2.2. MODEL STUDY

2.2.1. Introduction

Al-Wajh Bank was selected as the Model Area using the following criteria.

1. Species diversity
2. Threatened / endemic species
3. Biomass (productivity)
4. Low level of human impact
5. Consideration on managing a marine protected area
6. Logistics of the Study

The Gulf of Aqaba is very rich in coral species, but from other points of view (seagrasses / algae, fishes, benthos, marine mammals / marine turtles, mangrove / coastal vegetation and birds) it is not identified as a very important area. The area has very strict regulations for establishing a protected area in the future. The area is far from the site of the field research office in Al Wajh and it is rather difficult to carry out the Model Study efficiently.

The area around Tiran Islands is rich in all taxa except mangrove and birds. It is also a sensitive area in terms of national security. It is not easy to carry out the Model Study efficiently within the limited time frame.

The area from Duba to Al-Wajh is in intermediate status for all points.

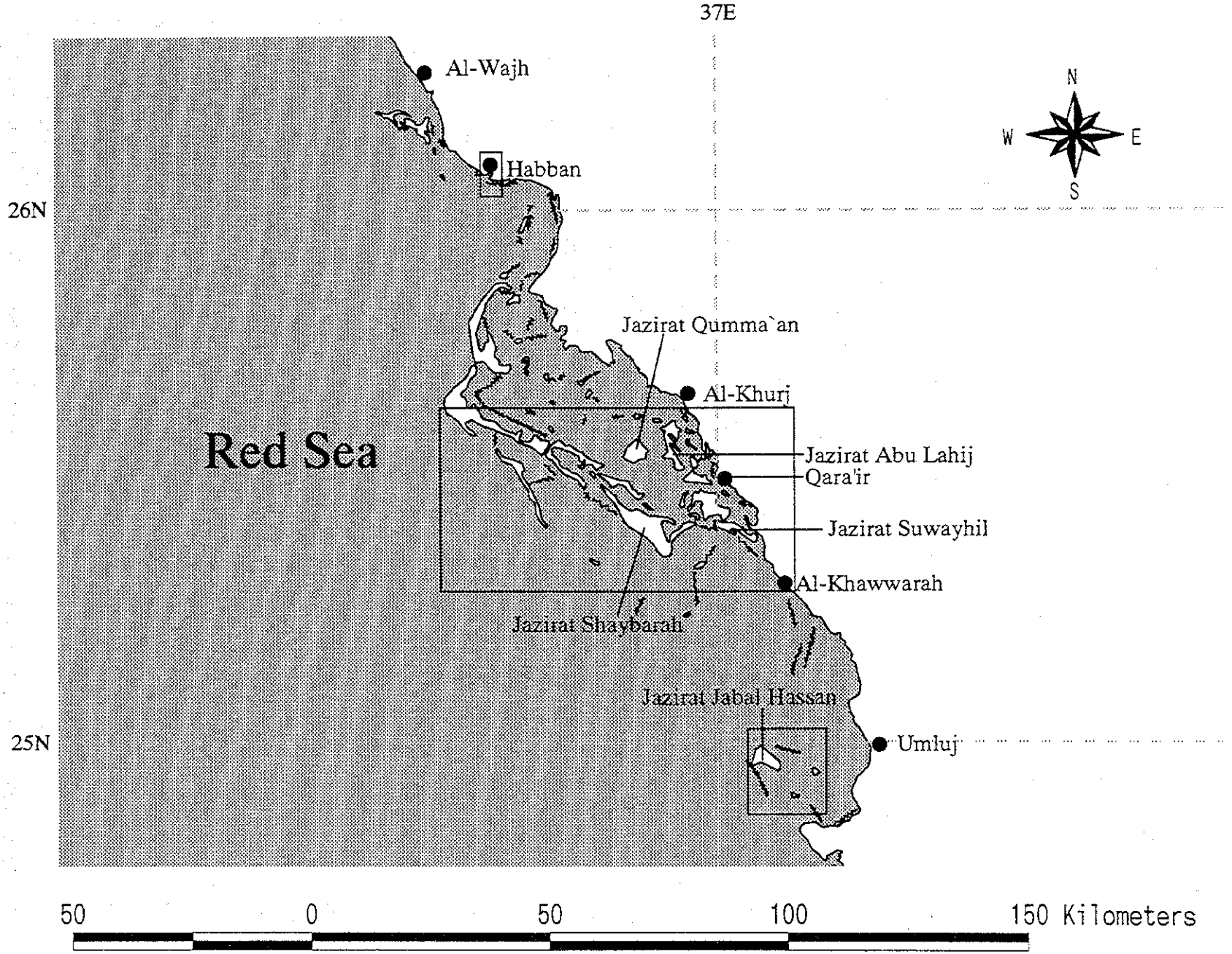
Al-Wajh Bank is rich in all taxa and has a set of all habitats which appear in the Red Sea. The southern section is richer in coral species and it is important for mangroves. The Wajh Bank is already a candidate to be a NCWCD's marine protected area.

The area Umluj / Ra's Baridi is in intermediate status for all points.

The area from Yanbu' to Jeddah is rather poor in all taxa but some species of algae (e.g. *Sargassum* spp. and *Cystoseira myrica*) have the biggest biomass in the Study Area. The main point in this area is that large development has been undertaken and the damage to the biological resources is notable compared with other areas.

Based on these assessments, Al-Wajh Bank was selected as the Model Area (Fig. 6).

Since the Model Area is too large to conduct a detailed biological study, a "cross bank transect" survey was carried out. An area which contains as many habitats as possible was selected as a "cross bank" and it was the southern part of Al-Wajh Bank. In this cross bank, each team conducted their surveys in the most appropriate way to achieve the goal.


37E
Al-Wajh
Habban
26N
N
W
E
S
Jazirat Qumma`an
Al-Khurj
Red Sea
Jazirat Abu Lahij
Qara'ir
Jazirat Suwayhil
Al-Khawwarah
Jazirat Shaybarah
Jazirat Jabal Hassan
25N
Umluj
50
0
50
100
150 Kilometers

2.2.2 Coral

1. Introduction

Coral communities of Al-Wajh Bank (Model Area) were assessed in terms of their faunistic composition, representativeness-uniqueness and 'quality' (i.e. high species diversity, high coral cover, and importance as reservoirs of biodiversity and replenishment, including representation of rare and endemic taxa). The main objectives of the Model Study were to provide NCWCD with information for future Marine Protected Areas (MPA) 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.

2. Methods

2-1. Field

1). Site selection: The surveys were undertaken at a representative range of habitats, including mainland fringing reefs, sharms, island fringing reefs, offshore patch reefs and barrier reefs, as selected from the habitat maps. The sites were accessed by car (mainland) or boat. At each site, the coral communities were surveyed using SCUBA Where reef slopes descended to > 5 m depth, deep (6 - 15 m) and shallow (1 - 5 m) sites were surveyed separately.

2). Bio-inventory surveys: The Bio-inventory surveys from Phase II of the Study were continued, as this method provides the most detailed information for assessing conservation

values of reefs, essential for informed MPA planning. Two types of information were assimilated and recorded on water-proof data-sheets during the ~ 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. These data provided 'ground-truth' points for refinement and accuracy assessment of the Habitat Maps. A standard set of 'environmental' variables, including depths of the sites (maximum and minimum), average angle of reef slope to the horizontal, amount of reef development, level of exposure to waves, sea temperature and underwater visibility were 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 recorded. A comprehensive reference collection of coral specimens and photos was prepared.

