2.2.3. CORAL

2.2.3.1. Introduction

A major goal of the NCWCD-JICA study was to provide detailed information on a sub-region of the central-northern Red Sea study region, to be of use in future Marine Protected Areas planning. In terms of coral communities, three sub-regions were of outstanding conservation value – the Gulf of Aqaba, the Tiran Area and Al-Wajh Bank (see preceding sections in 2.1.2 of the this Report).

Because of the wide range of habitat types, the presence of populations of endemic and endangered species, and its high priority for future MPA designation and management, and because of logistic considerations, Al-Wajh Bank was selected as the Model Area. Detailed rationale for selection of the Al-Wajh Bank was provided in the Interim Report and in other sections of the present report.

1. Model Area

Within Al-Wajh Bank, a cross-bank transect (Bank Transect Area) was selected for detailed study, incorporating the central and southern portion of Al-Wajh Bank, bordered by the geographic co-ordinates:

North - 25° 45.00' N,

South - 25° 20.00' S,

West - 36° 30.00' E,

East - 37° 00.00' E.

This transect extended from the mainland coast to barrier reefs west of the island of Jazirat Umm Rumah and south to Jazirat Shaybarah and Jazirat al-Waqqadi. The transect includes most major habitats in the central – northern Red Sea study region, supporting a wide variety of reef and soft bottom benthic types, algae and seagrass beds, important mangrove stands and dugong, dolphin, turtle, fish and bird populations (see other sections of this Report).

However, the Bank Transect Area did not include any major coastal sharms or offshore islands surrounded by deep waters. Inclusion of the latter habitats was considered essential to obtain a complete representation of habitat types, and thus the area from Sharm Habban to Sharm Muraybirah (N of Al-Wajh Bank), and reefs and islands south to Jabal Hassan (W of Umluj) were included as separate sub-areas of the Model Area (Fig. 42). The Model Area is affected to some degree by local human impact, supporting reef fisheries supplying the towns of Al-Wajh in the north and Umluj in the south (see Socio-economics section of this report). These towns provided suitable bases from which to conduct the Model Study, and also could provide suitable sites for future location of management facilities.

2. Objectives

The main objectives of the Model Study were to provide basic information for future MPA management planning, to initiate monitoring studies, and to develop survey and monitoring expertise among the NCWCD counterpart personnel. These objectives were achieved through assessment of the:

i. Distribution of coral habitats and reef development,

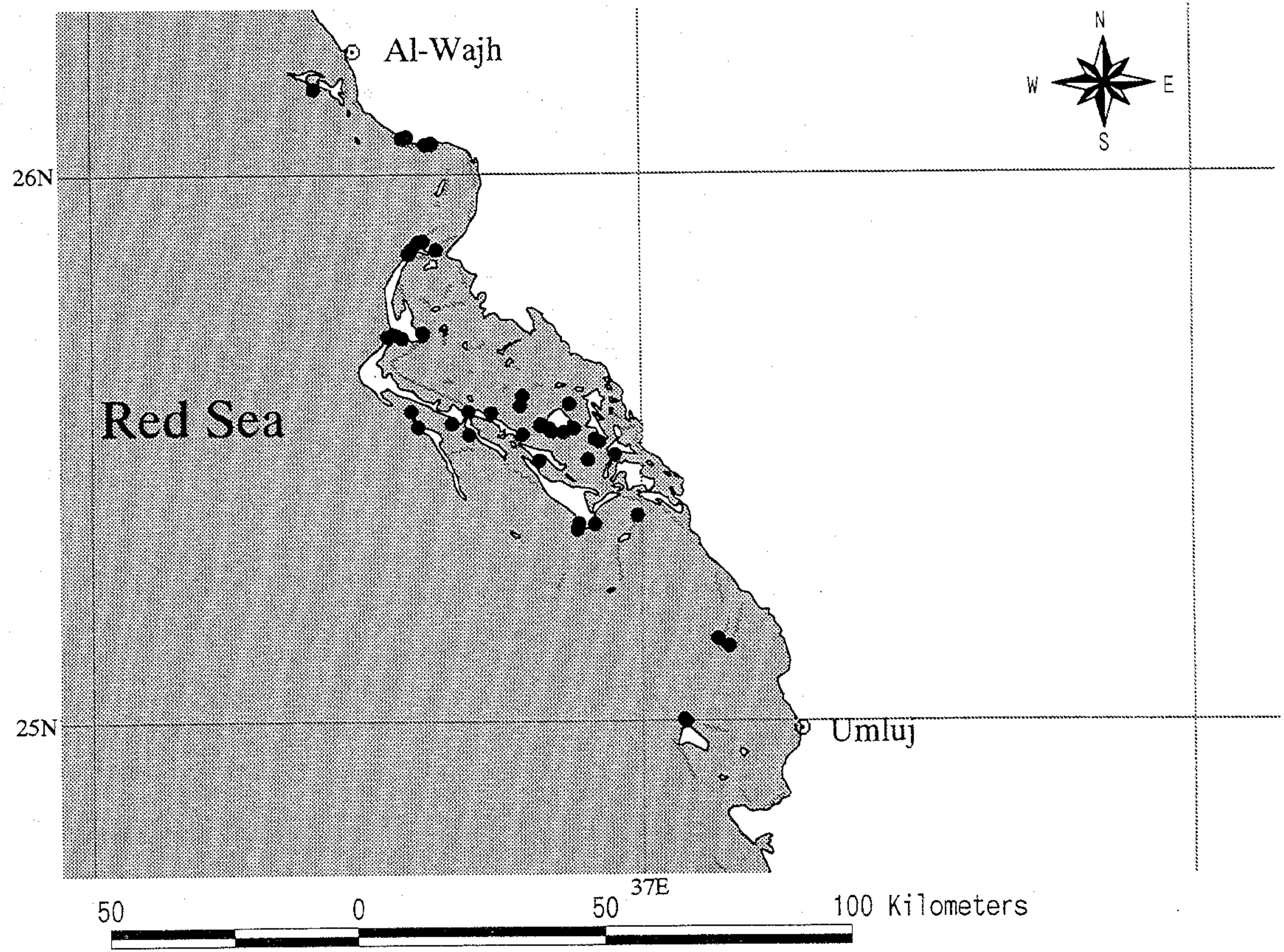
ii. levels of coral cover,

iii. species diversity and coral community types,

iv. present status – effects of natural disturbances and human impacts,

v. conservation value of individual sites and larger areas.

Fig. 42. Map of the Model Area showing appropriate locations of survey sites.



3. Management implications

Coral communities in the Model Area were assessed to indicate sites of special conservation value and management significance in terms of:

- representativeness of species and community types,
- uniqueness of species and community types, including presence of rare, endemic and previously undescribed species,
- maintenance and replenishment of these attributes in the future.

Thus, results from the Model Study should prove useful for future Marine Protected Areas planning by NCWCD, in accordance with the recommendations of CHILD & GRAINGER (1990):

> "Ideally the design of a representative system plan would require a specially prepared prior classification and inventory of natural biological communities".

2.2.3.2. Methods

1. Site selection and access

Within the Model Area, specific sites for detailed coral survey and monitoring were selected using the draft Habitat Maps. The sites were chosen to provide as representative a range of coral reef community types as practicable (Table 80, Fig. 42). Nearshore and mid-Bank survey sites were accessed using the NCWCD-JICA zodiac and NCWCD fibre-glass boat. Outer-Bank patch and barrier reefs were accessed in larger vessels provided by the Umluj and Al-Wajh coast-guard stations.

Table 80. Reef locations surveyed using Bio-inventory, Reef Check and/or GCRMN during Model Study, Al-Wajh Bank, February – June 1999, where: a - deep slope (> 8 m depth) and b - shallow slope (< 7 m depth). * G - Global Coral Reef Monitoring Network sites. Site Ap34a was a Crown-of-thorns Starfish collection site only.

Reef Check	Bio-Inventory	Reef-type	Reef name	Latitude			Longitude			Date
				deg.	min.	sec	deg.	min.	sec	
RC1a	53a, b	P	Mid-Bank	25	28	37	36	48	41	17/2/99
RC2a, b	54a, b	P	Outer Bank	25	34	6	36	34	49	18/2/98
RC3a	55a	P	Mid-Bank	25	35	49	36	46	55	20/2/99
RC4a	56a	P	Mid-Bank	25	34	41	36	46	38	20/2/99
RC5a, b	57a, b	B	J. Shaybarah	25	21	40	36	53	4	21/2/99
RC6a, b	58a, b	P	J. Shaybarah	25	21	38	36	54	47	21/2/99
RC7a	59a	P	SW J. Qumma'an	25	32	38	36	48	54	22/2/99
RC8a	60a	P	E J. Qumma'an	25	32	13	36	52	31	22/2/99
RC10a, b	61a, b	P	N J. Ummahat Shaykh	25	33	53	36	43	31	24/2/99
RC12a, b	62a, b	P	SW J. Ummahat Shaykh	25	31	33	36	46	56	24/2/99
RC13a, b	63a, b	SF	Sh. Habban outer	26	3	59	36	33	56	25/2/99
RC14b	64b	SF	Sh. Habban inner	26	4	8	36	34	28	25/2/99
RC15a	65a	P	NE of J. Qumma'an	25	34	55	36	52	3	27/2/99
RC16a	66a	P	SW J. Abu Lahij	25	31	2	36	54	48	27/2/99
RC18a, b	67a, b	P	W J. Qumma'an	25	32	11	36	49	52	2/3/99
RC19a	68a	P	E J. Qumma'an	25	31	49	36	51	25	2/3/99
RC21a, b	69a, b	B	J. Mizab	25	42	22	36	32	14	7/6/99
RC22 b	70b	P	J. Umm Rumah	25	42	47	36	36	08	7/6/99
RC23a, b	71a, b	B	Mid-Bank	25	32	19	36	35	33	8/6/99
RC24a, b	72a, b	P	Channel slope	25	34	04	36	41	03	8/6/99
RC25a, G1*	73a, b	P-B	Mid-bank slope, outside channel	25	31	31	36	41	06	9/6/99
RC26a	74a	P-B	Mid-bank slope, outside channel	25	32	44	36	39	13	10/6/99
RC27a, b	75a, b	B	N Jabal Hassan	25	00	15	37	04	23	13/6/99
RC28a, b	76a, b	B	N Jabal Hassan	25	00	07	37	04	34	13/6/99
RC29a, b	77a, b	P	S of Al-Wajh Bank	25	09	06	37	08	06	14/6/99
RC30b	78b	P	S of Al-Wajh Bank	25	08	14	37	09	19	14/6/99
G2*	79a	P	SW J. Qumma'an	25	32	31	36	48	53	15/6/99
G3*	80a	P	S J. Qumma'an	25	31	53	36	50	06	16/6/99
RC33a		P	E J. Qumma'an	25	32	11	36	52	22	16/6/99
Ap34a		P	J. Abu Lahij, SW	25	31	23	36	54	71	16/6/99
RC38a	81a	P	SW of J. Jusur Shurayrat	25	28	46	36	54	04	17/6/99
RC39a	82a	P	S of J. Jusur Shurayrat	25	29	17	36	57	00	17/6/99

2. Rationale for selection of field survey methods

2-1. Bio-inventory and ecological survey

The bio-inventory and ecological surveys of Phase II were continued during the Model Study (see section 2.1.2, and Table 80 and Appendix 5), as these methods provide the most detailed information for assessing conservation values of reefs, essential for informed MPA planning (DEVANTIER et al. 1998). At each site, the coral communities were surveyed using SCUBA.

2-2. Quantitative survey and monitoring

Worldwide, a great deal of effort has been devoted to development of coral reef monitoring methods and many quantitative methods have been developed over the past 30 years (see e.g. DEVANTIER & DONE 1995 and references cited therein). Presently, two major programmes are underway in the Indo-Pacific region:

- Reef Check,
- Global Coral Reef Monitoring Network (GCRMN).

One or both of these programmes are supported by most reef-bearing countries in the Indo-Pacific region. Thus the programmes have well-developed international networks for the sharing and dissemination of information. Data are collected annually from selected monitoring sites, and analysed using standard protocols developed by the two programmes.

Following detailed training of in-country field personnel, both programmes can provide reliable quantitative information on the status of coral communities, and because of their adoption by most countries in the region, allow regional and global comparisons of the levels of living and dead coral cover and changes through time.

The main quantitative method employed during the present study was the Reef Check protocol. Time and logistic constraints precluded the widespread use of GCRMN methods (DEVANTIER 1986, ENGLISH et al. 1997), which were limited to three 'demonstration sites' conducted in June 1999 (Table C1). The surveys were undertaken at a representative range of habitats, including mainland fringing reefs, sharms, island fringing reefs, offshore patch reefs and barrier reefs.

3. Bio-inventory and ecological survey

These surveys were conducted at most sites in the Model Area (Table 80). Two types of information were assimilated and recorded on water-proof data-sheets during ~ 40 min. survey swims: 1) a detailed inventory of sessile benthic taxa; and 2) an assessment of the relative percent cover of the substrate by the major benthic groups and amount of reef development (DONE 1982, SHEPPARD & SHEPPARD 1985, 1991, DEVANTIER et al. 1998).

3-1. Taxonomic inventories

A detailed inventory of benthic taxa was compiled during each survey swim. Taxa were identified *in situ* to the following levels:

hard corals

- species wherever possible, (VERON & PICHON 1976, 1980, 1982, VERON, PICHON & WIJSMAN-BEST 1977, VERON & WALLACE 1984, VERON 1986, 1993, SCHEER & PILLAI 1983, HOEKSEMA 1989, SHEPPARD & SHEPPARD 1991, SHEPPARD & JOHNSTONE 1997, WALLACE & WOLSTENHOLME 1998), otherwise genus and growth form (e.g. *Porites* spp. of massive growth-form). Hard corals that could not be readily identified in the field were labeled with a sequentially numbered tag, photographed (Nikonos V with 28 mm lens for colony morphology, and with close-up kit and strobe flash unit for corallite morphology), collected and bleached for detailed study. The bleached corals are stored as a permanent reference collection with the NCWCD. Specimens for which expert confirmation of identity was required were shipped for study by Dr. J.E.N. Veron (Australian Institute of Marine Science) and Dr. C.C. Wallace (for *Acropora* spp., Museum of Tropical Queensland). This facilitated comparison of specimens and photographs from the present collection with the most comprehensive compilations of extant Scleractinia to date. Corals for which taxonomic status remain unresolved at time of reporting are listed as '*genus cf. species*'.

soft corals, zoanthids, corallimorpharians and anemones

- genus whereever possible, otherwise family (VINE 1986, ALLEN & STEEN 1995, COLIN & ARNESON 1995, GOSLINGER et al. 1996, REINECKE 1998).

other sessile macro-benthos, such as sponges, ascidians and most algae

- higher taxonomic level, usually phylum plus growth-form (VINE 1986, ALLEN & STEEN 1995, COLIN & ARNESON 1995, GOSLINGER et al. 1996).

At the end of each swim, the inventory was reviewed, and each taxon was categorized in terms of its relative abundance in the community (Table 81). The categories reflect relative numbers of individuals in each taxon, rather than its contribution to benthic cover (DEVANTIER et al. 1998). These ordinal ranks are similar to those long employed in vegetation analysis (BARKMAN et al. 1964, BRAUN-BLANQUET 1964). For each coral taxon present, a visual estimate of the total amount of injury present on colonies at each site was made, in increments of 0.1, where 0 = no injury and 1 = all colonies in the site dead. The approximate proportion of colonies of each taxon in each of three size classes was also estimated. The size classes were 1 - 10 cm diameter, 11 - 50 cm diameter and > 50 cm diameter (Table 81).

Table 81. Categories of relative abundance, injury and sizes (maximum diameter) of each benthic taxon in the biological inventories.

