastes nigricans	+		1.48	
Lutjanus kasmira	−			1.45
Amblyglyphidodon leucogaster	−	1.43		
Scarus frenatus	+		1.41	
Chrysiptera unimaculata	+	1.33		
Variola louti	−			1.32
Hemitaurichthys zoster	−	1.30		
Scarus scaber	+		1.28	
Balistoides viridescens	−			1.28
Anthias evansi	−	1.26		
Plectropomus pessuliferus	−			1.25
Total	+ = 6	8.91	7.87	14.02

significant effect of mining either on the reef flats or slopes, but for both of these indices the values are significantly higher for the slopes than for the flats. There is also a significant interaction effect ($p < 0.1\%$ for number of species, $p < 5\%$ for Species Richness): these two indices are lower on mined than non-mined reef flats, but higher on slopes adjacent to mined flats than non-mined ones.

For *k*-dominance curves of both abundance and biomass, the DOMSIG test indicates that there are no significant differences between mined and non-mined sites for either the reef flats or reef slopes. Comparisons of *k*-dominance curves for abundance and biomass (ABC curves) have been used as an indicator of disturbance for non-mobile assemblages of benthic organisms from soft bottoms (Warwick 1986, Warwick et al. 1987). In such communities disturbance results in assemblages dominated by high abundances of small individuals, whereas small numbers of large individuals dominate the biomass of undisturbed assemblages. This results in curves for biomass lying above those for abundance in undisturbed conditions, and the reverse in grossly disturbed situations, with overlapping or crossing curves at intermediate levels of disturbance. There is no theoretical reason why this situation should carry over to the assemblages of mobile organisms such as fish, but we have tested the utility of this method for assessing disturbance affects on the fish communities from mined and non-mined sites. Taking the means (or totals) of all sites within each of the four groups (mined reef flats, non-mined reef flats, reef slopes adjacent to mined flats, and reef slopes adjacent to non-mined flats), the ABC plots are given in Fig. 5. There is a clear reversal between slope and flat sites with the biomass above the abundance for the flat and below the abundance for slope sites, regardless of the level of mining activity, and this is confirmed by formal tests of significance. Thus, the ABC method does not seem appropriate for assessing the level of disturbance to the fish assemblages.

Table 6. Percentage contribution by the top twenty species to the Bray-Curtis dissimilarity in species abundances (SIMPER analysis) between reef slopes adjacent to non-mined flats and slopes adjacent to mined flats, by trophic grouping. + denotes slopes adjacent to non-mined flats > slopes adjacent to mined flats, – denotes slopes adjacent to non-mined flats < slopes adjacent to mined flats.

Species		Planktivore	Benthic herbivore	Omnivore
Anthias squamipinnis	–	3.01		
Lepidozygus tapeinosoma	–	2.49		
Amblyglyphidodon leucogaster	+	2.25		
Chromis dimidiata	–	2.22		
Chromis lepidolepis	–	2.04		
Pterocaesio pisang	–	1.86		
Dascyllus carneus	–	1.82		
Anthias evansi	–	1.79		
Myripristis vittatus	–	1.73		
Adudefduf vaigensis	–			1.70
Caesio sp. 1	–	1.55		
Chromis viridis	–	1.54		
Chromis ternatensis	–	1.52		
Chromis agilis	–	1.52		
Melichthys indicus	–	1.51		
Hemitaurichthys zoster	–	1.51		
Chromis atripectoralis	+	1.46		
Lutjanus kasmira	–			1.34
Apogon sp. 2	+	1.30		
Thalassoma amblycephalum	–			1.30
Total	+ = 3	31.12		4.34

Discussion and conclusions

A major problem with environmental impact studies of this kind, as with all so-called 'natural experiments' (Connell 1972, Diamond 1986), is that their validity rests on the assumption that the control sites differ only from the impacted sites in the intensity of the human activity under consideration (Connell 1972, Paine 1977, Underwood 1984, McGuinness 1988). This is generally rather difficult to achieve in practice. Mining operations are likely to be geographically localised on the same sort of spatial scale as natural community changes, so that it is very difficult to untangle the two potential causes of community differences. In this study, all the mined sites are located at the southern end of North Malé atoll. Except for site D, all non-mined sites were situated on neighbouring atolls (Fig. 1). However, the non-mined reef flat community at site D on North Malé atoll does cluster with the other non-mined reef flat sites (Fig. 2, 3), which is consistent with community structure being determined more by mining activity than by natural geographical variability. This is supported by the fact that the fish fauna of the non-mined reef flats show a high degree of similarity, even between geographically far-distant stations, whereas the fauna of the mined reef flats in North Malé show much less similarity (Fig. 2, 3), even though the stations are grouped closely in the geographical sense.