3). Reef Check surveys: Quantitative assessment of coral cover in the Model Area was carried out using the Reef Check protocol. The percentage cover of 8 categories of sessile benthos (including live hard coral, dead coral, soft coral, fleshy macro-algae) was estimated using four replicated 20m line transects, laid parallel to the selected depth contour at 1 or 2 depths at each reef. The depths surveyed were ~ 8-10 m and ~ 3-4 m below the reef crest. On each transect, the benthic category located under the transect tape at points of 50 cm interval was recorded. This method provides a rapid means of acquiring quantitative estimates of percent cover of the major structural components of coral reefs. 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.

2-2. Analysis

Bio-inventory surveys

1). Site description: Principal components analysis was used to illustrate relationships between the cover and environmental variables. Relationships between coral community types and these variables were also illustrated using PCA.

2). Community types: Site groups defined by community type were generated by hierarchical cluster analysis of species-abundance in the bio-inventories of each site. 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).

3). Conservation value: The relative conservation values of individual sites and larger areas, in terms of their importance as reservoirs of biodiversity and replenishment, were determined using ecological indices.

Reef Check surveys

Quantitative estimates of average cover of living and dead hard corals and soft corals in the Reef Check sites was calculated from the line transect data.

3. Results

3-1. Reef types and development

The Model Area supports a coral reef tract composed of a wide range of reef types of generally high ecological integrity. These include mainland fringing reefs, island fringing reefs, platform, submerged and 'reticulate' patch reefs, and barrier reefs. Levels of reef development varied widely, from submerged patch reefs with no reef flat, to large platform and barrier reefs with reef flats often > 100 m wide, sometimes supporting sand-coral islands. Notably Al-Wajh Bank supports the longest near-continuous barrier reef system in the

Study Region, stretching for ~ 100 km along the outer seaward edge of the Bank and divided only by several narrow channels (< 200 m width).

3-2. Coral cover

Within the Model Area, living stony coral cover ranged from < 10 % to ~ 75 % (average ~ 42 %), soft coral cover ranged from < 1 to ~ 50 % (average ~ 12 %) and dead coral cover from < 10 % to ~ 30 % (average ~ 8 %). Highest cover of dead corals was caused by predation by crown-of-thorns starfish *Acanthaster planci*, moderate-large populations of which were present on most mid-Bank patch reefs in 1999.

3-3. Species diversity and community composition

Coral communities of the Model Area were composed of ~ 200 species of reef-building stony corals from 58 genera in 14 families of the Scleractinia, with the families Acroporidae, Faviidae and Poritidae being predominant, both in terms of species composition and contributions to coral cover. A further ~ 30 taxa of soft corals, hydrozoan 'fire corals', gorgonians, corallimorpharians and zoanthids were also present, several species of which (*Millepora* and *Sinularia* spp.) were major reef-builders on some reefs.

Some species in the assemblages have very widespread Indo-Pacific distributions, others are widespread in the Indo-west Pacific, others in the central Indo-west Pacific, others only in the Indian Ocean, W Indian Ocean or endemic to the Red Sea. The communities also included five species new to science (*Anacropora sp. nov.*, *Goniopora sp. nov.*, *Cyphastrea sp. nov.*, *Echinopora sp. nov. 1*, *Echinopora sp. nov. 2*). Overall, there was a high degree of homogeneity in species composition, with most sites having a subset of the Model Area's (and larger study region's) species-pool. There were however, major differences in abundance of particular taxa in certain biotopes, and thus clear zonation patterns in the structure of coral

communities, related largely to degree of exposure, water clarity, depth and steepness of reef slope:

1). Exposed - semi-exposed biotopes

Community A, characteristic of mid - lower reef slopes

Mid - lower slope communities were composed of diverse mixed assemblages of encrusting and massive coral taxa. Key indicator coral species include *Montipora danae, Fungia* spp., *Astreopora myriophthalma* and *A. gracilis, Pachyseris speciosa, Stylocoeniella guentheri* and *Leptoseris* spp.

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 (~ 2 m) and high water clarity. Key indicator species include *Acropora gemmifera, Leptoria phrygia, Hydnophora microconos, Stylophora wellsi, Favia stelligera, Favites pentagona, Pocillopora verrucosa* and *Millepora* spp.

2). Sheltered biotopes

Community C, characteristic of turbid areas

Coral communities of sheltered biotopes were developed on the protected sides of patch reefs, in lagoons behind barrier reefs and inside sharms. These communities experience little wave energy (< 0.5 m), although resuspension of fine sediments can reduce water clarity. Key indicator species include *Montipora* spp., *Pavona decussata, Fungia concinna, Cantharellus noumeae, Echinopora fruticulosa* and *E. forskaliana* and *Platygyra lamellina.*

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 *Acropora pharaonis, Oulophyllia*

crispa, Favia rotundata, Diploastrea heliopora, Barabattoia amicorum and *Ctenactis echinata.*

3-4. Present status - disturbances

There was little direct human impact (e.g. destructive fishing, anchor damage, coral mining or pollution) on the majority of reefs. There was also little evidence of coral bleaching. However, some coral communities had been adversely affected by predation by crown-of-thorns starfish *Acanthaster planci*, with populations estimated at up to ~ 100 starfish ha^{-1}. Predation had caused loss of living stony coral cover and shifts in coral community structure and relative abundance at most mid-Bank patch reefs. Specimens of *A. planci* were mostly small (15 - 30 cm diameter). Their small size notwithstanding, most animals were gravid, developing gametes for spawning, probably during the summer period. Such spawning could initiate outbreaks of the starfish on other reefs in the Model Area and study region generally over the next several years. The moderate - high abundance of *A. planci* in Al-Wajh Bank may be related to fishing of predatory fishes in the families Lethrinidae, Balistidae, Serranidae and Lutjanidae.

4. Conclusions

4-1. Conservation value

Reefs of special conservation significance in terms of representativeness-uniqueness and 'quality' (i.e. high species diversity, high coral cover, and importance as reservoirs of biodiversity and replenishment) were widely distributed within the Model Area (Table 10). These sites are mostly located on mid-Bank patch reefs and outer barrier reefs, and provide good representation of the four major coral community types. These reefs should be considered a high priority for future conservation.

Table 10. Sites in Al-Wajh Bank of special management significance in terms of high conservation values. GPS locations are listed in Appendix C1. Reef types: B – Barrier, P – Patch, IF – Island Fringing. Hard coral cover ranks: 2 = 11-30 %, 3 = 31-50 %, 4 = 51-75 %. Coral species diversity, ratings (1-10) within the Model Area for indices of replenishment potential (CI) and rarity (VI), the presence of undescribed species and coral community type are listed for each site. n/a: not applicable – denotes that the attribute was not important in the specific site. Results for these sites are listed in Appendices of the main report.

Site	Reef name	Reef Type	Hard coral cover	Species diversity - all corals	Repleni - shment (CI)	Rarity (VI)	Undes cr- 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

4-2. Management Implications

Al-Wajh Bank supports a wide range of reef types (and other marine and coastal habitats), hosting diverse coral communities including Red Sea endemic corals, presently undescribed coral species and species with apparently restricted distributions. This coral community composition, and the likely high level of ecological connectedness because of larval dispersal in ocean currents, afford Al-Wajh Bank great significance for future conservation. Thus the present study supports the earlier identification by NCWCD-IUCN of Al-Wajh Bank as an Environmentally-Sensitive Area of special conservation importance. Most reefs of the Model Area were little affected by local human impact, other than by reef fishing and some coastal littering near villages. Some reefs in the Model Area appear to be naturally buffered against the worst effects of coral bleaching, because of the prevalence of cool water upwelling and their depth. The major threat to reef status in the Model Area at present arises from predation by crown-of-thorns starfish. The starfish populations should be monitored and if deemed necessary, control programs may be implemented on worst-affected reefs.