Rank	Relative abundance	Injury – damage	Size frequency distribution
0	absent	0 - 1 in increments of 0.1	proportion of corals in each of 3 size classes: 1) 1 - 10 cm 2) 11 - 50 cm 3) > 50 cm
1	rare		
2	uncommon		
3	common		
4	abundant		
5	dominant		

3-2. Categorization of benthic cover and reef development

At completion of each swim, six ecological and six substratum attributes (Table 82) were assigned to 1 of 6 standard categories, based on an assessment integrated over the length of the swim. These broad categories have been shown to be relatively insensitive to biases among different observers (MILLER & DE'ATH 1995) and capable of discriminating among contrasting benthic assemblages (DONE 1982, DEVANTIER et al. 1998). The reef itself was also classified into one of four categories based on the amount of reef development (after HOPLEY 1982, HOPLEY et al. 1989, SHEPPARD & SHEPPARD 1991), where:

1) reefs with extensive reef flats (> 50m wide);

2) reefs with moderate flats (< 50m wide);

3) reefs with no flats but with some carbonate accretion (incipient reefs); and

4) coral communities developed on rock, sand or rubble.

The sites were also classified into one of four categories based on the degree of exposure to wave energy, where:

1) Sheltered;

2) Semi-sheltered;

3) Semi-exposed;

4) Exposed.

Sea temperatures were recorded in °C with a thermometer mounted on a SCUBA regulator (accuracy +/- 0.5 °C). The depths of the sites (maximum and minimum), average angle of reef slope to the horizontal, and underwater visibility were also recorded. The presence of any unique or outstanding biological features, such as particularly large corals or unusual community compositions, bleached corals (partial or total loss of pigments on living corals), coral predators, other cause(s) of coral mortality were also recorded.

Table 82. Categories of benthic attributes and % cover categories

Attribute		**% cover category**	
ecological:	**physical:**	**Rank**	**%**
Hard coral	Hard substrate	0)	Not recorded
Dead standing coral	Continuous pavement	1)	1 - 10 %
Soft coral	Large blocks (diam. > 1 m)	2)	11 - 30 %
Coralline algae	Small blocks (diam. < 1 m)	3)	31 - 50 %
Turf algae	Rubble	4)	51 - 75 %
Macro-algae	Sand	5)	76 – 100 %

All data were input to EXCEL for preliminary storage and analysis, and transferred to the NCWCD-JICA Study database and GIS for long-term storage.

4 Data Analysis

4-1. Site description

Principal components (Redundancy) analysis was used to illustrate relationships between benthic cover: hard coral, dead standing coral, coral rubble, soft corals, macro-algae, turf algae, coralline algae and sand (all as the rank scores) and the environmental variables: water clarity (underwater visibility, m), degree of exposure (1-4), slope angle and amount of reef development (1-4). Preliminary analysis of the remaining substratum site-descriptor variables (other than coral rubble and sand) did not prove useful and these were discarded.

4-2. Community types

Site groups defined by community type were generated by hierarchical cluster analysis using rank abundance of all coral taxa in the bio-inventories. The data were analyzed using the Euclidian metric and complete linkage, plotted using PCA, and the groups defined by K-means clustering were outlined. The 'community type' groups so produced were then plotted on the site descriptor PCA biplot to illustrate relationships between coral community types and the site descriptor variables.

The species that best characterized each community group (key indicator taxa) were determined, based on relative abundance and fidelity (percentage occurrence of sites in each group) using the method of DUFRENE & LEGENDRE (1997). Differences among the community groups in terms of their physical (reef development, exposure, depth) and ecological (benthic cover) attributes were examined using ANOVA.

4-3. Ecological and Biodiversity Indices

1). Rarity. The presence of rare species may afford some sites greater importance than others in terms of the conservation of regional biodiversity of corals. Two indices, *RI* and *VI*, to indicate the relative importance of rare versus common hard coral species was calculated for each site:

$$RI = \sum a_i / P_i$$

$$VI = \sum A_i / P_i$$

where a_i = 1 for the *i*th taxon present at a given site, A_i = abundance rank for the *i*th hard coral taxon at a given site (1-5, as in Table 81), and P_i = the proportion of all sites in which the taxon was present. The indices weight species on a continuum according to their frequency in the data set. *RI*, based on presence - absence of each taxon, takes no account of local abundance. The indices give highest values to sites which are least representative or most unusual faunistically (i.e. with taxa which are rare in the data set).

*2). **Coral replenishment.*** The presence of high species diversity, abundance and cover of corals may afford some sites greater importance than others in terms of their role as reproductive sources for replenishment of populations. Two coral indices, *CI* and *HCI*, which rate sites based on a combination of their coral cover and individual taxon rank abundance scores was calculated for each site:

$$CI = \sum A_i H_i / 100$$

where A_i = abundance rank for the *i*th coral taxon (all cnidarians) at a given site (1-5, as in Table 81), and H_i = sum of the rank values of hard and soft coral cover at the site (1-5, as in Table 82). The index give highest scores to sites which have high species abundance and cover of all corals.

$$HCI = \sum a_i h_i / 100$$

where a_i = abundance rank for the *i*th scleractinian coral taxon at a given site (1-5, as in Table 81), and h_i = rank of hard coral cover category at the site (1-5, as in Table 82). The index give highest scores to sites which have high species diversity, abundance and cover of hard corals.

All data analyses were conducted using S-PLUS ver. 3.3 (STATISTICAL SCIENCES 1995).

5. Reef Check

Quantitative assessment of the percentage cover of 8 categories of sessile benthos was made using four 20m line transects, laid parallel to the selected depth contour at 1 or 2 depths at each site. The depths surveyed were ~ 8-10 m and ~ 3-4 m below the reef crest. Surveys were conducted on SCUBA using a 100 m long transect tape laid tightly along the selected depth contour from a haphazardly selected starting point on the reef slope. The first 20 m transect started from the beginning of the tape. The second transect started after an interval of 5 m from the end of the first transect (i.e. 25 m) and similarly for the third and fourth transects. Deep transects were surveyed first, in accordance with safe diving practice. All transects were surveyed by the Coral team. Many of the survey sites were established concurrently with the Fish team. A total of 156 transects at 39 sites on 29 reefs were surveyed from February - June 1999.

The 8 categories of benthos recorded on the transects were:

- live hard coral (HC),
- dead coral (DC),
- soft coral (SC),
- fleshy macro-algae (MA),
- rock (RC),
- rubble (RB),
- sand (SD) and
- other sessile benthos (OT).

On each transect, a point sampling method was employed, whereby the benthic category (listed above) located under the transect tape at points of 50 cm interval was recorded as 1 of the 8 categories listed above. The results were recorded on waterproof data-sheets and input to an EXCEL spread-sheet for analysis of percent cover.

This method provides a rapid means of acquiring quantitative estimates of percent cover of the major structural components of coral reefs, without requiring detailed taxonomic knowledge. Detailed descriptions and photographs of the field and analytical protocols are found in HODGSON (in press).

6. Abundance of Crown-of-thorns Starfish

The abundance of coral predatory Crown-of-thorns Starfish (*Acanthaster planci* (LINNEAUS 1758)) were assessed in areas of approximately 500 m^2 at each site and depth. During the survey swims, specimens of *A. planci* were counted, their size (aboral diameter - cm) and levels of injury (missing / regenerating arms) were recorded. The counts are underestimates of the actual abundance of *A. planci* in the sites, as starfish usually remain cryptic during daylight. Nonetheless, the abundance estimates provided a standard means for comparison of population levels among sites.

7. Coral and starfish genetic studies

During the June 1999 field period, samples of selected corals *Pocillopora damicornis* (LINNEAUS 1758) , *Acropora hemprichi* (EHRENBERG 1834) and *Acropora austera* (DANA 1846) and of the Crown-of-thorns Starfish *Acanthaster planci* (LINNEAUS 1758) were collected for genetic analysis. These studies were undertaken to improve understanding of genetic connectivity of populations of reef species within the study region and with those of the greater Indian Ocean and Indo-Pacific regions, crucial for informed management decision-making.

Small 'nubbins' (finger-sized samples) were collected from the tips of coral colonies at selected sites (Table 83). These were labeled with site details and stored in sealed plastic bags in liquid Nitrogen for genetic analyses. For *Acanthaster planci*, small samples (~ 2 cm^3) of the digestive organ (pyloric caeca) were removed, labeled and stored in sealed plastic bags in liquid nitrogen for genetic analysis.

The genetic samples were forwarded to Dr. J. Benzie of the Australian Institute of Marine Science for genetic analysis. Backlogs of samples from other regions have delayed analysis of the Red Sea samples. However, the results of all analyses will be forwarded to NCWCD and JICA as they are conducted, in accordance with the 'Understanding on the specimens collected during the study'.

Table 83. Details of sampling for genetic analyses. For location of sites, see Table 80.

Site	**Bio-inventory**	***Pocillopora damicornis***	***Acropora hemprichi***	***Acropora austera***	***Acanthaster planci***	***Date***
RC27a, b	C75	13 nubbins	15 nubbins	2 nubbins		13/6/99
RC28a, b	C76	36 nubbins	15 nubbins			13/6/99
RC29a, b	C77	21 nubbins	27 nubbins	21 nubbins		14/6/99
RC30b	C78				1 sample	14/6/99
G2	C79				11 samples	15/6/99
RC33a	C80				1 sample	16/6/99
34a	Near C66				5 samples	16/6/99
RC38a	C81				23 samples	17/6/99
	C83	5 nubbins	19 nubbins	31 nubbins		21/6/99
	C84	33 nubbins	34 nubbins	26 nubbins		21/6/99
	Near C28	30 nubbins	21 nubbins	29 nubbins		22/6/99
	C86	20 nubbins	20 nubbins	20 nubbins		23/6/99

2.2.3.3. Results

1. Reef types and levels of reef development

Al-Wajh Bank and adjacent coastline supports all major reef types present in the northern-central Red Sea, including mainland and island fringing reefs, patch reefs and barrier reefs. The Bank has one of the longest near-continuous barrier reef systems of the Red Sea, stretching for ~ 100 km along the outer edge of the Bank, and broken only by several narrow

(< 200 m width) channels (see Habitat Map section of this report). The Bank also supports a large number of patch reefs, some little more that scattered coral colonies developed on sand, others with substantial reef flats and sand islands, covering several km^2. Thus, levels of reef development ranged widely within Al-Wajh Bank (Appendix 6), from the small, sub-surface (incipient) reef patches, through reefs with moderately developed reef flats (< 50 m width) to well developed reefs with wide flats (> 50 m).

2. Coral cover - Reef Check

Cover of living hard corals in the Model area ranged between ~ 15 % and 65 %, with an average of 42 % (s.e. 1.4 %). Highest cover of hard corals (> 60 %) occurred on mid-Bank patch reefs at sites RC10a, RC12b and RC22b, and on the shallow slopes of outer barrier reefs at sites RC21b and RC23b (Fig. 43). Cover of soft corals was usually less than cover of hard corals, ranging between 0 % and 38 %, with an average of 12 % (s.e. ~ 1 %).

Highest cover of soft corals (> 30 %) occurred at on mid-Bank patch reefs at sites RC6a, 10a and 25a (Fig. 44). Cover of dead corals also was usually less than that of live hard or soft corals, ranging between 0 % and 29 %, with an average of 8 % (s.e. < 1 %). Highest cover of dead corals (> 20 %) occurred on mid-Bank patch reefs at sites RC4a, 7a and 18a, b (Fig. 45). High cover of dead corals was caused by predation by *Acanthaster planci* (LINNEAUS 1758), particularly on patch reefs in the central area of the S. Al-Wajh Bank in the vicinity of J. Qumma'an.

If logistically feasible, it is strongly recommended that NCWCD initiate the annual resurvey of these sites or a representative sub-set thereof, to form the basis of a long-term coral reef monitoring programme for Al-Wajh Bank.

Relations among benthic cover of corals and algae with the environmental variables of exposure, water clarity and depth, and the amount of reef development are displayed in Fig.

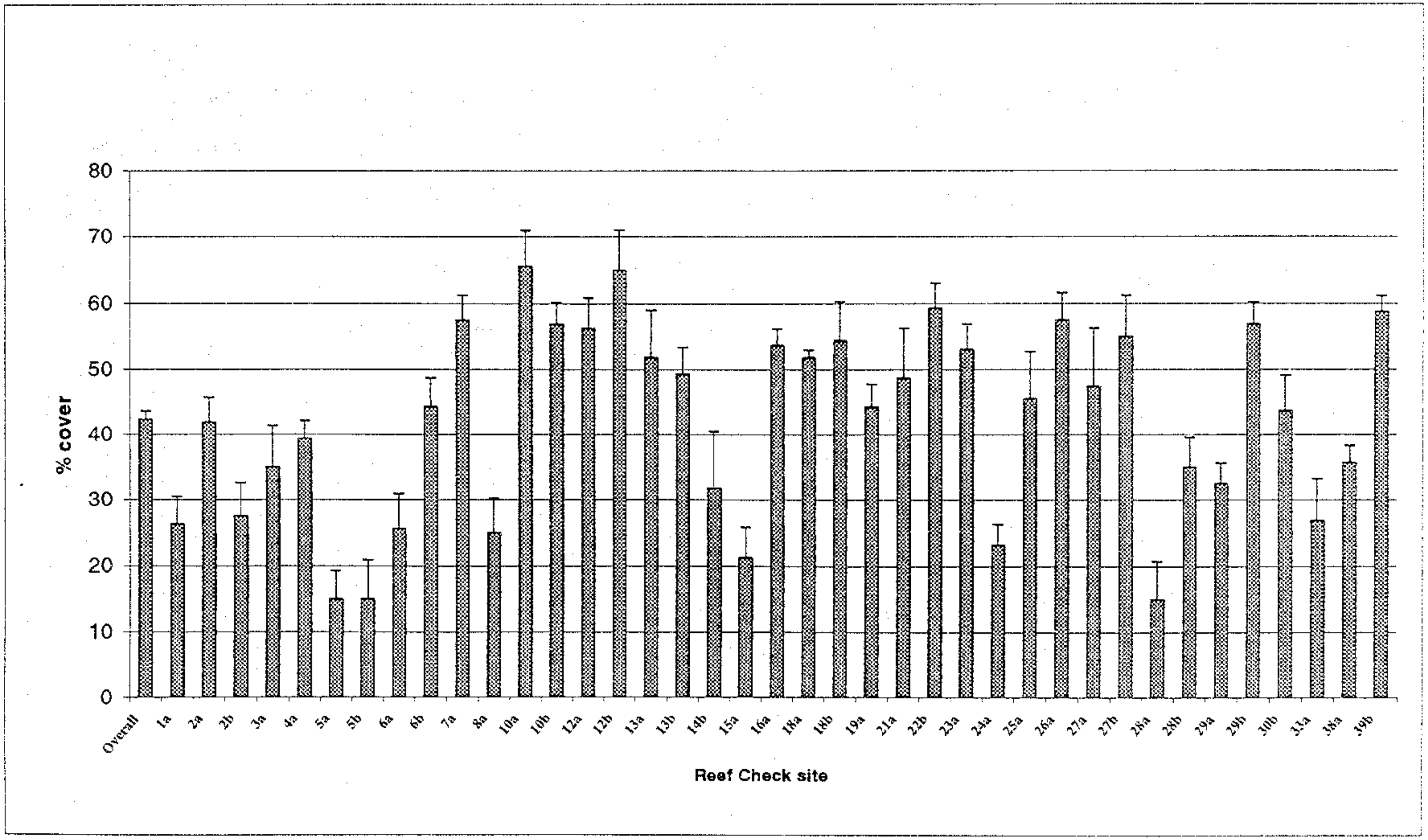


Fig. 43. % cover of hard corals (+ 1s.e.), Model Area, 1999.