Multivariate techniques show significant differences in the community structure of mined and non-mined reef flats and, perhaps more surprisingly, adjacent reef slopes. It is useful to analyse these differences at the trophic level to identify their ecological basis, and also at the species level because individual species have an ecological, aesthetic, or economic value that may far outweigh their community contribution as determined by their biomass or abundance.

Reef mining reduces overall biomass and abundance of reef-flat fish communities across the planktivorous, benthic herbivorous, and omnivo-

Table 7. Percentage contribution by the top twenty species to the Bray-Curtis dissimilarity in species biomasses (SIMPER analysis) between reef slopes adjacent to non-mined flats and slopes adjacent to mined flats, by trophic grouping. + denotes slopes adjacent to non-mined flats > slopes adjacent to mined flats, − denotes adjacent to non-mined flats < slopes adjacent to mined flats.

Species		Planktivore	Benthic herbivore	Omnivore
Melichthys indicus	−	2.11		
Lutjanus gibbus	−			2.02
Caranx spp.	−			1.92
Lutjanus kasmira	−			1.90
Amblyglyphidodon leucogaster	+	1.87		
Cephalopholis miniata	−			1.84
Plectropomus pessuliferus	+			1.76
Myripristis vittata	−	1.71		
Anthias squamipinnis	−	1.68		
Hemitaurichthys zoster	−	1.50		
Lutjanus monostigma	−			1.49
Macolor niger	+			1.48
Balistoides viridescens	−			1.46
Abudefduf vaigiensis	−			1.42
Lepidozygus tapeinosoma	−	1.39		
Variola louti	−			1.33
Gracila albomarginata	+			1.31
Gnathodentex aurolineatus	−			1.29
Plecttorhinchus orientalis	−			1.27
Lethrinus xanthochilus	−			1.24
Total	+ = 4	10.26		21.73

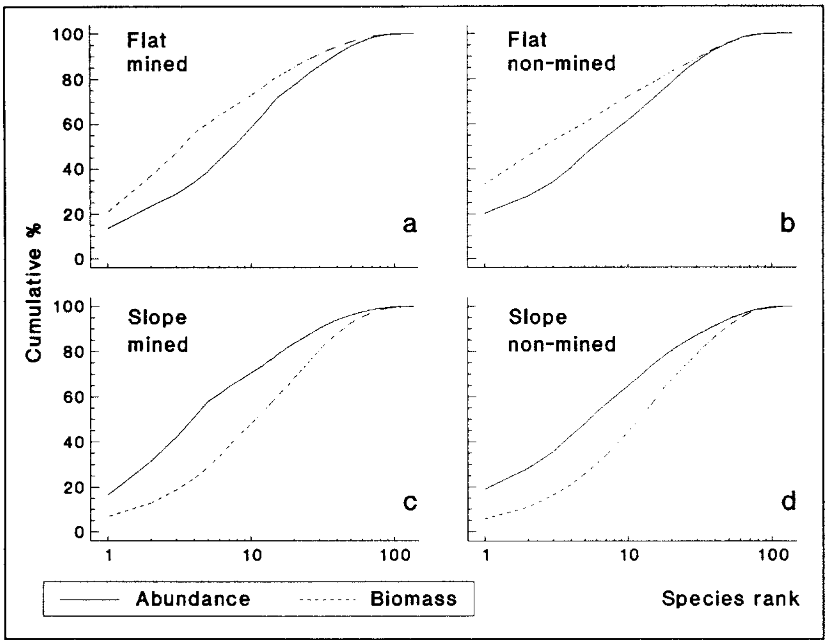

Fig. 5. Abundance biomass comparison (ABC) plots for species totals at mined and non-mined sites on reef flats and slopes. Note reversal of abundance and biomass curves between reef flats and slopes, but no effect of mining.

rous trophic groupings. Total number of species, species richness, evenness, and Shannon diversity indices do not differ significantly, although significant reduction in diversity has been reported elsewhere (Bell & Galzin 1984, Sano et al. 1984). Reduction in abundance accords with reports on the effects of reduction in live coral cover on reef fish populations (Bell & Galzin 1984, Sano et al. 1984, Bouchon-Navaro et al. 1985). Certain species are more abundant on mined reef flats and these tend to prefer sand and low rugosity rubble habitats. Species that are less abundant on mined reef flats tend to be the ones that prefer high rugosity habitat that provides shelter. Indeed, rugosity appears to be extremely important in determining reef fish abundance and diversity at these sites and this is also reported elsewhere (Luckhurst & Luckhurst 1978).

Graphical distributional plots, whether based on relative species abundances or biomass, showed no significant difference between mined and non-mined sites. To explore the reasons why ABC plots were not useful indicators of disturbance, we have examined the relative contributions of different size-classes of fish to the community structure. Table 9 summarises information on the average abun-

Table 8. Univariate indices (± standard deviation) of fish community structure for mined and non-mined reef flats and the adjacent reef slopes.