Because Al-Wajh Bank is already subject to a degree of human use, specific decisions regarding future Marine Protected Areas zoning and management options may require consideration of socio-economic and other factors additional to reef conservation values. Within these constraints, one potential approach to future MPA planning is the creation of cross-Bank zones of high conservation value (Biological Reserves or Special Nature Reserves), from the mainland coast to the outer barrier reef system. For coral communities, three sub-areas within the Model Area were of particular conservation significance:

- Central Bank from mainland coast – J. Qumma'an – channel – outer barrier reefs;
- Southern Bank from mainland coast – reticulate patches – J. Shaybarah – outer barrier

reefs;

- South of the Bank to J. Jabal Hassan, from mainland coast – patch reefs – outer barrier reefs.

In the overall zoning scheme for Al-Wajh Bank and adjacent waters and reefs, these sub-areas (zoned for highest protection) could be 'nested' within zones of lower conservation status (Nature Reserve, Resource Use Reserve).

1). 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. It is recommended that NCWCD continue to monitor the Reef Check sites (or a representative sub-set thereof) on an annual basis. This would require development of a dedicated coral reef monitoring team. Training during the present study has fostered sufficient expertise within the NCWCD Marine Department for development of such a team. Various monitoring programs, most linked with Reef Check and the Global Coral Reef Monitoring Network (GCRMN), already exist in many Indo-Pacific countries, and consideration should be given to Saudi Arabia (through NCWCD) becoming an official member of both Reef Check and GCRMN. This would facilitate the continued development of coral reef monitoring and research within the Kingdom, essential adjuncts to future MPA management.

2). 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

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 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. A total of 59 quadrat spots were surveyed in the bank transect. 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.

2. Results

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

2-1. 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. Seagrass 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 occurred at the depth of 0.5 m at maximum.

2-2. 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, sustaining macro algae of the genera *Sargassum*, *Cystoceira* and *Turbinaria*. A drifted *Sargassum* community and a drifted *Cladophora* (green algae) communities were found in a sandy

bottom area which was protected against swell and strong wind-driven waves. Turf and small algae were widely distributed outside and inside the barrier reef and were dominant on reef flats which had little or no silt on the hard substrate.

In the sabkhahs of the super-tidal zone, Cyanophycea coverage was high. In the subtidal zone, a Cyanophycea community was found in calm areas behind the barrier reef, where silt particles originated from coral reef are accumulated and other vegetation can not grow on.

2-3. 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 northern boundary at the coast in the vicinity of Jeddah (ALEEM 1979). The finding of this Study extends its distribution boundary to the north.

3. Discussion

3-1. Seasonal difference

Though the number of species showed little difference between spring and summer, a seasonal difference appeared in the coverage of macro algae. *Turbinaria* was abundant in spring, and was observed to start diminish in summer. *Sargassum* and *Cystoceira* showed higher coverage in summer than in spring. These findings indicated that *Turbinaria* reached its maximum biomass in summer, while *Sargassum* and *Cystoceira* might become most abundant in autumn, then they began to diminish, leaving only roots on the substrate, and later they again started to grow.

3-2. 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 seagrasses 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 deposit 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 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 provide 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 seagrasses and algae where silt particles do not deposit and herbivores can not reach under the rough weather condition.

3-3. 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

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.

2.2.4. Fishes

1. Methods

A belt transect method was used to understand ecological changes of fish population of the area. Indicator species which are important for their ecosystem were selected based on 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 and Global Coral Reef Monitoring Network (GCRMN) protocol were undertaken. Thirty-three indicator fishes were selected for monitoring.

2. Results

2-1. Indicator species

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

The most often observed species was Redsea Bannerfish *Heniochus intermedius*, followed by Indian Ocean Longnose Parrotfish *Hipposcarus harid* and Yellowbar Angelfish *Pomacanthus maculosus*.

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

3. Discussion and conclusion

3-1. Overfishing and monitoring

In this Model Study, monitoring the issue of overfishing was tried as one example.

Three fish species are selected from the commercial fish families as representatives of each family. This is because many of them were often on the menu at restaurants along the highway. They were observed at almost every survey spot: the number and the size of

individuals are shown in Fig. 7. There are many species of commercial fish families around Jazirat Qumma'an, because all three main commercial fish species are observed there.

The difference in the number of individuals and mean length of commercial fishes between the two surveys (February and June 1999) is shown in Fig. 8. The survey was conducted at the same spots on the east and west sides of Jazirat Qumma'an in both stages. In this Model Study, a method has been introduced to examine the issue 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 understand the effects of fishing in the area, further monitoring study is strongly recommended.

3-2. Monitoring of species

Although 33 fish species were selected as the monitoring species, only three species were observed at almost all survey spots. To continue monitoring fishes in Al-Wajh Bank, the monitoring species are recommended to be changed.

3-3. Monitoring site and methods

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

(1) some of these fish species were observed,

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

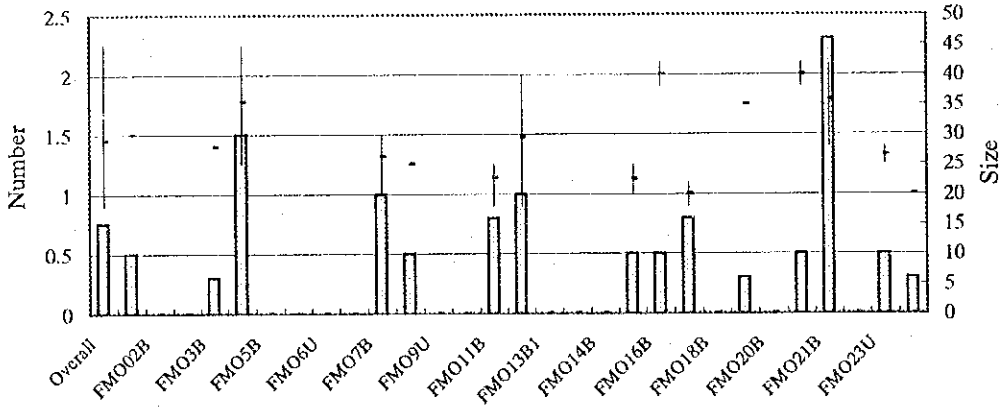
(3) there are many patch reefs with high coral coverage,

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

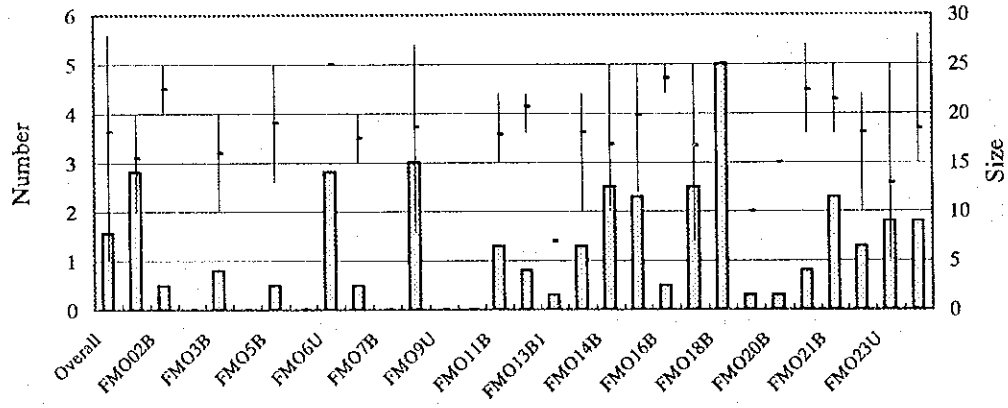
(5) it has comparatively easier access than other areas.