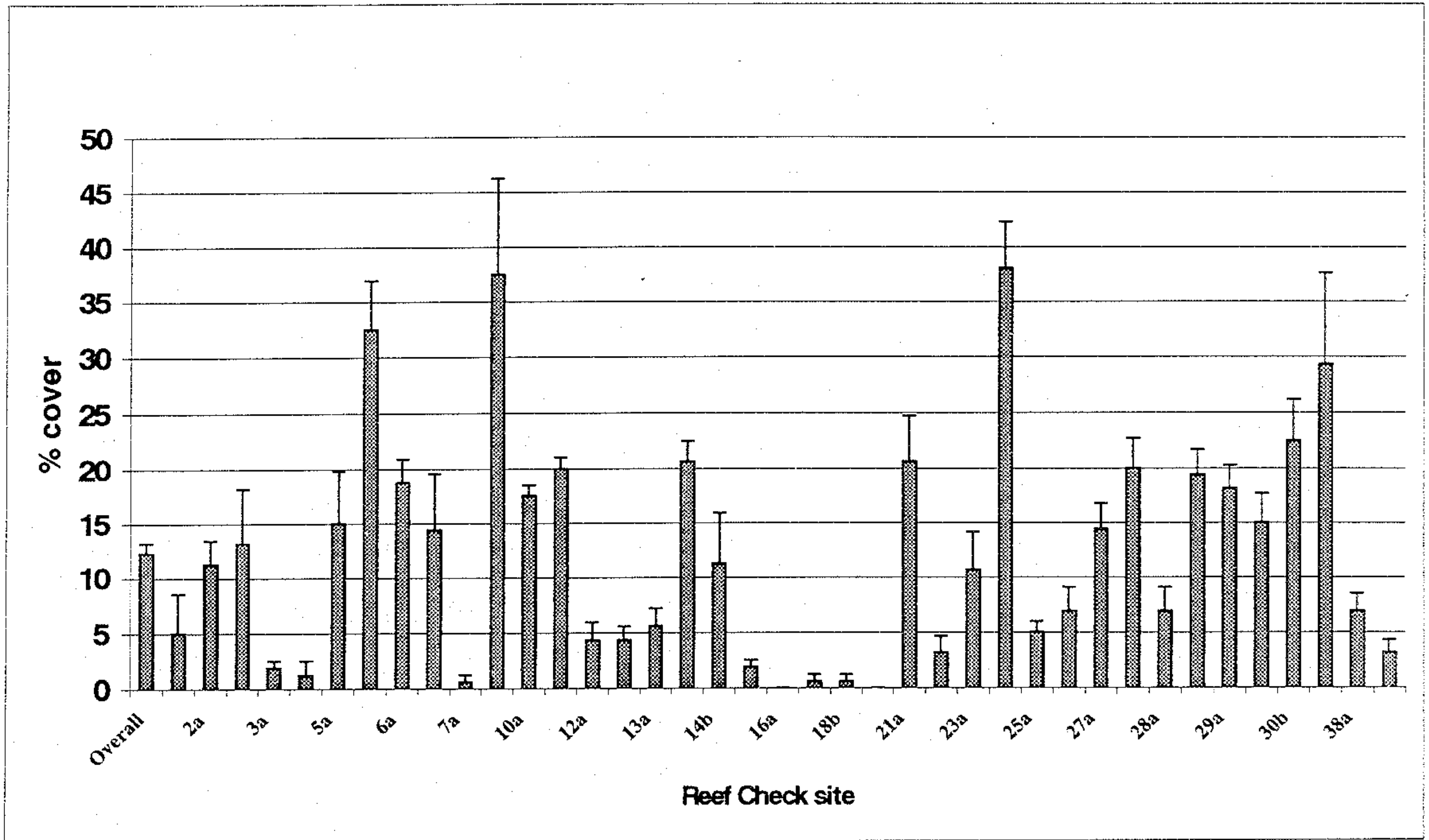


Fig. 44. % cover of soft corals (+ 1s.e.), Model Area, 1999.

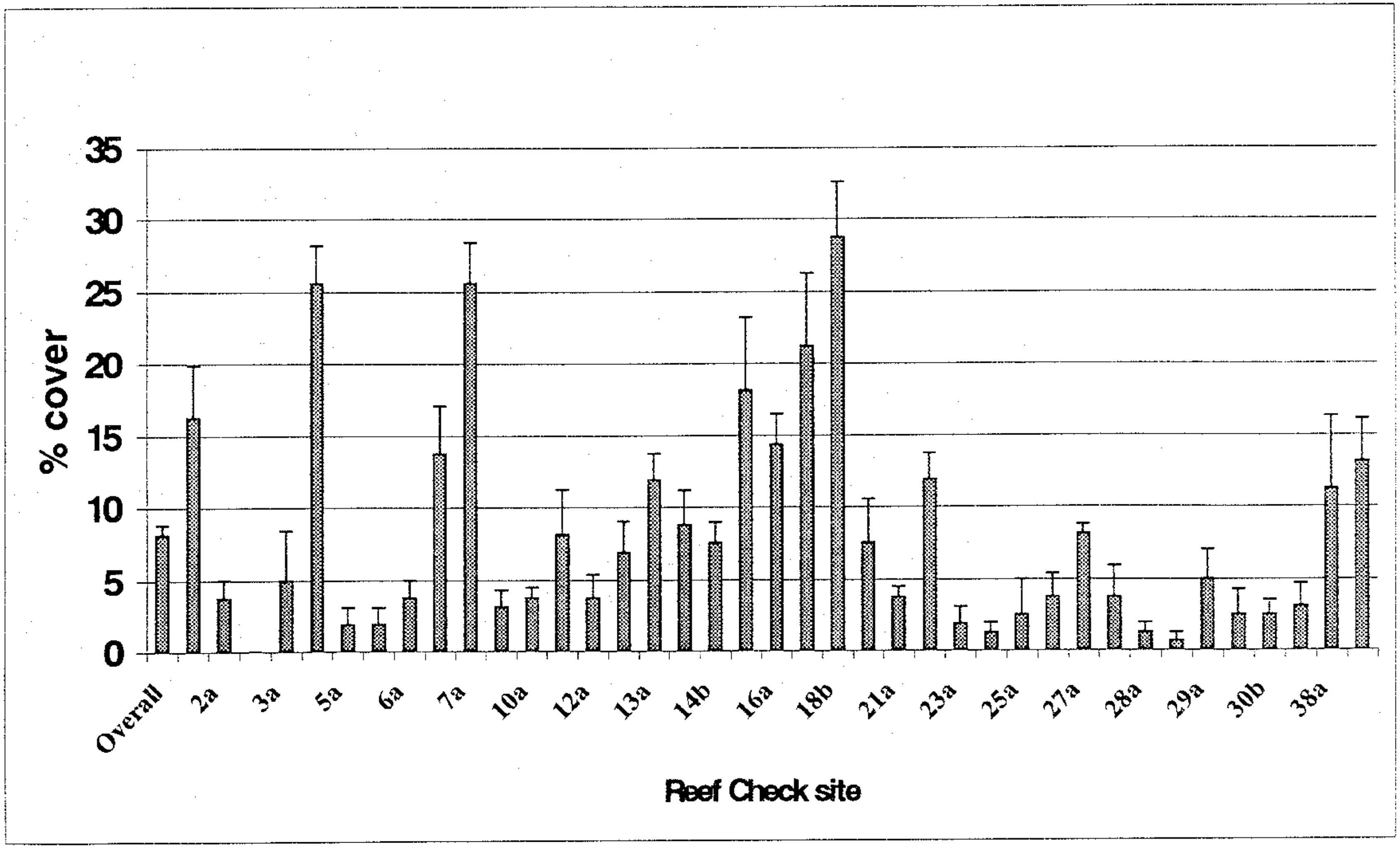


Fig. 45. % cover of dead corals (+ 1s.e.), Model Area, 1999.

46. There were strong associations between high levels of hard coral cover, high water clarity (visibility) and high levels of physical exposure to waves. There were strong associations between high levels of dead coral and algal cover, and there were strong associations between high levels of soft coral cover and steepness of reef slopes (Fig. 46).

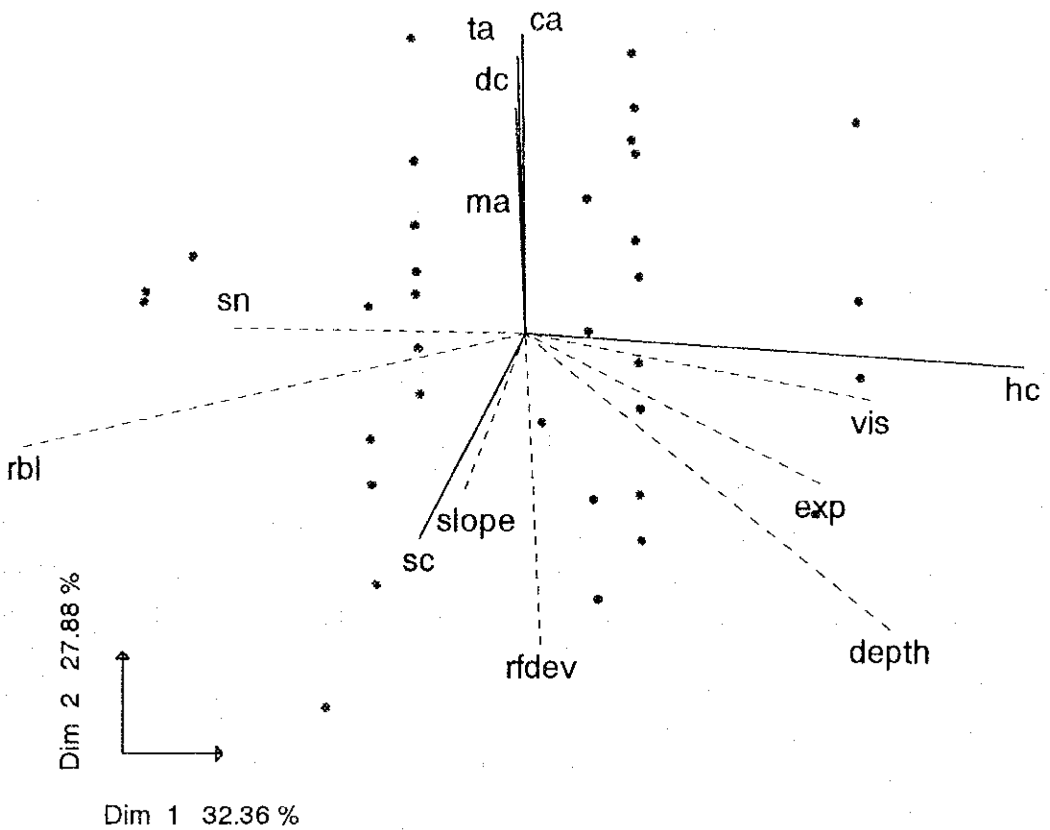
3. Coral species diversity

As with the entire study region (see Section 2.1.2.3.5), coral communities of Al-Wajh Bank were composed of a mix of species with different geographic distribution ranges:

- Widespread across the entire Indo-Pacific - e.g. *Pocillopora damicornis* (LINNEAUS 1758), *Gardineroseris planulata* (DANA 1846),
- Widespread in the Indo-west Pacific - e.g. *Stylophora pistillata* (ESPER 1797), *Acropora muricata* (LAMARCK 1816),
- Widespread in the Indian Ocean - e.g. *Coscinaraea monile* (FORSKAL 1775), *Siderastrea savignyana* MILNE EDWARDS & HAIME (1850),
- Widespread in the western Indian Ocean - e.g. *Acropora hemprichi* (EHRENBERG 1834),
- Red Sea 'endemics' - e.g. *Stylophora wellsi* SCHEER (1964), *S. mamillata* SCHEER & PILLAI (1983), *Symphyllia erythraea* (KLUNZINGER 1879), *Echinopora forskaliana* (MILNE EDWARDS & HAIME 1850), *Merulina scheeri* Head (1983), *Cantharellus doerderleini* (VON MARENZELLER 1907),
- Presently undescribed (e.g. *Montipora sp. nov., Anacropora sp. nov., Goniopora sp. nov., Cyphastrea sp. nov., Echinopora spp. nov.*).

Some reefs within Al-Wajh Bank were among the most diverse of the entire study region (Table 84), supporting most of the known Red Sea endemic corals and also presently

Fig. 46. Redundancy analysis biplot of relationship between cover and environmental variables in the Model Area, 1999. Dimensions 1 and 2 account for ~ 60 % of the observed variance. The vectors point in the direction of the highest scores for the indicated variables, where hc - hard coral, dc - dead coral, sc - soft coral, ta - turf algae, ca - coralline algae, ma - macro-algae, rbl – rubble, sn – sand, exp - exposure, vis - water clarity, rfdev - reef development.



undescribed species (Table 85).

Table 84. Sites in the Model Area with highest hard coral diversity (> 75 spp.), 1999. J. – Jazirat (island), Sh. – Sharm (coastal inlet), a - deep slope, b - shallow slope. Reef types: MF - mainland fringing, IF - island fringing, SF - Sharm fringing, P - patch, B - Barrier. GPS locations of sites are listed in Table C1. Rank scores for hard coral cover (HC) and ratings for reef development and exposure are also listed.

Site No.	Reef name	Reef type	HC cover	Reef devel.	Expo-sure
C74a	W of J. Qumma'an	B	3	2	2
C78b	N of Umluj	P	4	4	2
C77a	Nof Umluj	P	4	2	3
C63a	Sh. Habban	SF	2	4	2
C73a	W of J. Qumma'an	B-P	3	4	1
C58a	J. Shaybarah	P	2	4	2
C73b	W of J. Qumma'an	B-P	2	4	3

Table 85. Sites in the Model Area supporting undescribed species of Scleractinia, where *An. sp.* - *Anacropora sp. nov.*, *Go. sp.* - *Goniopora sp. nov.*, *Cy. sp.* - *Cyphastrea sp. nov.* (Family Faviidae), *Ec. sp. 1* - *Echinopora sp. nov. 1*, *Ec. sp. 2* -*Echinopora sp. nov. 2*. Rank abundance score (1-5, Table C2) of each species in each site is given. GPS locations of sites are listed in Table C1.

Site	Reef type	Reef name	*An. sp.*	*Go. sp.*	*Cy. sp.*	*Ec. Sp.1*	*Ec. Sp.2*
C49a	P	S. of J. Shaybarah			1		
C62a	P	J. Ummahat Shaykh	2				
C67a	P	W J. Qumma'an	1				
C70b	P	J. Umm Rumah				1	
C73b	P-B	W of J.				1	
C74a	P-B	W of J.		1			
C77b	P	N of Umluj			1		
C78b	P	N of Umluj			1		
C79a	P	SW J. Qumma'an				1	
C82b	P	S of J. Juzur Shurayrat					1

4. Coral communities

As with the study region generally, there was a high degree of homogeneity in species composition within the Model Area, with most sites supporting a subset of the same species-pool (see also SHEPPARD & SHEPPARD 1985, 1991). There were however, major differences in abundance of particular taxa in certain biotopes, and thus clear zonation patterns in the structure of coral communities. These were related largely to degree of physical exposure, water clarity-irradiance, depth and steepness of reef slope (also see DONE 1982, SHEPPARD 1983). Because of the wide variety of reef types, and differences in levels of exposure and water clarity characteristic of Al-Wajh Bank, reefs in the Model Area supported the four major coral community types found in the overall study region (Communities A - D, see Fig. 13 in Section 2.1.2.3.5 of this report). The community types form part of a continuum, with particular species exhibiting differences in occurrence and abundance related to site-specific habitat characteristics and disturbance-histories.

4-1. Exposed - semi-exposed biotopes

1). Community A, characteristic of mid - lower reef slopes

Mid - lower slope communities were composed of mixed assemblages of encrusting and massive taxa (faviids, agariciids, siderastreids, pectiniids, poritids, merulinids and acroporids – notably:

- Encrusting *Stylophora mamillata* SCHEER & PILLAI (1983), and *Montipora* spp. and 'tree-like' to open tabular colonies of *Acropora,* mostly *Acropora pharaonis* (EDWARDS & HAIME 1860), *A. clathrata* (BROOK 1891) and *A. downingi* WALLACE (1999).
- Soft corals, notably xeniids, gorgonions, antipatharian 'black corals' and 'sea whips' also occurred.