	Reef flats		Reef slopes	
	mined	non-mined	mined	non-mined
No. of spp.	73.0 (±2.6)	81.1 (±2.4)	108.3 (±2.8)	97.2 (±2.6)
D	6.5 (±0.21)	6.7 (±0.20)	8.6 (±0.23)	7.9 (±0.21)
H′	3.1 (±0.11)	3.1 (±0.11)	3.0 (±0.12)	2.9 (±0.11)
J	0.73 (±0.02)	0.71 (±0.02)	0.64 (±0.03)	0.64 (±0.02)

dance and biomass of 13 species of baitfish and 12 species of herbivores on mined reef flats, non-mined reef flats, and on adjacent reef slopes. The biomass curve lies above the abundance curve on mined reef flats because moderate numbers (221) of intermediate sized herbivores (106 g) such as the surgeonfish *Ctenochaetus striatus* and the parrotfish *Scarus sordidus* predominate over relatively low numbers (53) of small sized (4 g) planktivorous fish. This situation is also reflected on non-mined reef flats, because they support larger populations of small planktivorous reef fish and intermediate sized benthic herbivores reach maximum abundance at these sites. This continues to tip the balance in favour of the k-dominance biomass curve. The abundance curve lies above the biomass curve on reef slopes because the fish community is dominated by large numbers of a few species of small planktivores and because the numbers of intermediate sized benthic herbivores are relatively low. Fourteen of the 20 species contributing most to the difference in numbers between non-mined reef flat and reef slope communities are small planktivores (see Table 4). These species, like the damselfish *Chromis ternatensis* and the basslet *Anthias squamipinnis,* depend on the reef for shelter and on a pelagic supply of food. In addition, the contribution from intermediate sized benthic herbivores is lower in both numbers and biomass on reef slopes than it is on non-mined reef flats and is much the same as on mined reef flats. Intermediate sized benthic herbivores are relatively more common on non-mined reef flats, perhaps because of higher benthic algal productivity. In summary, reef slopes are dominated by large numbers of relatively few species of small planktivores while intermediate sized benthic herbivores are relatively rare. Thus, the abundance *k*-dominance curve lies above the biomass curve. Intermediate sized benthic herbivores are relatively more common on non-mined reef flats than on slopes and the abundance of small planktivores is lower. The biomass curve, therefore, lies above the abundance curve. Coral mining selectively removes the habitat that provides shelter for small planktivores. Intermediate sized benthic herbivores are also reduced. The biomass curve continues to lie above the abundance curve on mined reef flats. We suggest that it is the difference in rugosity between the reef flats and slopes that is the overriding factor in determining the size distribution of the fish assemblages in these habitats. This disturbance will not give rise to an assemblage which is in an early successional stage as it does with in situ benthic invertebrate communities.

Reef slopes adjacent to mined reef flats support a higher biomass and abundance of reef fish than do reef slopes adjacent to non-mined reef flats. This is the opposite of what might be expected if reef-flat mining were to have a knock-on effect to nearby reef areas. The difference in abundance is primarily due to the higher incidence of planktivorous reef fish adjacent to mined reef flats. The difference in biomass is due to a combination of the higher incidence of planktivores and omnivores. Total number of species, species richness, evenness, and Shannon diversity, do not differ significantly. Three possible explanations of increased abundance and biomass might be (i) greater planktonic resources are available, with reduced competition from planktonic feeders on the reef flat at mined locations, (ii) the increase results from an

Table 9. Comparison of abundance and biomass between mined and non-mined reef flats and adjacent reef slopes for 13 species of baitfish (planktivores) and 12 species of benthic herbivores.

	Baitfish			Herbivore		
	Flat mined	Flat non-m	Slope	Flat mined	Flat non-m	Slope
Number	53	164	1005	221	676	213
Biomass (g)	220	1540	7790	23560	59560	18550
Mean weight (g)	4	9	8	106	88	87

influx of planktivores onto the reef edge from the mined reef flat where all cover has been removed, or (iii) the increase is due to some factor specific to the reef location in the southern part of North Malé atoll.

The methods generally employed to make management decisions regarding environmental impact, e.g. changes in number of species, species diversity etc., proved to be insensitive in this study, and in themselves would not have indicated any cause for concern. However, the multivariate methods of data analysis indicated very clear-cut effects of mining, even on the reef slopes adjacent to the mined sites. Such methods were just as sensitive when the data on species presence/absence, rather than quantitative data, were analysed. Having identified these changes in community composition, and the species mainly responsible for them, management decisions can be made according to the commercial and aesthetic value of these species.

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