As a monitoring method for the issue of overfishing, an underwater size estimation method was proposed and undertaken in this study. But other methods might be considered, such as test sampling by fishing net or fishing line to measure fish size, body weight and

Summana Grouper (*Epinephelus summana*)



Indianocean Longnose Parrotfish (*Hipposcarus harid*)



Orangespotted Trevally (*Carangoides bajad*)

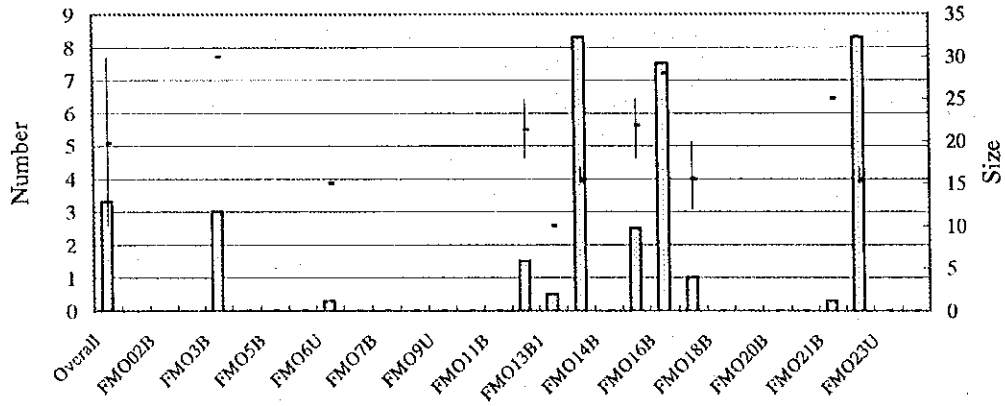


Fig. 7. Number and size of three main commercial species.

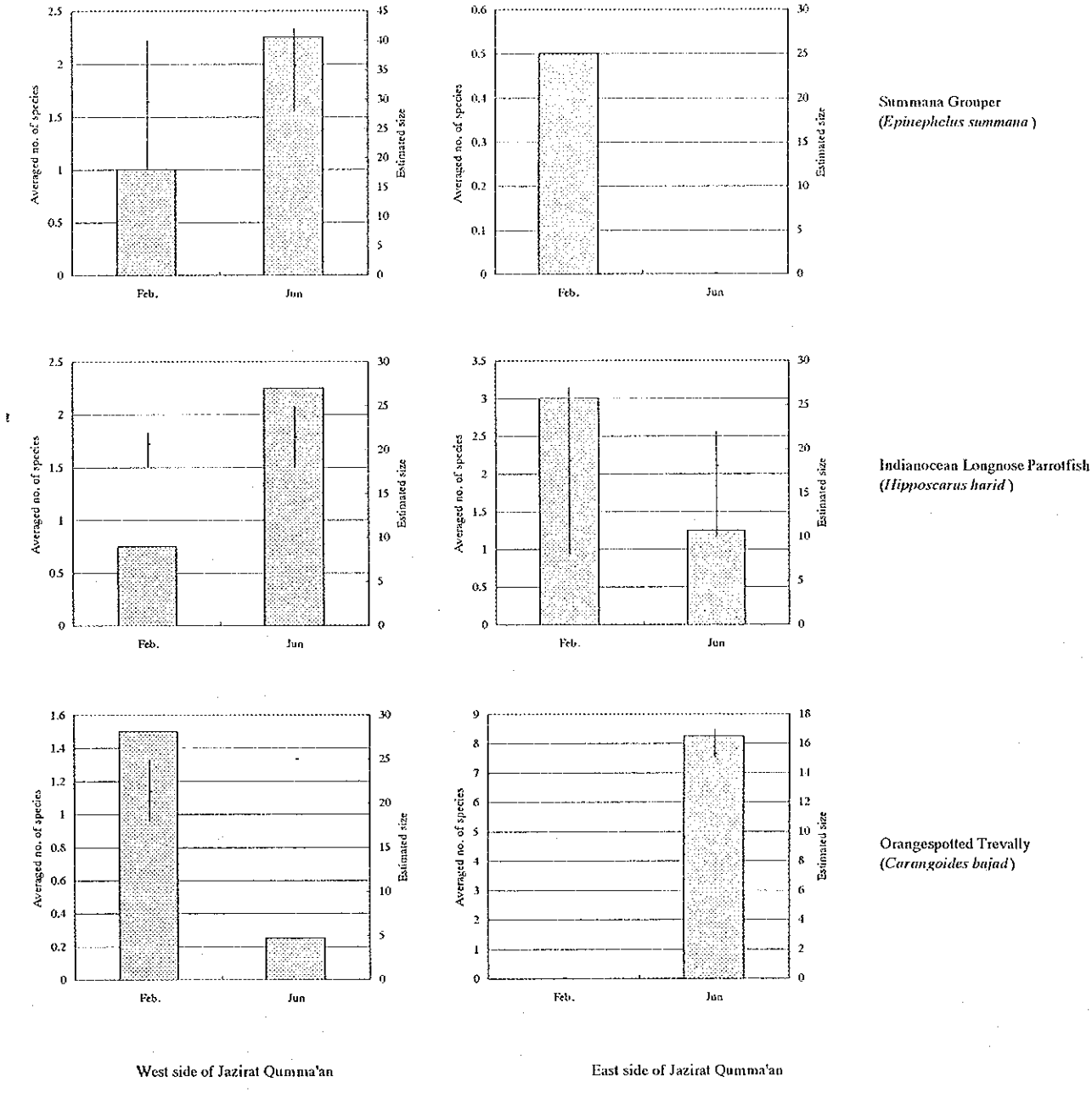


Fig. 8. Difference in numbers of individuals and mean length of commercial fish in Feb. and June 1999.

weight of reproductive organs. It is suggested that the most important thing is to continue these surveys regularly -- at least once a year.

2.2.5. Benthos

1. Methods

The monitoring survey method should be easy and standardised so that monitoring can be carried out by anybody. For this purpose, selection of monitoring species should meet the following requirements;

- common occurrence in the Red Sea;
- species that can easily be found and identified; and
- species typical for each habitat such as tidal zone and bottom type.

Prior to the survey, 17 monitoring species were selected (Table 11).

Table 11. Species monitored in the benthos survey.

Phylum	Scientific name	English name
CRUSTACEA	*Scopimera* cf.*globosa*	stalk-eyed crab
CRUSTACEA	*Macrophthalmus* cf.*convexus*	Stalk-eyed crab
CRUSTACEA	*Uca* cf.*lactea perplexa*	fiddler crab
CRUSTACEA	*Uca* cf.*tetragnon*	fiddler crab
ECHINODERMATA	*Diadema setosum*	diadematid
ECHINODERMATA	*Echinometra mathaei*	echinometrid
ECHINODERMATA	*Ophiocoma scolopendrina*	ophiocomid
MOLLUSCA	*Tridacna maxima*	clam
MOLLUSCA	*Dendropoma maxima*	worm shell
MOLLUSCA	*Conus arenatus*	Sand Cone
MOLLUSCA	*Cellana eucosmia*	limpet
MOLLUSCA	*Acanthopleura haddoni*	chitons
MOLLUSCA	*Nerita polita*	slipper winkle
MOLLUSCA	*Pinctada margaritifera*	Black-lip Pearl Shell
MOLLUSCA	*Pedum spondyloideum*	scallop
MOLLUSCA	*Coralliophila violacea*	Violet Coral Shell
MOLLUSCA	*Lambis truncata sebae*	Spider Conch

A quadrat (3m x 3m) was set up on the typical bottom of a survey spot, and an overview of the bottom conditions such as mud, sand, bedrock, hard coral or seagrass was recorded. The number of each monitoring species found in the quadrat was counted. However, in the case of stalk-eyed crab *Scopimera* cf.*globosa*, stalk-eyed crab *Macrophthalmus* cf.*convexus* and *Uca* species, only nest holes were counted, because they hide in their holes

when observers approach.