Vertical to overhanging sections and occasional caves were dominated by encrusting corals, notably

- agariciids *Gardineroseris planulata* (DANA 1846), *Pachyseris speciosa* (DANA 1846) *Leptoseris mycetoceroides* WELLS (1954), *L. hawaiiensis* VAUGHAN (1907), *Pavona varians* VERRILL (1864) and *P. explanulata* (LAMARCK 1816),
- faviids *Echinopora lamellosa* (ESPER 1795),
- pectiniids *Echinophyllia aspera* (ELLIS & SOLANDER 1786), *Oxypora lacera* (VERRILL 1864) and *O. crassispinosa* NEMENZO (1980),
- siderastreids *Coscinaraea monile* (FORSKAL 1775) and *Psammocora haimeana* MILNE EWDWARDS & HAIME (1851),
- and merulinids *Hydnophora exesa* (PALLAS 1766).

The agariciids, adapted to low levels of irradiance, more commonly occur on deeper reef slopes, but also occupy shallower areas where topographic steepness provides habitats of low irradiance.

Growing commonly on less-steep substrates:

- branching and tabular *Acropora* spp., including *Acropora hemprichi* (EHRENBERG 1834), *A. valida* (DANA 1846) and *A. eurystoma* (KLUNZINGER 1879),
- massive poritids (*Porites* spp.) and faviids (*Favia* and *Favites* spp.),
- and the alcyonarian soft corals *Xenia* spp. and large 'tree-like' colonies of *Sinularia* sp. The latter species was a major reef-builder at some sites, forming large (~ 2 m high) pillar like colonies covering 10's of m along the slopes.

Coral cover was usually moderate, mostly ranging between 20 and 50 % (average ~

25 %). Mid - lower slopes receive no direct wave energy and also lower levels of irradiance, in comparison with the shallower biotopes. Thus, differences between deep communities at exposed sites and those of more sheltered locations were less marked than their shallow counterparts. Key indicator coral species include *Montipora danae* (MILNE EDWARDS & HAIME 1851), *Fungia* spp., *Astreopora myriophthalma* (LAMARCK 1816) and *A. gracilis* BERNARD (1896), *Pachyseris speciosa* (DANA 1846), *Stylocoeniella guentheri* BASSETT-SMITH (1890) and *Leptoseris mycetoseroides* WELLS (1954).

2). Community B, characteristic of reef crests – upper reef slopes

Coral communities of exposed reef crests were dominated by stout taxa of low growth-form, adapted to high wave energy environments:

- digitate-branching acroporids notably *Acropora humilis* (DANA 1846), *A. digitifera* (DANA 1846), *A. gemmifera* (BROOK 1892), *A. lutkeni* CROSSLAND (1952), *A. acuminata* (VERRILL 1864), *A. polystoma* (BROOK 1891) and *A. secale* (STUDER 1878),
- pocilloporids *Stylophora wellsi* SCHEER (1964), *S. pistillata* (ESPER 1797), *Pocillopora verrucosa* (ELLIS & SOLANDER 1786),
- encrusting – massive faviids *Favia stelligera* (DANA 1846), *Favites pentagona* (ESPER 1794), *Echinopora gemmacea* (LAMARCK 1816) and *Leptoria phrygia* (ELLIS & SOLANDER 1786)
- and merulinids *Hydnophora microconos* (LAMARCK 1816).

Because of minimal tidal exchange (< 1 m), and shallowness of the crests, rich coral assemblages were generally limited to the outer 5 – 10 m of reef crest and reef flat. Further inshore, corals tended to become both less species-rich and more sparse, as turf and short macro-algae predominated (see Algae - Seagrass section of the Report).

These communities are physically-structured by wind-driven waves (generally from the north-west and < two m in height) and episodic exposure during 'catastrophic' low tides (e.g. FISHELSON 1973), and are also most-affected by changes in irradiance and sea surface temperature that can induce coral bleaching and death. Water clarity is generally high, with underwater visibility of 30 – 40 m not uncommon.

Slightly deeper (~2 – 6 m depth) on exposed - semi-exposed reefs, assemblages were dominated by:

- fire corals (*Millepora* spp.),
- by tabular and branching species of *Acropora cytherea* (DANA 1846), *A. cf. hyacinthus* (DANA 1846), *A. muricata* (LAMARCK 1816), *A. hemprichi* (EHRENBERG 1834), *A. eurystoma* (KLUNZINGER 1879) and *A. valida* (DANA 1846),
- branched pocilloporids,
- massive faviids (*Goniastrea*, *Favia*, *Favites* and *Platygyra* spp.) and poritids (*Porites* spp.).

In areas of moderate exposure, these assemblages occurred on the reef crest, interspersed with or replacing the former high-exposure taxa.

Coral cover was usually moderate to high, ranging between ~ 30 and 75 % (mean ~ 55 %). Key indicator species include *Acropora gemmifera* (BROOK 1892), *Leptoria phrygia* (ELLIS & SOLANDER 1786), *Hydnophora microconos* (LAMARCK 1816), *Stylophora wellsi* SCHEER (1964), *Favia stelligera* (DANA 1846), *Favites pentagona* (ESPER 1794), *Pocillopora verrucosa* (ELLIS & SOLANDER 1786) and *Millepora* spp.

4-2. Sheltered biotopes

Community C, characteristic of turbid areas

Coral communities of sheltered biotopes were commonly developed on the sides and tops of submerged patch reefs, and in lagoons behind barrier reefs. These communities experience little wave energy (< 0.5 m) although the resuspension of fine sandy – silty sediments can reduce water clarity in shallow locations. Often, the depth range of these communities was restricted by shallow waters and turbidity to < 15 m depth. The sides of these reef patches commonly supported coral taxa characteristically occurring in deeper assemblages in waters of greater clarity further offshore.

These communities were composed of mixed assemblages:

- digitate, encrusting, branching and tabular acroporids *Acropora, Montipora* and *Astreopora* spp.,
- encrusting and massive faviids (*Favia* and *Favites* spp., *Erythrastrea flabellata* PICHON, SCHEER & PILLAI (1983), *Echinopora* spp.), agariciids (*Pavona* spp.), poritids (*Porites, Goniopora* and *Alveopora* spp.) and mussids (*Lobophyllia* spp.),
- encrusting pectiniids (*Echinophyllia* and *Mycedium* spp.), oculinids *Galaxea fascicularis* (LINNEAUS 1767), 'mushroom' fungiids (*Fungia* and *Cantharellus* spp.) and soft corals (*Xenia, Sarcophyton, Paraerthropodium* and *Sinularia* spp).

Key indicator species include *Montipora* spp., *Pavona decussata* (DANA 1846), *Fungia concinna* VERRILL, 1864, *Cantharellus noumeae* HOEKSEMA & BEST (1984), *Echinopora fruticulosa* KLUNZINGER (1879) and *E. forskaliana* (MILNE EDWARDS & HAIME 1850), *Platygyra lamellina* (EHRENBERG 1834) and *Acropora* spp. Coral cover was usually low to moderate (average ~ 25 %).

4-3. Biotopes of moderate exposure

Community type D, characteristic of reef 'cusps'

This community occurred in a wide range of habitats and depth ranges, but was commonest on moderately-exposed reef corners ('cusps'). This community had relatively low fidelity among indicator taxa. Key indicator species include:

- branching-table colonies of *Acropora pharaonis* (MILNE EDWARDS & HAIME 1850),
- massive colonies of the faviids *Oulophyllia crispa* (LAMARCK 1816), *Favia rotundata* VERON et al. (1977), *Diploastrea heliopora* (LAMARCK 1816) and *Barabattoia amicorum* (MILNE EDWARDS & HAIME 1850),
- and mushroom fungiids *Ctenactis echinata* (PALLAS 1766).

The distribution of each site in the community type groups is listed in Appendix 6. Communities A and B commonly occurred on outer barrier reefs, while Communities C and D were prevalent in more sheltered biotopes inside Al-Wajh Bank, particularly on patch reefs, and in lagoons behind barrier reefs. Thus, there were major differences among the four coral community types in terms of the distribution of sites at different depths and exposures, and in terms of the levels of reef development and species diversity.

- Community type A occurred commonly on mid – deep slopes of well developed reefs in waters of moderate to high clarity, notably on outer barrier reefs. Because of their depth, these sites had low - moderate levels of physical exposure. These communities were on average the most species rich, with moderate levels of coral and algal cover.
- Community type B occurred mostly in shallow sites of well developed reefs subject to high exposure, notably on the exposed seaward slopes of the outer barrier reefs. These communities had highest average cover of living hard corals and algae, and

were on average the second-most species rich after Community A.

- Community type C was more commonly found on mid-Bank patch reefs of relatively low exposure and high turbidity (moderate to low water clarity - visibility). These communities had highest average levels of dead coral cover and lowest average coral species diversity (probably related to predation by Crown-of-thorns Starfish).
- Community type D occurred commonly in both shallow and deep sites, on well-developed reefs of moderate exposure. This community type had lowest average cover of living hard corals and highest average cover of soft corals.

5. Present status - disturbances

Reefs in the Model Area had some of the highest levels of dead coral cover and injury to coral species in the entire study region (Tables 86, 87), mostly related to ongoing predation by Crown-of-thorns Starfish *Acanthaster planci*.

Table 86. Sites in the Model Area with highest proportion of species that exhibited injury and the average level of injury per species at those sites, 1999. Probable cause(s) of injury are also listed, where predation - p, bleaching - b, sedimentation - s,unknown - u. Reef types: SF - Sharm Fringing, P - Patch, B - Barrier. GPS locations of sites are listed in Table 80.

Site No.	Reef name	Reef type	Prop. spp. injured	Ave. injury per sp.	Cause
C81a	SW of J. Juzur Shurayrat	P	0.58	0.29	p
C59a	SW J. Qumma'an	P	0.57	0.50	p
C66a	SW J. Abu Lahij	P	0.50	0.25	p
C53a	N of J. Qumma'an	P	0.47	0.22	p
C55a	NW of J. Qumma'an	P	0.45	0.15	p
C68a	S. J.Qumma'an	P	0.44	0.33	p
C79a	SW J. Qumma'an	P	0.44	0.31	p
C60a	SE J. Qumma'an	P	0.38	0.16	p
C56a	NW of J. Qumma'an	P	0.33	0.29	p
C7b	S of Sh. Habban	SF	0.32	0.33	s
C1a	Sh. Al-Muraybirah	SF	0.31	0.21	s
C53b	N of J. Qumma'an	P	0.29	0.16	p
C4b	J. Shawyk Murbat	P	0.28	0.13	s
C69b	J. Mizab	B	0.27	0.19	u
C1b	Sh. Al-Muraybirah	SF	0.27	0.12	s
C6b	S of Sh. Habban	SF	0.26	0.22	u
C67a	W J. Qumma'an	P	0.26	0.26	p
C57b	W of J. Shaybarah	B	0.25	0.16	u

Table 87. Sites in the Model Area with highest average level of injury per species and proportion of species with injury at those sites. Probable cause(s) of injury are also listed, where predation - p, bleaching - b, sedimentation -s, unknown - u. Reef types: MF - Mainland Fringing, IF - Island Fringing, SF - Sharm Fringing, P - Patch, B - Barrier. GPS locations of sites are listed in Table 80.

Site No.	Reef name	Reef type	Ave. injury per sp.	Prop. spp. injured	Cause
C59a	SW J. Qumma'an	P	0.5	0.57	p
C14b	J. Jabal Hassan	IF	0.4	0.06	-
C68a	S. J.Qumma'an	P	0.33	0.44	p
C7b	S of Sh. Habban	SF	0.33	0.32	s
C65a	NE of J. Qumma'an	P	0.32	0.23	p
C79a	SW J. Qumma'an	P	0.31	0.44	p
C9b	N. Al-Wajh Bank	B	0.3	0.02	s
C56a	NW of J. Qumma'an	P	0.29	0.33	p
C81a	SW of J. Juzur Shurayrat	P	0.29	0.58	p
C67a	W J. Qumma'an	P	0.26	0.26	p
C48b	J. Malihah, Jabal Hassan	P	0.26	0.13	u
C66a	SW J. Abu Lahij	P	0.25	0.5	p

5-1. Coral predation

Predation had caused loss of living hard coral cover and shifts in coral community structure and relative abundance at most patch reef sites, through starfish feeding preferences for particular prey species of corals. Censused specimens of *A. planci* were mostly 15 - 30 cm diameter (Table 88). The average diameter was 22.9 cm (s.e. < 1 cm), with a median of 24.5 cm and mode of 26 cm. Given that specimens of *A. planci* can attain diameters of > 70 cm, most starfish present on Al-Wajh Bank were small. When small, the starfish tend to remain cryptic during the day, and thus are not easily censused. The large amount of dead coral and number of recent feeding scars (white circular areas of dead coral) at some sites suggest that 'incipient outbreak' populations of *A. planci* are present, with densities likely to be of the order of > 100 starfish ha^{-1}. Their small size notwithstanding, most animals were gravid (Table 88), developing gametes for spawning, probably during the summer months.

Table 88. *Acanthaster planci* in Al-Wajh Bank, 1999. Site details in Table 80.

Site No.	Diameter	Injury	Gravid
RC30b	28	-	y
	30	-	y
GCRMN2	20	-	y
	19	-	y
	18	-	y
	26	2 arms	y
	26	-	y
	12	3 arms	n
	18	-	y
	28	-	y
	17	-	n
	17	-	n
	23	-	y
RC33a	19	-	y
34a	24	-	y
	27	-	y
	27	-	y
	26	-	y
	17	-	n
RC38a	23	1 arm	y
	17	-	y
	27	2 arms	y
	26	1 arm	y
	28	-	y
	26	-	y
	26	-	y
	25	-	y
	28	-	y
	27	-	y
	18	-	y
	25	-	y
	30	1 arm	y
	19	-	y
	25	-	y
	19	-	y
	18	-	y
	30	-	y
	20	-	y
	26	-	y
	20	1 arm	y
	22	-	y
	16	2 arms	n

5-2. Coral Bleaching

Most sites in Al-Wajh Bank Model Area had been little affected by bleaching, probably related to the submerged nature of many of the patch reefs (> 5 m depth) and likely influx of cool waters onto the barrier reef system. Limited evidence of recent bleaching was apparent at some shallower sites, notably RC23b, an outer barrier reef crest, and also S of Al-Wajh Bank, on reefs off Jazirat Jabal Hassan (RC26, 27), probably linked to high sea surface temperatures in September 1998.

6. Biodiversity and replenishment

Despite the impact of disturbance, sites in Al-Wajh Bank were among the highest scoring of all reefs in the central-northern Red Sea study region in terms of their importance as reservoirs of biodiversity and potential in replenishment of populations (Tables 89, 90). These reefs should be considered as high priority for future conservation management.

Table 89. Sites of special importance in terms of species uncommon or rare in the Model Area (RI, VI). Community types are also listed. Reef types: MF - Mainland Fringing, IF - Island Fringing, SF - Sharm Fringing, P - Patch, B - Barrier. GPS locations in Appendix 5.

Site	Reef name	Reef Type	RI value	VI rating	All coral diversity	Hard coral diversity	Community type
70b	J. Umm Rumah	P	9.978	1	67	64	C
10a	S of J. Qumma'an	P	7.514	5	68	63	C
73a	W of J. Qumma'an	B-P	7.079	4	89	79	A
77a	S of Al-Wajh Bank	B	7.077	3	110	91	A
82b	S Al-Wajh Bank	P	6.935	2	53	50	C
67a	W J. Qumma'an	P	5.879	10	65	61	C
74a	W of J. Qumma'an	B-P	4.974	6	111	98	A
69a	J. Mizab	B	4.671	8	76	64	D
81a	S of J. Juzur Shurayrat	P	4.553	7	84	74	C
8a	N Al-Wajh Bank	B	4.434	14	62	54	D
54b	W of J. Qumma'an	B	4.378	9	77	66	B
60a	SE J. Qumma'an	P	4.324	15	79	71	C
78b	S of Al-Wajh Bank	P	4.076	12	108	97	B
69b	J. Mizab	B	3.592	11	68	55	B
75a	J. Jabal Hassan	B	3.707	13	81	67	B

Table 90. Sites in the Model Area likely to be of special importance for coral replenishment, in terms of coral cover and species abundance (*CI*, *HCI*). Community types are also listed. Reef types: IF - Island Fringing, P - Patch, B - Barrier. GPS locations in Table 80.

Site	Reef name	Reef Type	CI value	HCI rank	All coral diversity	Hard coral diversity	Community type
C74a	W of J. Qumma'an	B-P	10.7	3	111	98	A
C78b	S of Al-Wajh Bank	P	9.55	1	108	97	B
C77a	S of Al-Wajh Bank	B	8.95	2	110	91	A
C77b	S of Al-Wajh Bank	P	8.28	7	70	60	B
C49b	S. J. Shaybarah	P	7.9	4	82	69	B
C23a	J. Raykhah	IF	7.05	11	76	63	D
C69b	J. Mizab	B	7.05	10	68	55	B
C50b	S Al-Wajh Bank	P	6.95	5	74	63	B
C81a	S of J. Juzur Shurayrat	P	6.6	8	84	74	C
C73a	W of J. Qumma'an	B-P	6.52	9	89	79	A
C80a	S J. Qumma'an	P	6.3	6	69	63	C

2.2.3.4. Discussion and conclusions

The wide variety of coral reef types present in the Model Area - barrier reefs, patch reefs, and island and mainland fringing reefs - supported four major coral community types characterized by minor differences in species-composition and major differences in species abundance. The community types exhibited different levels of fidelity to the various reef types, in response to characteristics of the physical and environmental regimes, particularly wave energy and water clarity-turbididty. The community types formed part of a continuum, with particular species exhibiting differences in occurrence and abundance related to site-specific habitat characteristics and disturbance-histories.

The major form of disturbance to coral communities within the Model Area was predation by the crown-of-thorns starfish. Incipient outbreak populations were distributed on most of the mid-Bank patch reefs in 1999. These populations may contribute large numbers of larvae for future recruitment, potentially initiating large starfish outbreaks causing major destruction of coral communities in the region, as has occurred elsewhere in the Indo-Pacific over the past 40 years.

Considerable scientific controversy surrounds the issue of starfish population fluctuations and causation of outbreaks (see MORAN 1986, BIRKELAND & LUCAS 1990 for reviews). As noted above (see section 2.1.2.4.2), there are several hypotheses regarding causation, ranging from those proposing that the outbreaks are completely natural or 'normal' features of reef ecology, to those proposing that the outbreaks arise following human interference in reef ecology. The latter hypotheses focus on over-fishing of starfish predators, notably reef fishes of the families Lethrinidae, Serranidae, Lutjanidae, Ballistidae and Labridae, and on nutrient enrichment fostering high survival of starfish larvae.

In Al-Wajh Bank, little is presently known of nutrient levels, although human-induced nutrient enrichment is not likely to be a factor, given the low human population density in the area. However, fishing of key predators of the starfish may be significant. Notably, increased abundances of other coral reef echinoderms (e.g. the asteroid *Echinometra mathaei*) have been shown to be related to over-fishing (MCCLANAHAN & OBURA 1995), and several species of reef fish have been shown to be significant predators of *Acanthaster* in other regions of the Red Sea and greater Indo-Pacific (ORMOND et al. 1990, and references cited therein).

Predation by fishes may be an important mechanism regulating *Acanthaster* abundances in Al-Wajh Bank, and thus fishing could be a key factor influencing *Acanthaster* population dynamics there. By world standards, such fishing pressure in Al-Wajh Bank is low. Nonetheless, given the restricted area of coral habitat of the reef patches (see Habitat Maps section of this report), natural abundances of associated fishes are likely to be highly susceptible to over-fishing. Commercial reef fisheries operate from several ports in the Model Area (see Socio-economics section of this report), placing considerable fishing pressure on the more-accessible reefs, particularly around and to the south of J. Qumma'an.

Notably, injury levels on starfish in Al-Wajh Bank were low, with only eight of the

42 censused *A. planci* (19 %) exhibiting injury (Table 88). This suggests only low levels of predation pressure are operating on the starfish in the Model Area. Such evidence of predation on the starfish, in the form of missing and/or regenerating arms, is often present on > 33 % of animals in a population (MORAN 1986, MACCALLUM et al. 1989, BIRKELAND & LUCAS 1990). It is recommended that annual monitoring of these starfish populations be continued. Consideration may also be given to initiation of starfish control programmes and to closing some reefs to fishing, following establishment of a MPA in the area.

1. Management implications

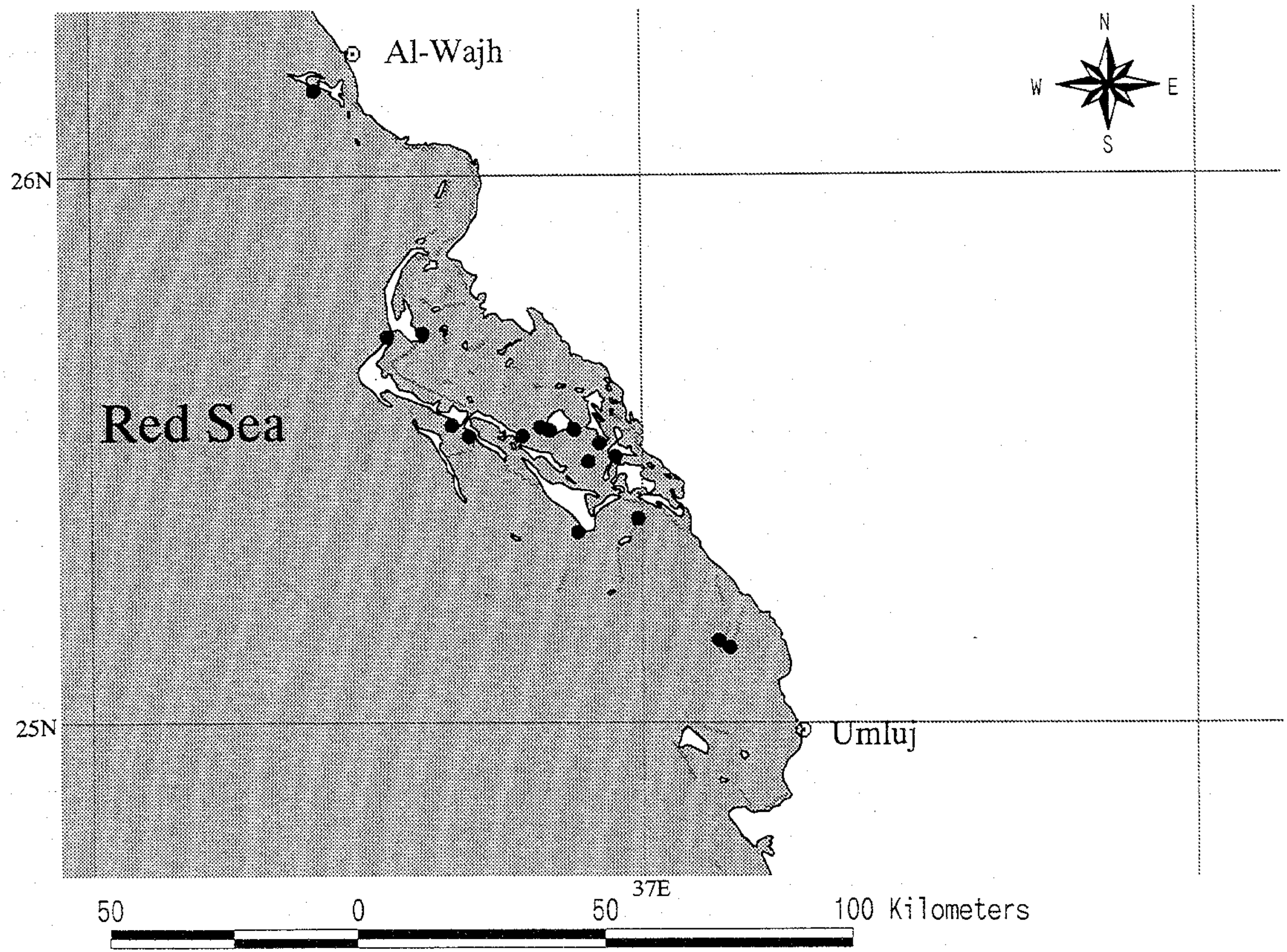
The previous analyses have identified sites of special management significance in terms of a variety of conservation values (ecological, biodiversity and replenishment attributes). Many of these sites scored highly for several conservation values (Table 91). These sites are mostly located on mid-Bank patch reefs and outer barrier reefs (Fig. 47), and provide good representation of the four major coral community types (Table 91). These reefs should be considered a high priority for future MPA planning.

Discussion of the rationale and options for consideration in planning of MPAs was given in section 2.1.2.4 of this report. In relation to Al-Wajh Bank, one potential approach to the future zoning is the creation of cross-Bank zones of high conservation value (Biological Reserve or Special Nature Reserve), stretching from the mainland coast to the outer barrier reef system. In the overall zoning scheme for the Bank and adjacent waters and reefs, this high conservation zone(s) could be 'nested' within zones of lower conservation status (Nature Reserve, Resource Use Reserve).

Based on the above analyses and considerations, three sub-areas within the Model Area are of particularly high conservation significance:

- Central Bank from the mainland – J. Qumma'an – narrow channel – outer barrier

Fig. 47. Map of the Model Area showing appropriate locations of sites of special conservation value.



reef system;

- Southern Bank from mainland – J. Shaybarah – outer barrier reefs;
- S of Al-Wajh Bank from mainland – patch reefs – J. Jabal Hassan.

These three sub-areas also are of conservation significance in terms of other ecological attributes (e.g. mangrove stands, algae and seagrass habitats and turtles).

Table 91. Sites in the Model Area of special management significance in terms of high conservation values. GPS locations are listed in Table 80. Rank cover (1-5) for hard corals, coral species diversity, ratings (1-10) within the Model Area for replenishment potential (CI) and rarity (VI) and presence of undescribed species are listed. n/a: not applicable – denotes that the attribute was not important in the specific site. Results for these sites are listed in Appendices.

Site	Reef name	Reef Type	Hard coral cover	Species diversity - all corals	Repleni-shment (CI)	Rarity (VI)	Undescr-ibed spp.	Comm-unity Type
C77a	S of Al-Wajh Bank	B	4	110	3	3	n/a	A
C74a	W of J. Qumma'an	B-P	3	111	1	6	y	A
C78b	S of Al-Wajh Bank	P	4	108	2	n/a	n/a	B
C77b	S of Al-Wajh Bank	B	4	70	4	n/a	y	B
C70b	J. Umm Rumah	P	3	67	n/a	1	y	C
C82b	S Al-Wajh Bank	P	4	53	n/a	2	y	C
C49a	S. J. Shaybarah	P	2	69	n/a	n/a	y	D
C62a	J. Ummahat Shaykh	P	2	65	n/a	n/a	y	C
C67a	W J. Qumma'an	P	3	65	n/a	10	y	C
C73b	W of J. Qumma'an	B-P	2	87	n/a	n/a	y	A
C79a	SW J. Qumma'an	P	2	62	n/a	n/a	y	C
C10a	S of J. Qumma'an	P	3	68	n/a	5	n/a	C
C73a	W of J. Qumma'an	B-P	3	89	10	4	n/a	A
C69a	J. Mizab	B	2	77	n/a	n/a	n/a	D
C81a	S of J. Juzur Shurayrat	P	3	84	9	7	n/a	C
C49b	S. of J. Shaybarah	P	4	82	5	n/a	n/a	B
C23a	J. Raykhah	IF	3	76	6	n/a	n/a	D
C69b	J. Mizab	B	3	68	7	n/a	n/a	B
C50b	S Al-Wajh Bank	P	4	74	8	n/a	n/a	B
C60a	SE J. Qumma'an	P	2	79	n/a	n/a	n/a	C

2. Recommendations for future monitoring

The Model Study has established a series of Reef Check sites suitable for continued monitoring of both coral cover and reef fish abundances (see Fish section of this report). It is recommended that NCWCD continue to monitor the Reef Check sites (or a representative sub-set thereof) on an annual basis, if logistically feasible. This would require development of a dedicated coral reef monitoring programme. Various monitoring programmes, most linked with Reef Check and GCRMN, already exist in many Indo-Pacific countries, and consideration should be given by NCWCD to the Kingdom of Saudi Arabia (through NCWCD) becoming an official member of both GCRMN and Reef Check. Following training during the present study, sufficient expertise exists in the NCWCD Marine Department to form a monitoring team. This would facilitate the continued development of coral reef research and monitoring within the Kingdom, essential adjuncts to future MPA management.

3. Recommendations for further research

The present study has identified sites of special importance in terms of coral communities in Al-Wajh Bank. However, large gaps remain in the understanding of these communities, particularly in relation to future management. Additional studies that would be useful for management include:

- Coral reproduction – timing,
- oceanographic connectivity within the region, in terms of determining likely 'source – sink' dispersal relationships for maintenance and replenishment of populations,
- coral recruitment and growth rates,
- recovery of coral cover and community structure following disturbance,
- genetics – linkages with other areas.

2.2.4. SEAGRASSES / ALGAE

2.2.4.1. Methods

Field survey for the Model Study was conducted in spring (16 February – 1 March 1999) and summer (6 - 16 June 1999).

Coverage of seagrasses and algae was observed in each habitat to analyse the relationship between seagrasses, algae and their physical environments.

Observations and sample collection were made in a bank transect line of the Model Area and in its surrounding areas. Survey spots were determined by using the aerial photographs and the habitat maps. The locations of the survey spots extended from the inner tidal zone to the subtidal zone. The surveys were conducted on rocky shores, shallow and deep subtidal sands, patch reefs and reef flats. The location of survey spots is listed in Appendix 15. A total of 59 quadrat spots were surveyed in the bank transect during the Model Study. Among them SA.1 to SA.36 were surveyed in spring, while the rest were done in summer.

The surveys were conducted by wading, snorkelling and SCUBA diving employing the quadrat method. The coverage of each species or taxon and the composition rate of substratum were measured in a 9 m^2 quadrat. Triplicate observation was conducted in every spot. The coverage of silt on the leaves was measured in seagrass beds. Depth and temperature were measured by digital depth-meter and thermometer. Collected seagrasses and algae were preserved as dry specimens.

2.2.4.2. Results

There were 12 survey spots in coral communities, 14 survey spots in algae ones, 18 survey spots in seagrass beds, two survey spots in mangrove ones, six survey spots in Cyanophycea beds and seven survey spots in bare sand areas. All spots were protected from swell by the barrier reefs, the patch reefs, or the islands. The depths of survey spots ranged from +0.2 meters to -15.0 meters (Appendix 15). The water temperature of survey spots ranged from 23.2 °C to 25.0°C in spring and from 28.6°C to 33.3°C in summer. Ecological features of survey spots are shown in Appendix 16.

A total of 82 taxa including nine seagrasses taxa and 73 algal taxa occurred through two field surveys in Model Study area. Number of species in spring (58) and summer (51) showed little difference.

1. Seagrasses

The seagrass beds developed well in the coastal inlets, which were protected against swell and wind-driven waves by reef flats. Broken waves became a moderate flow into the inlets, which made conditions suitable for seagrass beds. The moderate flow prevents silt from settling on the leaves of seagrass.

Seagrasses in the coastal inlets was found to grow at a depth of 12.2 m at maximum, though along the shoreline of the island (Jazirat Qumma'an), it grew at the depth of 0.5 m at maximum. *Halophila stiplacea* was distributed at a depth of 0.2-12.2 m. The coverage of silt on leaves in shallow survey spots was higher than that of the deeper survey spots (Table 92). In comparison with species of seagrasses, the coverage of silt on leaves of *Enhalus acoroides* was highest at 80%.