Among these species, the body size of the clam *Tridacna maxima*, Black-lip Pearl Shell *Pinctada margaritifera* and Spider Conch *Lambis truncata sebae* were measured and recorded. This is because they are caught for consumption and monitoring information is needed. In addition, if there were abundant or especially interesting species, these were recorded even if they were not among the species selected for monitoring.

In principle, surveys of three quadrats per spot were conducted and the average number of observed species calculated.

2. Results and conclusion

The locations and habitats types of survey sites and spots in the benthos survey are shown in Fig. 9. The number of survey sites is 17 and number of survey spots is 48. It was found that various microhabitats existed in each survey site.

The species of benthos which were observed in the Bank-transect Area could be observed anywhere in the Study Area.

The most characteristic habitat in the Model area is the mangrove habitat and the most important site among these is the one at Duqm Sabq. The reasons are that *Macrophthalmus* species and *Uca* species which are important for the tidal-flat ecosystem can be observed at this site, and sites where these species can be observed are limited in the Study Area.

Since the intertidal zone has a complex bottom of sand and bedrock or patch reef, the number and abundance of benthos are usually higher than at other survey sites in the Study Area. However, the number and abundance of benthos in the intertidal zone of the Model Area are lower than at other sites outside Al-Wajh Bank. This is because almost all bottoms of the intertidal zone in the Model Area are covered with sand or silt. For example, the number

and body size of *Tridacna maxima* observed at a coral reef in Al-Wajh Bank are smaller than at other sites outside the bank.

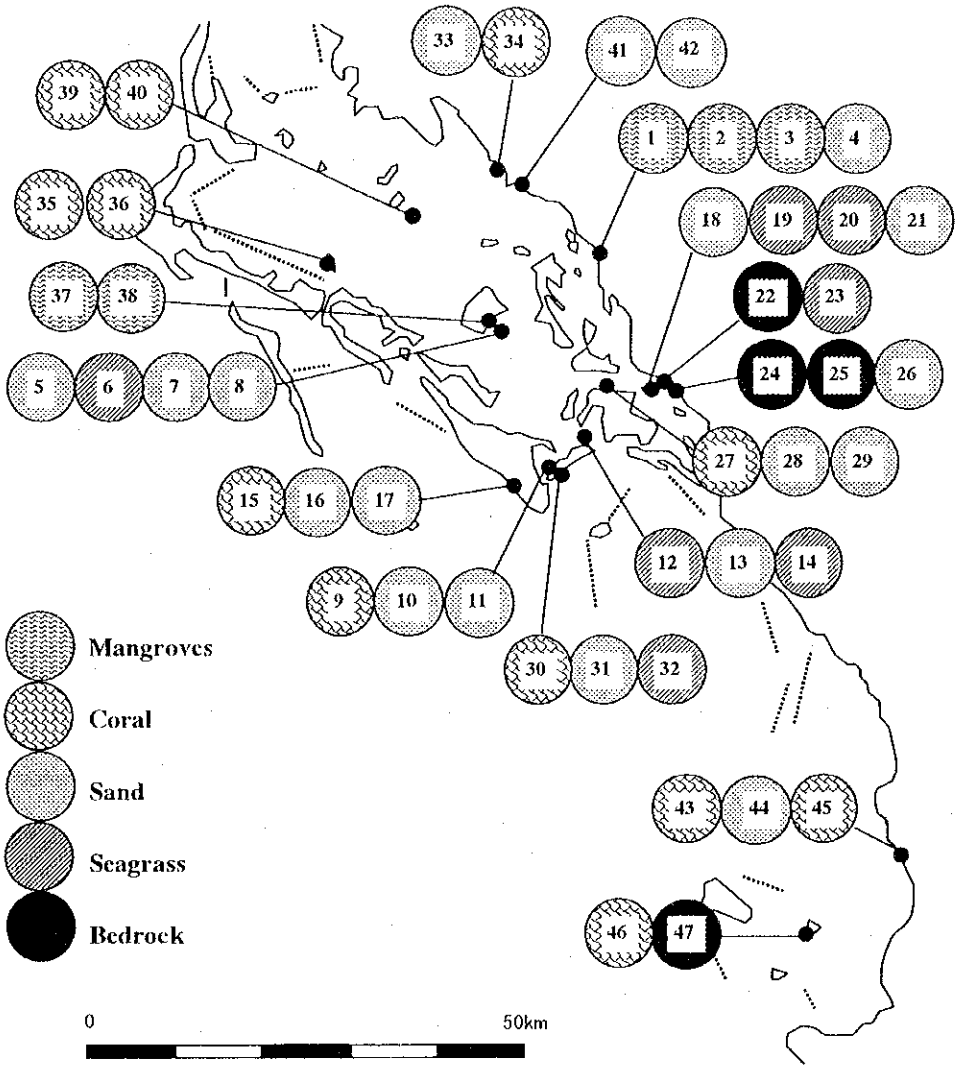


Fig. 9. Locations and habitat types of survey sites and spots in the benthos survey.

The characteristics of the benthos fauna of the Model Area are summarised as follows:.

1. Number of species is low
2. Abundance of each species is low, and
3. Body size of *Tridacna maxima* is smaller than in other areas.

Al-Wajh Bank is a relatively closed environment, and the sea water between the inside and the outside is not well exchanged: the sea water of the Model Area is therefore muddy. An environment like this is suitable for macro benthos which live beneath the sand or the silt rather than for megaro benthos which is the main subject of this study. It is assumed that macro benthos such as Polychaeta or Amphipoda are important as a secondary producer or food for benthos-feeding fish in Al-Wajh Bank. A survey on macro benthos could give an accurate understanding of the ecosystem of the Model Area.

2.2.6. Marine Mammals / Marine Turtles

1. Marine Mammals

1-1. Methods

The aerial transect survey on Dugong for the whole Al-Wajh Bank aiming to evaluate the status of the Dugong population was conducted on 15 –16 February 1999. Adjacent seagrass beds near to Al-Habban and Qara'ir coast guard stations and east of Shaybarah island were examined for evidence of Dugongs.

The present survey suggested a population of over 335 Dugong in the Al-Wajh Bank, with little human disturbance. The calf ratio was 4.7%. A 22 % calf ratio was reported in Hervey Bay, Australia in 1988, 1992 (PREEN 1995). Whether the calf ratio in the Model Area indicates reproduction condition, a high calf mortality rate, or bias in the method used needs to be carefully evaluated.

The sighting of Dolphins was recorded though the species was not identified. The calf ratio was found to be 16 %. Only Indo-Pacific Humpback dolphin, *Sousa chinensis* was confirmed in the Model area in 1998. Two species; Indo-Pacific Humpback Dolphin and Red Sea Bottle-Nosed Dolphin inhabit inshore areas, which means they are relatively vulnerable to habitat loss. The status and condition of the species need to be evaluated carefully.

In front of Ghawash coast guard station where fishermen told of frequent Dugong sightings, the seagrass beds grow in the area protected to some degree from waves by the patch reef. Five species of seagrasses were found of which only *S. isoetifolium* was apparently grazed by Dugong.