2. Algae

Algae communities developed in the shallow areas exposed to wind-driven waves and rapid current. These areas are situated on reef edges, reef flats and reef patches. The coverage of turf and small algae was high, composed of six to eight species. A lot of *Turbinaria* (brown alga, Sargassaceae) grew on a survey spot near the channel Shunbuzah, however the coverage looked low because the length of *Turbinaria* was less than 30 mm.

Macro algae of the genera *Sargassum*, *Cystoceira* and *Turbinaria* were distributed on

Table 92. Coverage (%) of silt on leaves of seagrasses.

Species	Survey spot	Depth	Substratum (%)		Coverage of silt
			Sand	Silt	
Halodule uninervis	SA 44	0.2 – 0.3	100	0	+
	SA 56	1.0	90	10	20
	SA 58	0.7	95	5	20
Halophila stipulace	SA 37	4.4	90	10	40
	SA 38	8.6	30	70	70
	SA 44	0.2 – 0.3	100	0	5
	SA 48	12.2	90	10	60
	SA 50	6.5	70	30	40
	SA 54	7.6	100	+	20
	SA 55	7.5	70	30	50
Halophila ovalis	SA 54	7.6	100	+	5
Cymodosea rotundata	SA 45	0.4 – 0.5	100	0	+
	SA 56	1.0	90	10	30
Thalassia hemprichii	SA 58	0.7	95	5	20
Enhalus acroides	SA 58	0.7	95	5	80

exposed shoreline areas, some reef edges and some patch reefs. Coverage of *Sargassum* in a survey spot on the shoreline was 52%, and that of *Turbinaria* on the reef patch was 72%. A drifted *Sargassum* community was present on sand bottoms in the south of Qara'ir. Its coverage was 100%.

One selected survey spot was originally categorised as seagrass bed, using the aerial photographs and the habitat maps. However the area was actually a drifted *Cladophora* (green algae) community. This community was found northwest of Jazirat Umm Sahar off the coast of Umluj. This area is protected against swell and strong wind-driven waves by Jazirat Jabal Hassn and the barrier reefs and the patch reefs developing around the island. The area of distribution of this species was at least 1,000 m^2. The seabottom was covered with sand at a thickness of 1-5 mm. The drifted *Cladophora* settled on the bottom at a thickness of 0-40 mm. Turf algae of 5% coverage and crustose coralline algae of 30% coverage were observed under the drifted *Cladophora* and the sand.

Turf and small algae were widely distributed outside and inside the barrier reef and were dominant on reef flats. However, a few algae were found on reef slopes. Inside the barrier reef, the turf and small algae community developed on shorelines of islands and the mainland. Those areas had little or no silt on the hard substrate.

Coral communities developed in the area facing directly to wind waves and/or rapid current. These areas are situated on the reef slopes, reef edges, reef flats and reef patches. A few algae were distributed in coral communities. The coverage of algae excluding crustose algae was <1% to 17%. The coverage of crustose algae was higher than that of turf and small algae.

In a sand area of the mangrove thickets on Jazirat Qumma'an, a few algae were found attached to the mangrove roots. This area was beside creeks washed by seawater. This passing seawater carried silt particles away, assisting the growth of algae. On the other hand, the mangrove thickets in Dugm Sabq on silt-sand substrate did not have any algae.

In the sabkhahs of the super-tidal zone, Cyanophycea coverage was high. In the subtidal zone, a Cyanophycea community was found behind the barrier reef. The substrate of those spots was sand-silt or silt. Calm waves and slow currents made the area silty. The calm area accumulates silt which is originated from coral reef and prevents other vegetation from growing.

3. Inventory

For biological inventory, seagrass *Enhalus acoroides* was discovered on the coast of Al-Kawwarah, north of Umluj. This species was formerly known to have its north boundary at the coast in the vicinity of Jeddah (ALEEM 1979). The finding of the Study extends its distribution boundary to the north.

2.2.4.3. Discussion and conclusions

1. Seasonal difference

In the Model Study, the surveys were conducted twice in spring and summer. The number of species showed little difference between the two seasons. However a seasonal difference appeared in the coverage of macro algae.

For example, *Turbinaria* was abundant in spring, and was observed to start breaking loose in summer. *Sargassum* and *Cystoceira* showed higher coverage in summer than in spring. These findings indicated that *Turbinaria* reached the maximum biomass in summer, while *Sargassum* and *Cystoceira* might become most abundant in autumn, then they began to break loose, leaving roots on the substrate, and they again started to grow from the roots.

2. Silts and marine flora

In principle, seagrasses grow on the sandy bottom and algae are distributed on hard substrates, such as rocks and dead coral reefs. The distribution of seagrass and algae is regulated largely by the physical conditions of the sea. Reef slopes usually do not give an attachment basis to algae, because the coral occupies them. On the reef edges, wave action and rapid current flow bring no sedimentation of silt particles and reduce grazing pressure on algae from herbivorous fish. This condition allows turf/small algae to thrive there. Just behind the reef edge, a calm water area appears, where negligible wave action and slow current flow allow silt particles originated from coral reef to accumulate on the deep parts of the reef flat. Such silty bottom allows only Cyanophyceae to exist. The shallow sea bottom in the reef flat receives small wave action to remove silt so as to allow growth of seagrasses or macro algae. Reef patches provide similar hydrographical conditions to the reef edge and give habitat to macro algae. Since the nearshore reef flat area has a longer fetch of waves from the barrier reef, the higher wave hits the shallow nearshore sea bottom. It sometimes forms a suitable habitat for seagrass and algae where silt particles do not deposit and herbivores can not reach under the rough weather condition (Table 93).

3. Monitoring

Monitoring of seagrasses / algae is required to conserve the wide variety of habitats in the northern Red Sea coast of Saudi Arabia. It is useful and convenient to use a permanent quadrat method, by setting up quadrats at fixed locations and conducting periodical observations in the quadrats. The items to be observed include:

- Number of species or taxa
- Coverage
- Individual number
- Total length of organism
- Thickness of silt on the substrate
- Thickness of silt on the plant leaf and silt coverage ratio
- Water temperature
- Animal bite marks as an evidence of impact by herbivorous animals

If the monitoring concentrates on some particular species, it is recommended that the following species be included:

seagrasses:

Thalassia hemprichii: prey of Green Turtle

Syringodium isoetifolium: prey of Dugong

Enhalus acoroides: rare species in the Model Area

Species identification of algae needs experience and skills because of the wide infraspecific variety of morphology. It is, therefore, not realistic to select certain species to be monitored, but reasonable to monitor the whole flora in certain monitoring sites periodically. Environmental impacts, such as silt deposition, temperature and grazing pressure, and the

Table 93. Summary of substratum, habitat and water movement.

Survey spot	Depth(m)	Sea Bottom	Habitat	Water movement		
				Swell	wind wave	Current
SA15	3.0-5.0	Hard substrate	Coral community with few small algae	exposed	exposed	rapid
SA28	2.9		Coral community with few small algae	protected	exposed	moderate
SA14	0.9		Crustose coralline algae community	exposed	exposed	moderate
SA8,23	0.3-0.7		Sargassum bed	protected	exposed	rapid
SA34, 40, 43, 46, 49, 52	2.6-15.0		Coral community with some algae	protected	exposed	moderate
SA3,13,32, 41, 57	0.0-0.8		Algae community with some or no coral	protected	exposed	moderate
SA53	8.6		Drifted *Cladophora* community	protected	protected	moderate
SA17,19	0.2-0.4	Hard substrate with sand	Small algae community with some seagrasses	protected	exposed	moderate
SA5	2.0		Small algae and sponge community	protected	exposed	moderate
SA47, 51	8.2-15.0		Coral community with some algae	protected	exposed	moderate
SA22	0.2		Small algae community	protected	exposed	slow
SA39, 42	0.4-1.4		Some or few coral and algae	protected	protected	slow
SA25	+0.1		Bare rock area	protected	protected	slow
SA16, 20, 31, 54	0.3-7.6	Sand	Bare sand area with some seagrass and/or algae	protected	exposed	moderate
SA4	0.0-0.5		Mangrove thicket	protected	protected	rapid
SA11, 21, 44,	0.2-0.8		Seagrass bed	protected	protected	rapid
SA30	1.2		Bare sand area with few coral and small algae	protected	protected	moderate
SA18	1.2		Drifted Sargassum bed	protected	protected	moderate
SA9,36,37, 38, 48, 50, 55, 56, 58	0.4-12.2	Sand with silt	Seagrass bed with some or few Cyanophyceae	protected	protected	moderate
SA1	+0.1-0.0		Intertidal bare sand flat	protected	protected	slow
SA2	0.2-0.4		Mangrove thicket	protected	protected	slow
SA10,27,29,35	3.5-6.0		Some seagrasses and/or Cyanophyceae	protected	protected	slow
SA6,7,12,24,26, 35	+0.2-13.8		Cyanophycea community	protected	protected	slow

consequent succession of algal community should be monitored.

Monitoring sites should be located by considering the intensity of environmental impacts on seagrasses and algae. Some should be set up in areas that receive little environmental impacts and others should be located in areas of environmental impacts of various degrees. The monitoring sites should be decided taking the accessibility into account because the difficulty to reach the sites tends to induce a low frequency of fieldwork. The frequency of a monitoring survey should ideally be four times a year to cover four seasons.

2.2.5. FISH

2.2.5.1. Methods

The belt transect method was used to gain an understanding of ecological changes in the fish population of the area. Indicator species which are important for the ecosystem were selected on the basis of the results of Phase II. These are candidate species for a future environmental monitoring survey.

SCUBA-diving line-transect observations based on Reef Check protocol (see Coral section 2.2.3.1 in this report) and Global Coral Reef Monitoring Network (GCRMN) protocol (see Coral section) were undertaken. Thirty-three indicator fish species shown in Appendix 1 were selected for monitoring. Survey sites were selected based on aerial photographs and habitat maps. Four 20m transect lines, using a single 100 m fibreglass measuring tape, were laid at the upper layer (1-3 m) and at the lower layer (6-10 m) in to each habitat. The 20 m long transect lines were spaced at 5 m intervals. One-depth surveys were conducted at sites not suitable for surveys at two depths. The coordination of the beginning of the transect lines were recorded by GPS (Global Positioning System).

The divers swam slowly along the transect line counting the number of each fish species and estimating the size of the fish as listed in Appendix 17. They stopped every 5 m, and waited two minutes for the fish to come out of their hiding places. The width of observation range was 5m, centred on the transect line. In all, 400 m^2 (4 sections x 20 m long x 5 m wide) of survey area were surveyed with 50 minutes survey time (2 minutes x 20 stop points + 0.5 minute x 19 movements), a combination of timed and area restricted survey.

Normally, the number of indicator fish was counted and their size estimated. However, the number of Pomacentridae (damsels), Caesionidae (fusiliers) and "Others" except for Serranidae (groupers) were noted by abundance categories as shown in Table 94, without any estimation of size.

Table 94. Logarithmic abundance categories used in estimating abundance of numerically dominant fish species (RUSS 1985).

Log 4 Abundance Category	Number of Fish
1	1
2	2-4
3	5-16
4	17-64
5	65-256
6	257-1024
7	1025-4096
8	4097-16384

In order to introduce a method of comparing the difference in numbers of commercial species in different seasons, which is related to the issues of overfishing and predation on coral (see Coral section), several of the same survey spots were selected in February 1999 and in June 1999.

2.2.5.2. Results

1. Indicator species

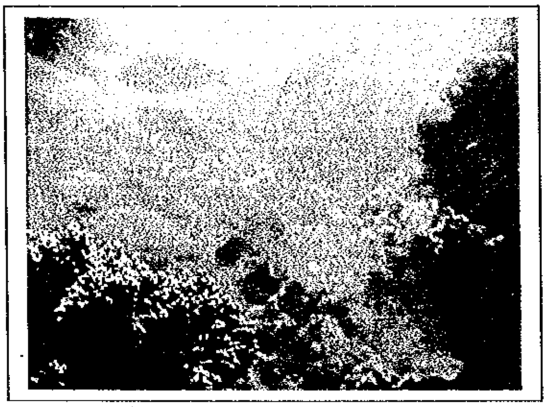
Locations of the survey spots are shown in Appendix 18 and the findings of the survey are shown in Appendix 19.

The survey was conducted at 29 depth-contours (spots) at 24 survey points.

Out of 33 indicator species, five species such as Vermilion Hind *Cephalopholis oligosticta*, Blackspot Emperor *Lethrinus harak*, Sky Emperor *Lethrinus mahsena*, the Painted Sweetlips *Diagramma pcitum* and Goldband Fusilier *Pterocaesio chrysozona* were not observed.

The most often observed species was Red Sea Bannerfish *Heniochus intermedius*, followed by Indian Ocean Longnose Parrotfish *Hipposcarus harid* and Yellowbar Angelfish *Pomacanthus maculosus*. (Photo. 7-1)

Heniocus intermedius



Hipposcarus harid

Pomacanthus maculosus

Photo. 7-1. Three most frequently observed speices.

Some degree of human impact, such as abandoned fishing lines and fish nets, and coral destroyed by boat anchors, was observed at almost all survey spots.

__2. Survey Spots and species__

The numbers of Chaetodontidae (butterflyfishes), Acanthridae (surgeonfishes) and Acanthridae (parrotfishes) were greater in seaward reef edge habitats (FMO02, 05, 06, 16, 18) than in other habitats.

In patch reef habitats (FMO01, 03, 04, 07, 08, 11, 12, 13, 14, 15, 17, 21, 22, 23, 24) the number of Serranidae (groupers) was high, especially around Jazirat Qumma'an (FMO08, 11,12, 21, 22).

On the east side of Jazirat Shaybarah (FMO09), which is sheltered and shallow, fewer fish were observed than at other survey spots.

In a typical seagrass bed habitat (FMO10) the number of fish species was less than in the other habitats; however, the number of Siganidae (rabbitfishes) was high.

Rare aquarium fish such as Yellowbar Angelfish *Bolbometopon muricatum*, Bicolor Parrotfish *Cetoscarus bicolor*, Crown Coris *Coris aygula*, Broomtail Wrasse *Cheilinus lunulatus* and Humphead Wrasse *Cheilinus undulatus* were observed in seawards habitats (FMO16, 17, 18, 19, 20).

The number of Serranidae (groupers) was high at FMO21, 22 spots on the west and east sides of Jazirat Qumma'an, and at FMO24, which is in the middle of Al-Wajh Bank.

Lethrinidae (emperors) were observed rarely all survey spots.

2.2.5.3. Discussion and conclusions

__1. Habitat and species__

The survey spot where the highest number of fish species was counted was FMO03 (north-west side of Jazirat Qumma'an), a patch reef habitat. The second was FMO12 (east side of Jazirat Shaybarah), the third FMO13 (south-west side of Jazirat Qumma'an) and the fourth FMO22 (east side of Jazirat Qumma'an) (Fig. 48).

The 29 survey spots where divers observed fishes were categorized into the two types shown below, taking into consideration the differences between the habitats:

- Inside habitat (18 spots); patch reef, sand bank with coral, seagrass bed
- Outside habitat (11 spots); seaward reef edge, channel, reef, reef edge

A comparison of number and size of fish between the inside and the outside habitats is shown in Table 95 and Fig. 49. Generally, the abundance of fishes inside Al-Wajh Bank was higher than outside Al-Wajh Bank. The average size of fishes estimated in the water was greater inside Al-Wajh Bank than it was outside the bank.

Fig. 50 shows the abundance ratio of the 10 main fish families (ratio of total number of individuals of each of 10 families). Chaetodontidae (butterflyfishes) have the highest ratio (27%) followed by Scaridae (parrotfishes) 17%, Pomacantridae (angelfishes) 15% and Acanthuridae (surgeonfishes) 14%. Siganidae (rabbitfishes) had the lowest ratio (1%), because they live in seagrass habitats, in which fewer survey spots were set up than in other habitats in this survey.

In this Study the survey spots were not selected randomly and fish families observed are not a good representation of the fish fauna in the Model Area. It is recommended that survey spots be selected more carefully for future monitoring.

2. Overfishing and monitoring

HEAD (1987) suggested that overfishing has become more serious in the Red Sea. SAKURAI (1998) pointed out that the size of the fisheries workforce over the last 10 years had been increased because of changes in food consumption patterns which now depend more on sea foods, and suggested that the maintainance of proper conservation measures and a

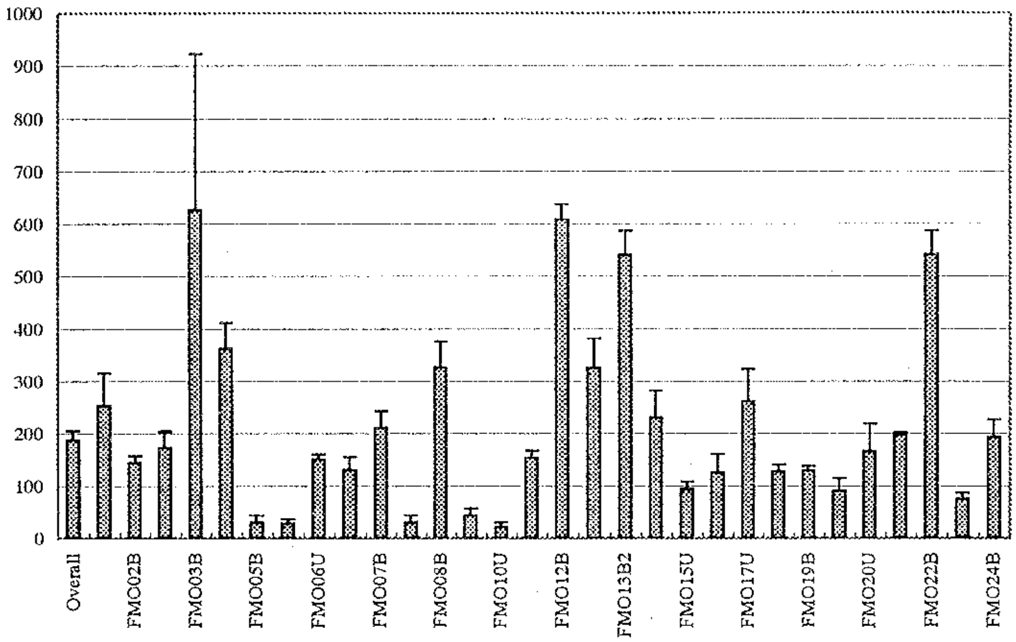


Fig. 48. Total number of individual fish and standard deviation (std) at each spot.

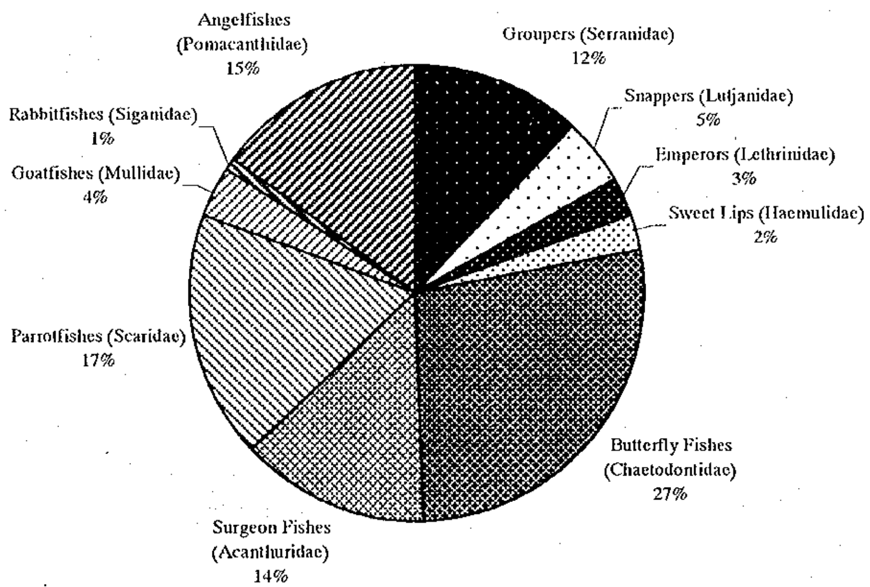


Fig. 50. Abundance ratio of 10 main families.

Table 95. Comparison of number and size of fish between the inside and outside habitats.

	Number(individual)		Size(cm)	
	Inside	Outside	Inside	Outside
Groupers (Serranidae)	0.8	0.5	13.1	23.5
Snappers (Lutjanidae)	1.4	0.6	20.7	17.9
Emperors (Lethrinidae)	0.8	0.3	0.0	0.0
Sweet lips (Haemulidae)	0.9	0.5	13.8	14.0
Butterfly fishes (Chaetodontidae)	1.5	1.5	14.3	14.5
Surgeon fishes (Acanthuridae)	1.6	2.2	14.0	17.5
Fusiliers (Caesionidae)	2	1	0.0	0.0
Jacks (Carangidae)	0.7	2.0	10.2	10.8
Wrasses (Labridae)	0.8	0.8	13.0	37.9
Damsels (Pomacentridae)	3	2	0.0	0.0
Parrotfishes (Scaridae)	0.9	0.9	20.9	26.5
Goatfishes (Mullidae)	0.8	0.5	7.6	10.5
Rabbitfishes (Siganidae)	0.9	0.7	14.0	11.5
Angelfishes (Pomacanthidae)	1.3	1.0	10.9	22.0

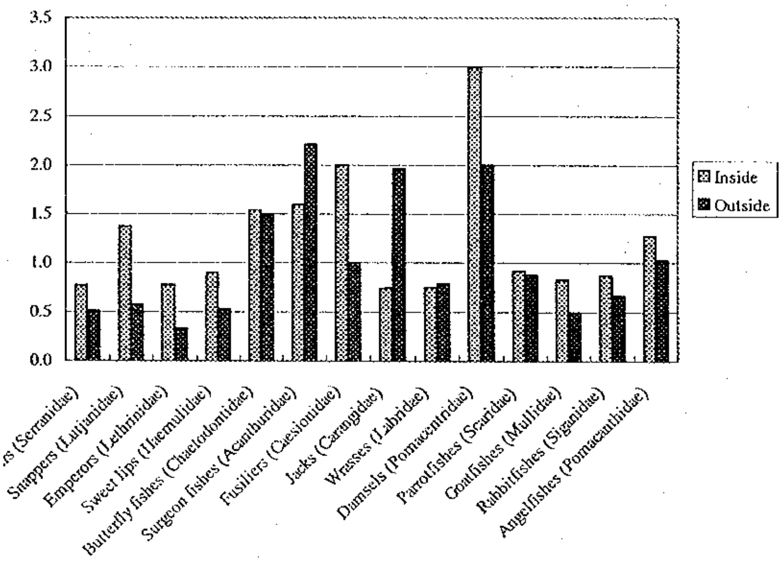


Fig. 49-1. Comparison of numbers of fish in the inside and outside habitats.

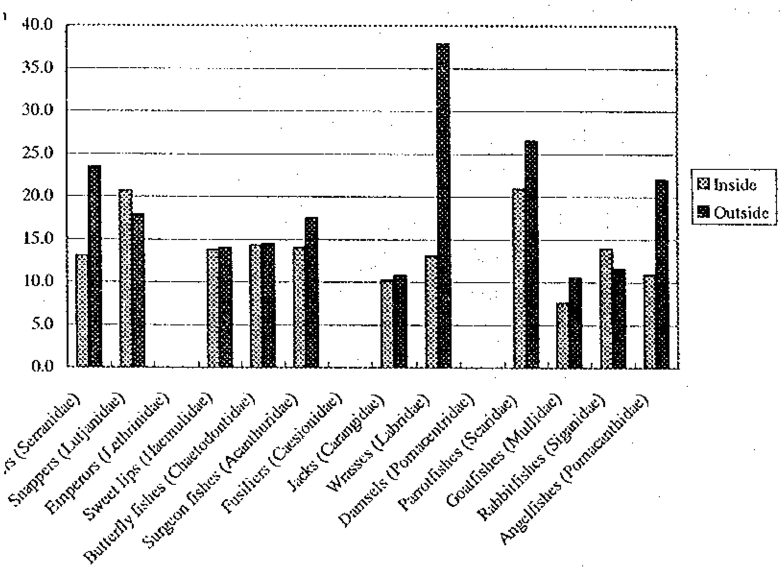


Fig. 49-2. Comparison of average size in the inside and outside habitats.

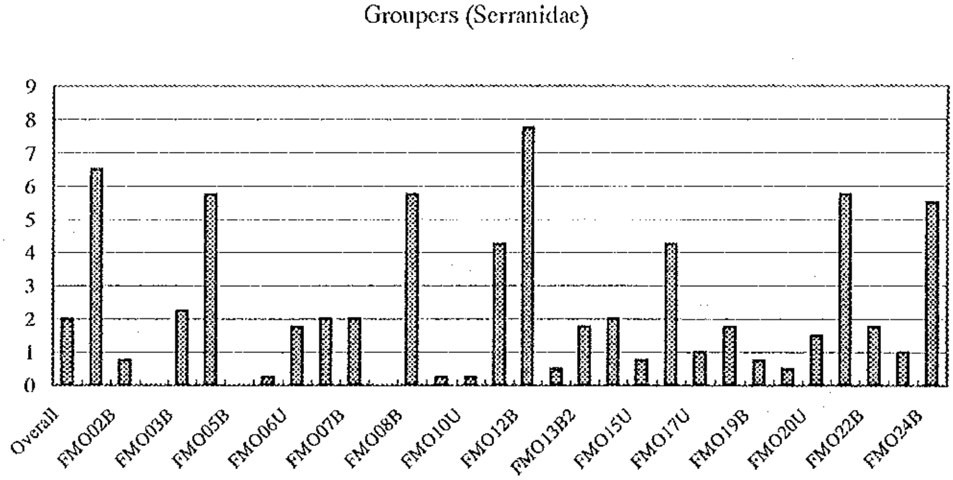
statistical data collection system would be important for the kingdom in the future.

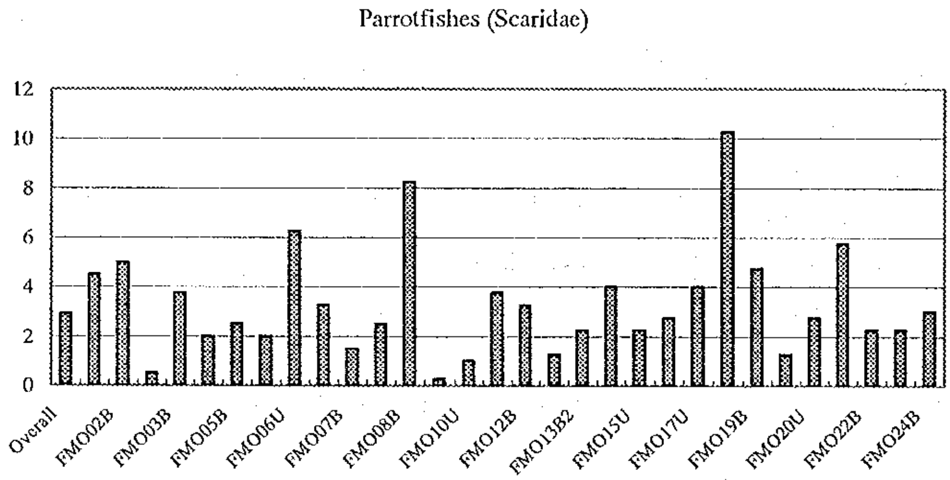
In this Model Study, in order to monitor these issues mentioned above the technique described below was tried as an example of a monitoring survey.

Comparison of the numbers of the three main commercial fish families is shown in Fig. 51. The top three survey spots which showed the highest number of individuals of each family are as follows;

- Serranidae (groupers): FMO12 (east side of Jazirat Shaybarah), FMO01 (north-west side of Juzur Madrah) and FMO04 (north-west side of Jazirat Qumma'an);
- Scaridae (parrotfishes): FMO18 (outside of Al-Wajh Bank close to the Shunbuzah channel), FMO08 (eastern edge of Jazirat Qumma'an) and FMO06 (southside of Jazirat Shaybarah); and
- Carangidae (jacks): FMO13 (south-west side of Jazirat Qumma'an), FMO22 (east side of Jazirat Qumma'an) and FMO16 (outside the channel south of Jazirat Umm Rumah).

The following three fish species are selected from the commercial fish families as representatives of each family: Summana Grouper *Epinephelus summana* (Serranidae), Indian Ocean Longnose Parrotfish *Hipposcarus harid* (Scaridae) and Orangespotted Trevally *Carangoides bajad* (Carangidae). This is because specimens of these species were often seen at restaurants along the highway. They were observed at almost every survey spot: the number and the size of individuals are shown in Fig. 52. FMO21 (west side of Jazirat Qumma'an) had the highest number of Summana Grouper, of relatively large size . FMO18 (outside Al-Wajh Bank close to the Shunbuzah channel) had the highest number and largest size of Indian Ocean Longnose Parrotfish. FMO16 (outside the channel south of Jazirat Umm Rumah) had a





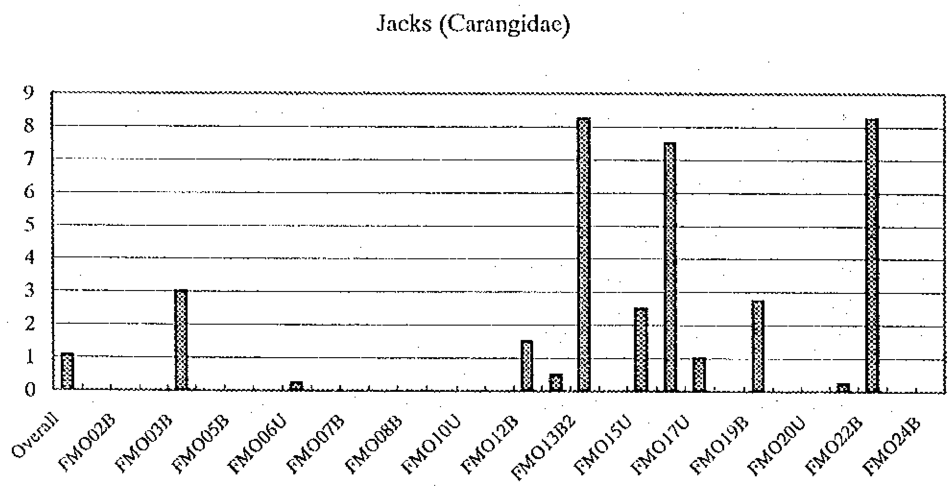
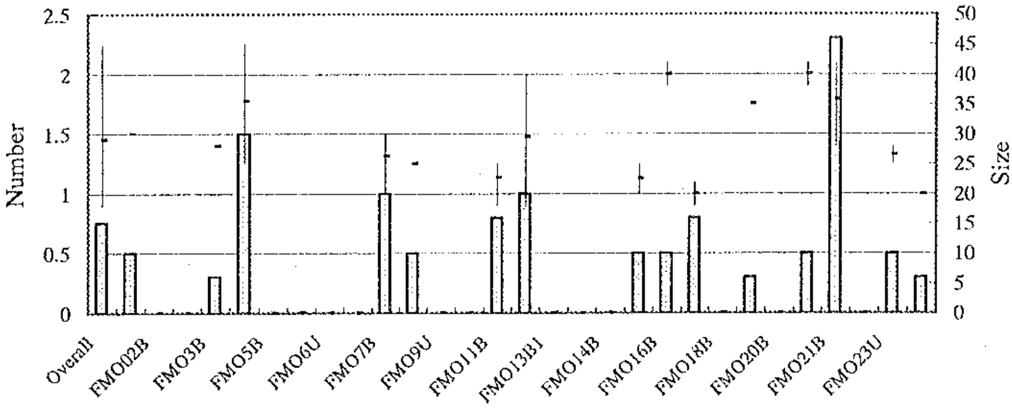
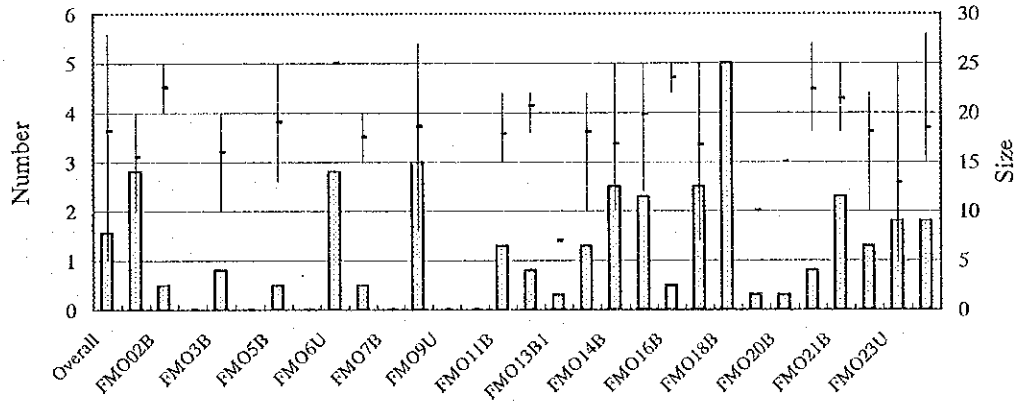


Fig. 51. Number of individuals of three main commercial families.