1-2. Conclusions

A Dugong population of over 335 was estimated in Al-Wajh Bank. The high sensitivity of the population was suggested by the calf ratio and limited seagrass habitats. The

intact environment of the Model area is the factor most contributing to their survival in the harsh environment. The seagrass habitats in Al-Wajh Bank should be given special attention for conservation management. Two inshore species of Dolphins; Red Sea Bottle-Nose Dolphin and Indo-Pacific Hump Back Dolphin need to be carefully evaluated in Al-Wajh Bank.

2. Marine Turtles

2-1. Methods

The two major nesting islands for Hawksbill Turtle; Jazirat Jabal Hassan and Jazirat al-Waqqadi were selected for Model Area Study. Nesting beach, nesting female and nest examination surveys were conducted in May and June 1999.

1). Nesting Activity

Thirty one trucks and two nests of Hawksbill Turtle, 15 trucks and 2 nests of Green Turtles were observed in Jazirat Jabal Hassan areas. One Green Turtle female laid eggs during the survey. At Ra's Baridi, 13 new trucks of Green Turtle were found on the beach. On Jazirat al-Waqqadi where over 44 trucks and 39 nests were counted in the previous year, 38 trucks and 15 nests were found in this season. All of the trucks and nests were of Hawksbill Turtles.

2). Nest examination of Hawksbill Turtle

The average clutch size was 56.5±13.1 (n=4), the number of yolkless eggswas 31.8 ±24.5 (n=4). The distance of the nests from the sea water at high tide was between 3.5 and 6.7 m. All nests were located within 3 m from the nearest vegetation but directly exposed to the sun. The reproduction rate of Hawksbill Turtles in Model area seems to be around less than half of those in the Seychelles, Indian Ocean. The strait carapace length of a nesting Hawksbill Turtle at al-Waqadi is 660 mm and body weight is 30 kg, which is comparatively small for a nesting female.

3). Sightings of marine turtles during the survey

Although coral reef habitat; a primary habitat for Hawksbill turtle, covers quite an extensive area in Al-Wajh Bank, the sighting of turtles was very limited. Only one juvenile Hawksbill turtle was sighted during the survey. All sightings of Green turtles including non-recorded one were estimated at sub-adult to adult size.

2-2. Conclusion

1). Hawksbill Turtle

In the Model Area, a relatively limited population due to the food availability in the area is suggested. The significant nesting activities take place in May – June. However, it needs to be confirmed whether significant nesting activities take place in September- October. The characteristics of the reproduction indicate high sensitivity of the turtle to any habitat loss or modification, exploitation, accidents and other human activities. The exploitation of marine turtles by humans takes place but it is a quite incidental event. The Model Area supports resident and nesting populations of Hawksbill Turtle though the habitats are of marginal condition or sub-optimum for them. The key factors of their survival need to be carefully studied for the purpose of conservation management.

2). Green Turtle

The results suggested there are only a few resident Green Turtles in the Model Area. The temperature suggests that nesting activity is from April to June at Ra's Baridi. It is essential to know the peak nesting season to have effective monitoring programmes. Studies on the migration pattern of the nesting population of Green Turtles and the condition of the resident population in the Model Area are needed for development of conservation management programmes.

3). Food availability (seagrasses and sponges), their bio-reproduction and fragility

Seagrasses and spongesare the main food for Hawksbill and Green Turtles respectively. Their distribution, abundance and their reproduction in Model area need to be evaluated to develop effective conservation management.

2.2.7. Mangroves / Coastal Vegetation

1. Methods

1-1. Quadrat census survey

In order to set up monitoring points for vegetation, six typical transect lines which had various plant communities were set on Duqm Sabq and Jazirat Qumma'an in the Model Area. In addition to them, one mature *Avicennia marina* community at Al-Quff was added in order to provide comparative data on community structure and soil conditions. Totally, the number of sites (quadrats) was 18, including eight in mangroves. In the mangrove sites, seven items (e.g. DBH) were measured for each individual Numbered PVC tags were attached to the stems of all mangrove individuals of more than 1cm DBH in the five typical mangrove sites. With regard to the sites of salt marshes and desert vegetation, at least four items (scientific name, location, height and branch spread) were recorded.

1-2. Soil survey

In order to understand the relationship between vegetation and its soil conditions, soil surveys were conducted at the same sites as of the quadrat census survey. Items measured in the soil survey were Eh (redox potential), salinity, pH, temperature, soil colour, soil type and site drainage condition. All these items were measured or recorded at eight typical mangrove sites. Soil samples at 10 cm and 40 cm depths were collected in salt marshes and desert vegetation at the same sites as in the quadrat survey. After transporting soil samples to the field office in Al-Wajh, EC (electrical conductivity), salinity and pH were measured in a soil / water suspension. After dividing the air-dried soil, the proportion of the particles within the soil was calculated according to the weight of each particle group.

1-3. Mapping of vegetation

Detailed vegetation maps (at the scale of 1:10,000) of two parts in the Model Area (around Duqm Sabq and Jazirat Qumma'an) , the eastern part of Jazirat Umm Rumah and Al-

Quff, were drawn by using the aerial photographs and results of the field surveys. Basically, legends were decided according to the dominant species; however, mangroves were divided not only by dominant species but also according to height and density.

2. Results

2-1. Quadrat census survey

1). Zonation

The zonation pattern of the vegetation was very clear in each transect line. A common zonation pattern from the seashore to the inland was as follows ; mangrove thickets were distributed in lagoons or tidal creeks with shallow water, behind the mangroves, the salt marshes consisted of *Halocnemum strobilaceum* and *Arthrocnemum macrostachyum* forming a dense sub-shrub community in a narrow belt parallel to the shoreline. *Halopeplis perfoliata* formed a community with low coverage in alluvial sandy flats behind the salt marshes, and it is replaced gradually by a *Zygophyllum album* community far from the shoreline.

2). Community structure of salt marshes and desert vegetation

The plant distribution of salt marshes and desert vegetation in the sites had peculiar patterns according to the dominant species. It has own community structure of coverage, density, population size and height.

3). Mangrove types

Mangroves in the surveyed area varied in community structure such as density, height and growing form. According to the growing species, habitat and community structure, mangroves including mature mangrove of Al-Quff are categorised as six types.

4). Mangrove tree census survey

Summary of the indicative values related to the community structure is shown in Table 12. The crown size increased in proportion to its height, but its ratio was different

among the sites. The crown of *A. marina* tended to be bigger than that of *R. mucronata*.

Table 12. Summary of the indicative values in five sites with numbered tags.

Site.	Dominant species	Quadrat size (m^2)	Number of individuals	Density (/100m^2)	Mean height (m)	Mean DBH (cm)	Mean diameter at stem base (cm)	Total basal area at breast height (cm^2)		Total basal area at stem base (cm^2)	
								Actual data	Calculated for 100m^2	Actual data	Calculated for 100m^2
Site 1	R.m	200	57	28.5	2.1	1.9	3.3	418.6	209.3	580.1	290.1
	A.m		27	13.5	2.6	3.3	10.6	1326.7	663.4	3790.6	1895.3
	A.m, R.m		84	42	2.4	2.6	6.9	1745.4	872.7	4370.7	2185.36
Site 2	R.m	25	14	56	3.0	5.0	5.1	631.9	2527.4	326.7	1306.9
Site 7	A.m	50	17	34	1.9	2.3	5.2	401.3	802.7	933.8	1867.7
Site 15	A.m	100	15	15	1.8	1.6	10.3	333.2	333.2	1528.4	1528.4
Site 18	A.m	100	28	28	3.6	5.6	9.5	1361.5	1361.5	2606.9	2606.9

Rm : *Rhizophora mucronata*, Am : *Avicennia marina*.