Summana Grouper (*Epinephelus summana*)



Indianocean Longnose Parrotfish (*Hipposcarus harid*)



Orangespotted Trevally (*Carangoides bajad*)

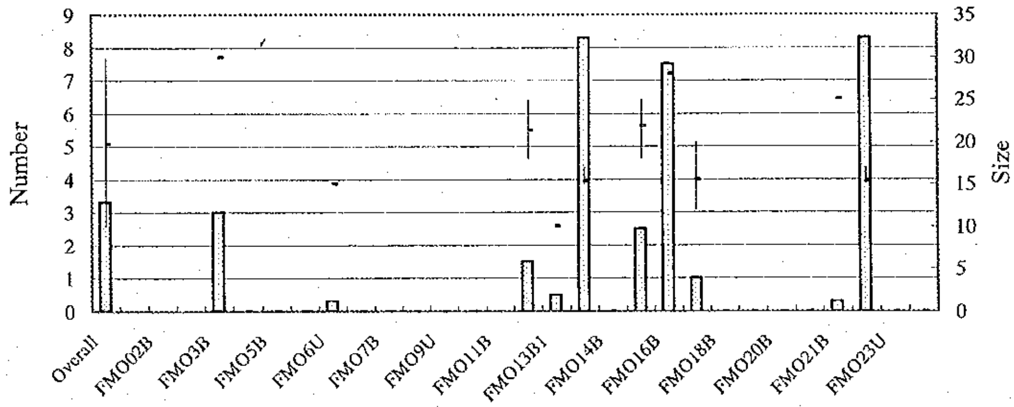


Fig. 52. Number and size of three main commercial species.

comparatively high number and the biggest size of Orangespotted Trevally. All three main commercial fishes were observed at Jazirat Qumma'an..

The difference in numbers and mean length of commercial fishes from the two surveys (February and June 1999) are shown in Fig. 53. The survey was conducted at the same spots on the east and west sides of Jazirat Qumma'an in both stages. Summana Grouper and Orangespotted Trevally are not compared on the east side of Jazirat Qumma'an because they were not observed there. There were fewer Indian Ocean Longnose Parrotfish on the east side of Jazirat Qumma'an in June than that in February, although the average size is almost the same in the two surveys. At the west side of Jazirat Qumma'an, in June, both Summana Grouper and Indian Ocean Longnose Parrotfish were more numerous and larger than in February, and the size of Orangespotted Trevally is greater in June than in February.

In this Model Study, a method was introduced to examine the question of the impact of commercial fishing on fish populations and fish size. Since the surveys were conducted within six months of each other and the data were not sufficient to indicate the effects of fishing in the area, further monitoring study is strongly recommended.

WOODLY (1979) suggested that reduction of part of the fish fauna could lead to important changes of abundance in other taxa, including territorial damselfish, algae, corals and echinoderms. Reduction of commercial fishes might change the balance of biological abundance. As LOWE & MCCONNELL (1987) illustrate in their description of the food chain in coral seas (Fig. 54), the monitoring of various fish fauna at various levels of the food chain will be important.

3. Monitoring species

Although 33 fish species were selected as monitor species, only three species were observed at most of the survey spots. To continue monitoring of fishes in Al-Wajh Bank, it is recommended that the monitor species be changed as follows;

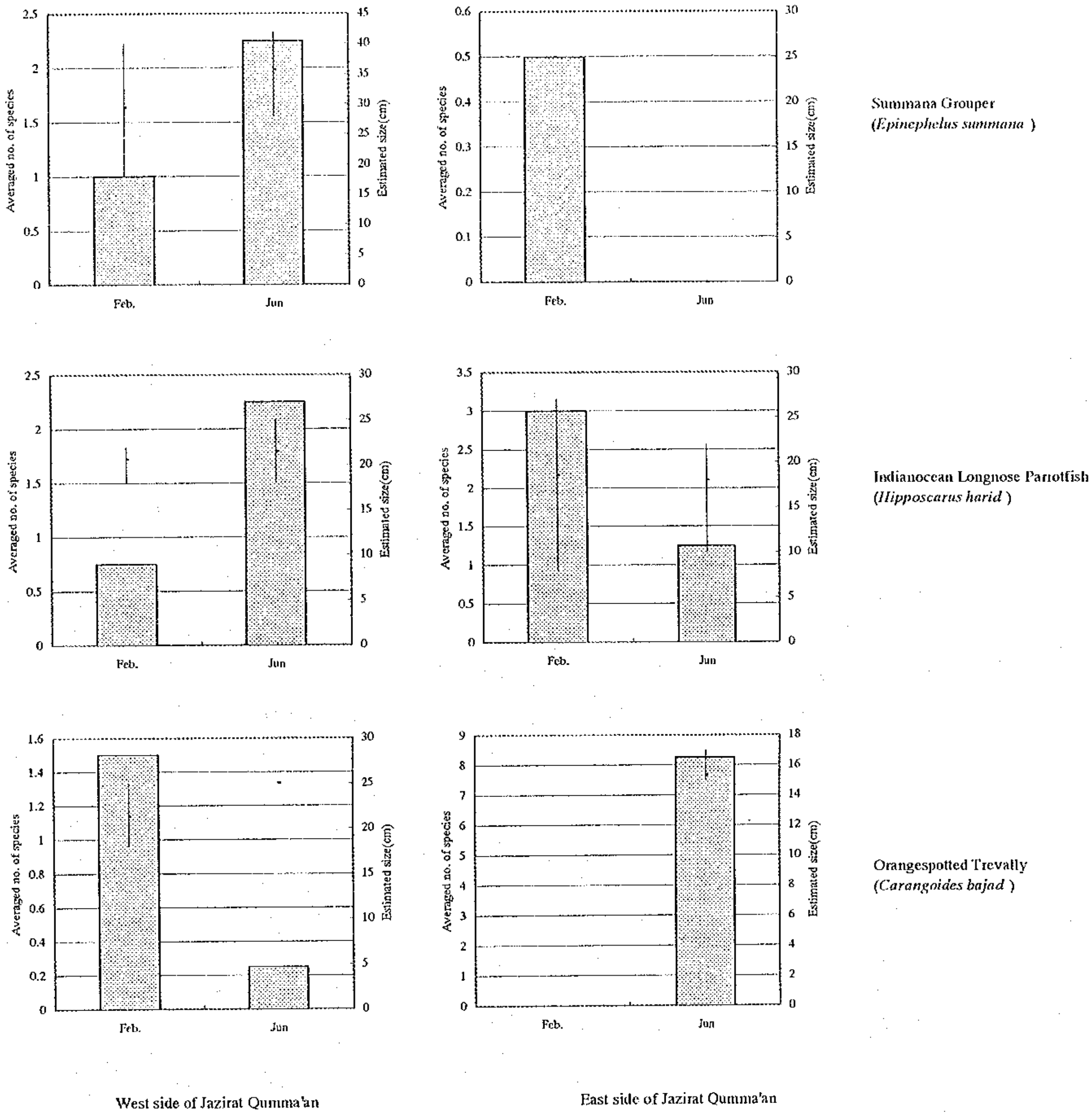


Fig. 53. Difference of numbers of individuals and mean length of commercial fish in Feb. and June 1999.

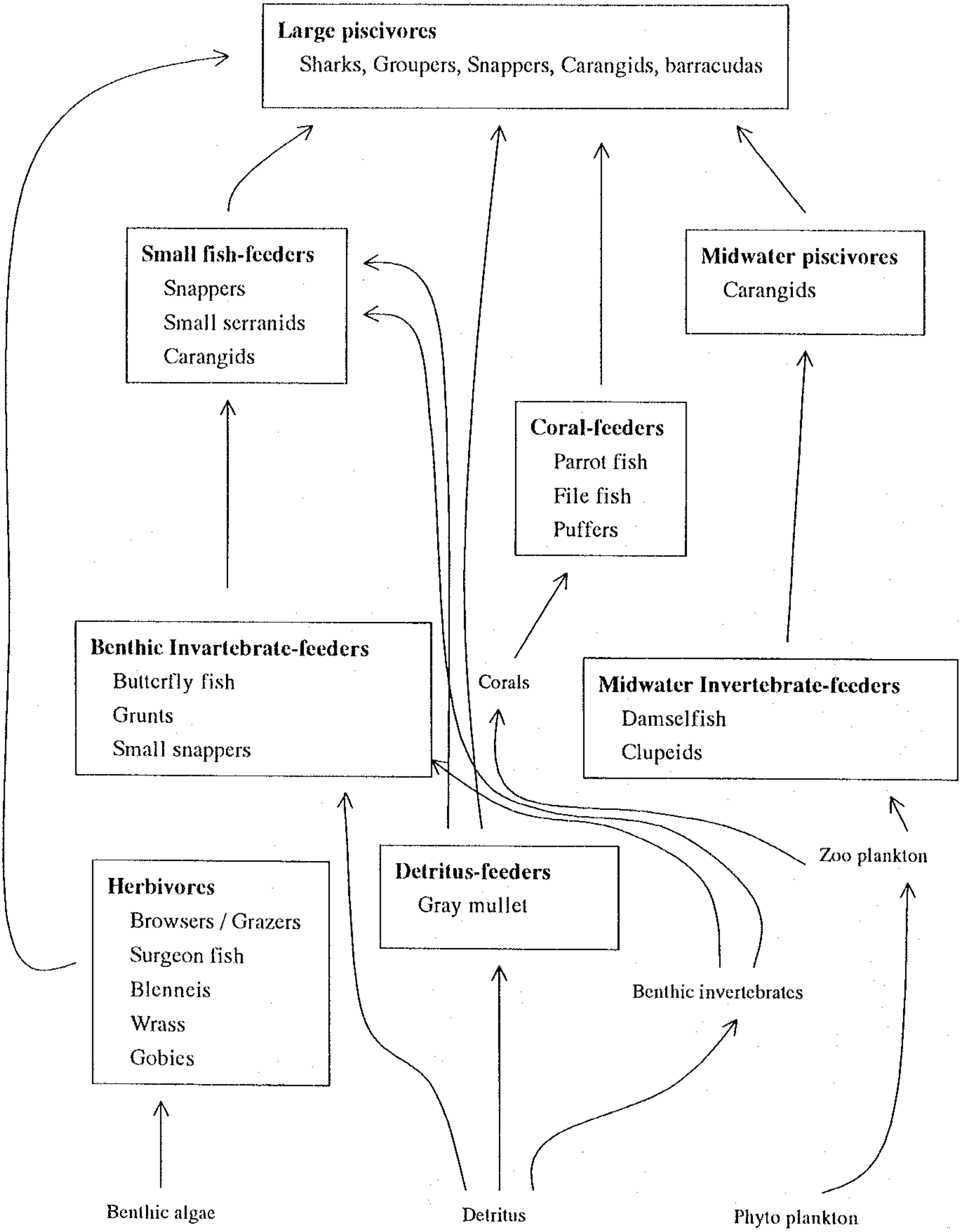


Fig. 54. Trophic relationships among coral reef fishes. (LOWE-McCONNELL 1987).

Serrannidae (groupers); *Cephalopholis miniata, Cephalopholis hemistiktos, Epinephelus summana, Epinephelus fasciatus, Variola louti*

Lutjanidae (snappers); *Lutjanus ehrenbergi, Lutjanus bohar*

Lethrinidae (emperors); *Lethrinus obsoletus, Lethrinus nebulosus, Lethrinus olivaceus*

Haemulidae (sweetlips); *Plectorhinchus gaterinus, Plectorhincus flavomaculatus, Plectorhincus gibbosus*

Chaetodontidae (butterflyfishes); *Heniochus intermedius, Chaetodon austriacus, Chaetodon semilarvatus*

Acanthuridae (surgeonfishes); *Ctenochaetus striatus, Zebrasoma veliferum*

Caesionidae (fusiliers); *Caesio striata, Caesio linaris, Caesio suevica*

Carangidae (jacks); *Carangoides bajad, Caranx sexfasciatus*

Labridae (wrasses); *Coris aygula, Hemigymnus fasciatus, Thalassoma klunzingeri, Cheilinus undulatus*

Pomacentridae (damsels); *Dascyllus marginatus, Neoglyphidodon melas, Pomacentrus trichrous, chromis dimidiata*

Scaridae (parrotfishes); *Hipposcarus harid, Cetoscarus bicolor, Scarus sordidus, Scarus niger, Scarus gibbus*

Mullidae (goatfishes); *Parupeneus barberinus, Parupeneus cyclostomus*

Siganidae (rabbitfishes); *Siganus rivulatus, Siganus argenteus, Siganus luridus, Siganus stellatus*

Pomacanthidae (angelfishes); *Pomacanthus maculosus, Pomacanthus asfur, Pygoplites diacanthus*

The monitor species listed above are not enough to monitor changes in the food chain system in a protected area. It is, however, recommended that a monitoring survey be conducted on these fish species as a start, since researchers are not accustomed to conducting this kind of survey yet. After divers are well trained, more fish species should be selected on the basis of the GCRMN method.

4. Crown-of-thorns Sea-star

The coral team indicated that the numbers of the Crown-of-thorns Sea-star, which is a predator of coral polyps, might increase, because of a drop in the numbers of Lutjanidae (snappers) and Lethrinidae (emperors) which are predators of the Crown-of-thorns Sea-star. It is therefore important to monitor the relationship between these fish speciesand between the fish species and corals.

5. Monitoring site and methods

It is suggested that the area around Jazirat Qumma'an would be an ideal area for the monitoring of these species. This is because;

(1) some of these fish species were observed there,

(2) number of commercial fish, especially Serranidae, is high,

(3) there are many patch reefs with a high coral coverage,

(4) the total number of species is high, and

(5) it has comparatively easier access than other areas.

The monitoring method proposed and adopted to monitor overfishing, in this study was the under-water size estimation. However, GRCMN method describes the disadvantages of this method as follows;

- Observers must be very well-trained and experienced,
- Fish may be attracted towards the divers, or actively swim away from the divers,
- Observer error and bias can occur in estimating numbers and sizes.

For these reasons other methods such as test sampling by fishing net or fishing line to measure fish size, body weight and weight of reproductive organs, might be considered.

The most important thing is to continue these surveys regularly. The Reef Check Survey is undertaken once a year worldwide, and no description about it on GCRMN method. However ,a regular survey at least once a year is recommended.