2-2. Soil survey

1). Soil conditions in mangrove sites

The summary of the soil survey in mangrove sites is shown in Table 13. Though there was no clear difference between *R. mucronata* sites and *A. marina* sites in Eh (redox potential), Eh seemed to indicate the degree of mangrove development among the sites. The soils of the surveyed sites was alkaline, pH ranged from 7.2 to 7.9. Almost all sites had a salinity (at 10 cm in depth) of less than 4.7%. But the salinity of site 8 located in the tidal mud of inner Jazirat Qumma'an was exceptionally high at 9.4%.

Table 13. Summary of the soil surveys in mangrove sites.

Place.		Duqm Sabq		Jazirat Qumma'an			Al-Quff	
No.		1	2	3	4	5	6	7
Site No.		TD2-site 1	TD3-site 15	TQ1-site 2	TQ2-site 7	TQ2-site 8	site 18	site19*2
Date (1999)		Jun.5	Jun.6	Jun.8	Jun.14	Jun.14	Jun.13	Jun.14
Dominant*1		Rm + Am	Am	Rm	Am	Am	Am	Am
Height (m)		2.5 - 4	2 - 2.5	2.5 – 3.9	1.5 – 3	2.5 - 3	1.6 - 5.1	1 – 2
	Depth(cm)							
Soil type	10	Mud, sand	Mud, sand	Mud, sand	Sand	Mud, sand	Mud	Sand, mud
	40	Mud, sand	Sand	Mud, sand	Sand	Mud, sand	Mud	Sand, mud
Eh(mV)	10	-66.0	-37.1	-37.9	379.3	329.3	-74.9	84.0
	40	-93.8	65.1	-86.8	384.3	177.7	-137.1	44.0
PH	10cm	7.4	7.5	7.5	7.9	7.3	7.4	7.2
	40cm	7.3	7.3	7.3	7.7	7.3	-	-
Salinity(%)	10cm	3.8	2.9	4.7	3.1	9.4	4.0	4.1
	40cm	3.5	3.1	4.2	3.2	-	-	-

* 1. Rm : *Rhizophora mucronata*, Am : *Avicennia marina*. *2. Soil survey was only carried out in the site.

2). Soil conditions in salt marshes and desert vegetation

The soils of these sites were generally alkaline with a pH range from 8.2 to 9.6. The salinity (in 1 : 5 soil / water suspension) ranged from 0.0 to 1.3 %. Each vegetation type had its own salinity range. Usually, the upper part (at 10 cm in depth) tended to show higher salinity than the deeper part (at 40 cm in depth).

3). Vegetation maps

A. marina dwarf shrubs with less than 2m in height were distributed along the shoreline in southern Duqm Sabq. The vegetation of Duqm Sabq was a relatively monotonic structure. *A. marina* communities with various heights of 2 - 6 m were distributed mosaically along the seashore in Al-Quff. The vegetation structure in Al-Quff was heterogeneous comparing with the other areas. *R. mucronata* was distributed along the tidal creeks in Jazirat Qumma'an and Jazirat Umm Rumah. The inner tidal mud area adjacent to these tidal creeks submerged by the seawater at the high tide, were covered by *A. marina* dwarf thickets, *Arthrocnemum macrostachyum, Halocnemum strobilaceum* and Cyanophyceae mats.

3. Discussion and conclusion

3-1. Mangrove distribution in Al-Wajh Bank

Mangrove distributions in Al-Wajh Bank tend to concentrate in the eastern and/or southern parts of offshore islands. In Al-Wajh Bank, through the seasons north – west winds prevail, and the north – west parts of offshore islands directly receive strong winds and waves. The downwind side with less winds and waves is considered a more favourable habitat for mangrove growth and settlement.

3-2. *R. mucronata* distribution

The northern tidal creek having *R. mucronata* in Jazirat Umm Rumah (around 25°44'00''N) is considered the northernmost place of the whole distribution of *R. mucronata* in Arabian regions.

3-3. Total destruction of R. mucronata community on Umm Rumah

Total destruction of the *R. mucronata* community is caused by sand sedimentation. Though this phenomenon occurs naturally, the status of the *R. mucronata* community needs to be monitored in order to protect the *R. mucronata* population from extinction.

3-4. The influence of grazing on mangroves

Damaged mangroves grazed by camels were found partly on the mainland coast. On the basis of these observations, the depth of seawater is considered as the most effective factor allowing camels to reach the mangroves. The limit of seawater preventing camel advance is assumed to be approximately 50 cm in depth.

3-5. The age of mangroves affected by cutting

Traditionally, mangroves were used for not only firewood but also timbers for building huts and boats in Arabian regions, and *R. mucronata* is preferred to *A. marina* (ORMOND et al. 1986). After the discovery of the oil fields, the use of mangroves is supposed to have reduced gradually. Considering both the change in life style of local people and the

present state of the mangroves as mentioned above, it is assumed that the age of mangroves is closely connected with the mangrove utilisation in the past.

3-6. Succession

In the case of site 1 in Duqm Sabq, *R. mucronata* coexisted with *A. marina*. The former individuals seemed to be younger than the latter, and *R. mucronata* individuals were distributed mainly at the landward edge. From these facts, a hypothetical process of mangrove formation in this site is assumed as follows. Initially *A. marina* germinated as the pioneer species and settled in a lagoon with shallow water, and their stems and roots accumulated sands and mud as they grew in the site. After the formation of *A. marina* thickets, floating viviparous seeds of *R. mucronata* reached the site from the offshore island with *R. mucronata* community. It settled the site and started growing under the protection from winds and wave by *A. marina*. *R. mucronata* seedlings were abundant around the prop roots in site 1, though a couple of *A. marina* seedlings were also found. This fact suggests that the regeneration of *R. mucronata* is more active than *A. marina* in the site. From the viewpoint of the dynamics of mangrove community, it is recommended to continue monitoring this site.

3-7. Soil – vegetation relationship

Since the soil conditions are so much changed by seasonal and daily tidal movements, the information obtained by this survey is not sufficient to understand the soil conditions of the sites. More detailed surveys concerning the mangrove soils will be needed in the future.

3-8. Evaluation on the area of Al-Wajh Bank, for selecting a marine protected area

The two offshore islands of Jazirat Qumma'an and Jazirat Umm Rumah, which have tidal creeks of *R. mucronata,* are evaluated as the most valuable in Al-Wajh Bank. Also Jazirat Shaybarah should be evaluated as of high value, because of its large distribution of *A. marina* communities. Duqm Sabq on the mainland has an *R. mucronata* community mixed with *A. marina*, though its area is small. This site is regarded as an important site for

monitoring.

3-9. Recommendation

Through the Model Area Study, the present situation of mangroves / coastal vegetation in Al-Wajh Bank has been understood, but is not sufficient to understand the vegetation structure, dynamics and function. A more detailed and deeper study on the basis of the result will be needed in the future. The recommendations concerning the mangroves / coastal vegetation are as follows ;

① Resurvey of the permanent quadrats

② Survey of tidal flooding / inundation

③ Survey of grazing pressure

④ Social survey related to mangrove use, in the past and present

⑤ Using the aerial photographs taken in the past

2.2.8. Birds

1. Methods

The Birds team co-ordinated its field survey work closely with the Mangroves / Coastal Vegetation team in order to understand the status of the avifauna together with the vegetation on which the bird species depend heavily for their survival.

Three survey sites were selected using the aerial photographs and the habitat maps; two on the mainland (Duqm Sabq and Qara'ir) and one on an island (Jazirat Qumma'an). The criteria for selecting the areas were as follows; an area which represents one of the major habitats in the Model Area; and an area with easy access, where permanent monitoring lines can be set up.

At the sites, census lines were set up: lines of about 2.5 km on the mainland and lines of about 1.2 km on the island. Lines were set up in different habitats in the sites. Four lines (Line 1 – Line 4) at Duqm Sabq, two lines (Line 5 – Line 6) at Jazirat Qumma'an and one line (Line 7) at Qara'ir were set up.

The study was conducted in two different seasons: February 1999 and June 1999.

In June 1999, Al-Quff, about 100 km north of Al-Wajh, was surveyed to compare the avifauna with the ones in Duqm Sabq and on Jazirat Qumma'an. It is outside the Model Area.

Binoculars of 10 x 40 and 8 x 30 were used for the survey. The bird list is based on the checklist in PORTER et al. (1996).

2. Results

Habitats and number of recorded species on each line are summarised in Table 14.

2-1. Species and habitats

The composition of bird species and number of individuals at each line are different. This is believed to be a result of the differences between their habitats. They are also affected

Table 14. Survey sites, lines, habitats and number of recorded bird species.

Survey site	Line	Habitat	No. of recorded species	
			February	June
Duqm Sabq	Line 1	The line is located along the shoreline. It is topographically flat. At the starting point, there is a mangrove thicket (mainly *Avicenia marina*), and at the end of the line, there is also a mangrove thicket (mainly *Avicennia marina*). The vegetation type along the line is a salt marsh with *Arthrocnemum macrostachyum* and *Halocnemum strobilaceum*.	30 spp.	15 spp.
	Line 2	The line is located about 500m inland Line 1. It is topographically flat. Its vegetation cover is very low and it is dominated by *Halopeplis perfoliata* and *Zygophyllum album*.	6 spp.	2 spp.
	Line 3	The line is located along the shoreline. It is topographically flat and there are small sand dunes. The vegetation cover is low and is dominated by *Zygophyllum album*. The soil is mainly sandy.	25 spp.	7 spp.
	Line 4	The line is located about 500m inland Line 3. Its topographical feature is more complex than the one of Line 2. Several small wadis are developed in the area. The vegetation is dominated by *Zygophyllum album*.	10 spp.	0 spp.
Jazirat Qumma'an	Line 5	The line is located on the island. It extends inland from the shoreline. It is topographically flat. There are mangrove thickets (*Avicennia marina*), salt marsh and dry land.	4 spp.	5 spp.
	Line 6	The line is located on the island. It runs along and in mangrove thickets (*Rhizophora mucronata* and *Avicennia marina*).	7 spp.	7 spp.
Qara'ir	Line 7	The line is located along the shoreline. It is topographically flat. The vegetation cover is very poor and there are a few small patches of *Halopeplis perfoliata*. The soil is mainly sandy.	18 spp.	8 spp.

Table 15. Lines and species.

	English name	Scientific name	Mean number of individuals													
			Line 1		Line 2		Line 3		Line 4		Line 5		Line 6		Line 7	
			February	June	February	June	February	June	February	June	February	June	February	June	February	June
1	Western Reef Heron	*Egretta gularis*	1.0	1.3			0.8	0.7			0.3		0.3		1.5	0.3
2	Goliath Heron	*Ardea goliath*	0.5	0.3												
3	Spoonbill	*Platalea leucorodia*		1.3												
4	Osprey	*Pandion haliaetus*		0.7		1.3		0.3				1.3	0.3			2.3
5	Oystercatcher	*Haematopus ostralegus*	0.3				3.5								0.5	
6	Crab Plover	*Dromas ardeola*	0.3	16.7				24.7				0.7		2.7		23.0
7	Ringed Plover	*Charadrius hiaticula*					0.3									
8	Kentish Plover	*Charadrius alexandrinus*	3.8	0.7			10.8	1.7					1.3		15.5	4.3
9	Lesser Sand Plover	*Charadrius mongolus*	0.8				0.3								5.0	
10	Greater Sand Plover	*Charadrius leschenaultii*	4.0				7.8								7.5	
11	Plover sp.	*Charadrius sp.*	0.3				6.8									
12	Grey Plover	*Pluvialis squatarola*	2.5				6.8								6.5	
13	Little Stint	*Calidris minuta*													0.5	
14	Dunlin	*Calidris alpina*	18.3				16.3								39.5	
15	Bar-tailed Godwit	*Limosa lapponica*	1.5				6.5								4.0	
16	Whimbrel	*Numenius phaeopus*												0.3		
17	Curlew	*Numenius arquata*	2.0				3.5		1.3				0.3		1.5	
18	Redshank	*Tringa totanus*	3.5								2.0		1.0	0.7	2.5	
19	Greenshank	*Tringa nebularia*	1.8				0.8								2.0	0.7
20	Green Sandpiper	*Tringa ochropus*					0.5								3.0	
21	Terek Sandpiper	*Xenus cinereus*	3.5												0.5	1.3
22	Turnstone	*Arenaria interpres*	15.8				7.3								4.5	
23	Sooty Gull	*Larus hemprichii*	0.8	6.0			1.0	2.7							0.5	1.0
24	White-eyed Gull	*Larus leucophthalmus*						0.7				0.7				
25	Slender-billed Gull	*Larus genei*	2.8	0.7			1.5								0.5	
26	Yellow-legged Gull	*Larus cachinnans*					0.5									
27	Gull sp.	*Larus sp.*	0.3	0.3												
28	Gull-billed Tern	*Gelochelidon nilotica*		0.7												
29	Caspian Tern	*Sterna caspia*	0.5	0.3												
30	Rock Dove	*Columba livia*		7.0												
31	Common Kingfisher	*Alcedo atthis*												0.3		
32	Desert Lark	*Ammomanes deserti*		1.0	0.3				4.3							
33	Hoopoe Lark	*Alaemon alaudipes*	0.3		2.0		3.5		7.8							
34	Crested Lark	*Galerida cristata*	5.8	5.0					0.3							
35	Lark sp.	*Calandrella sp.*													3.5	
36	Sand Martin	*Riparia riparia*	0.3													
37	Barn Swallow	*Hirundo rustica*	1.3				0.5									0.3
38	Red-rumped Swallow	*Hirundo daurica*			0.5				0.3							
39	White Wagtail	*Motacilla alba*	0.3		0.3		0.5									
40	Wagtail sp.	*Motacilla sp.*					0.3									
41	Tawny Pipit	*Anthus campestris*					2.5		3.3							
42	Desert Wheatear	*Oenanthe deserti*	1.8		0.8		2.5		4.5		0.3					
43	Graceful Prinia	*Prinia gracilis*	2.0	1.3					0.8		0.7		0.3	1.0		
44	Scrub Warbler	*Scotocerca inquieta*			0.8				0.8			0.3				
45	Warbler sp.	*Acrocephalus sp.*										0.3	4.0	5.3		
46	Warbler sp.	*Sylvia sp.*	1.0													
47	Chiffchaff	*Phylloscopus collybita*	0.3				0.3		0.3							
48	Brown-necked Raven	*Corvus ruficollis*	0.3				0.5	1.0								
		Total number of species	30	15	6	1	25	7	10	0	4	5	7	6	18	8

by season.

February (winter)

The species composition of Line 1 is similar to that of Line 3. At Lines 1 and 3, more shorebirds and gulls (e.g. Dunlin *Calidris alpina* and Slender-billed Gull *Larus genei*) were observed than terrestrial birds. The species compositions of Lines 2 and 4 are similar but the numbers of certain species are different. The avifauna on the island was poor. Only one terrestrial species (a lark) was observed on Line 7.

June (summer)

The number of bird species is very low. Crab Plover *Dromas ardeola* is the only exception. The species composition of Line 1, 3 and 7 are similar. Only Osprey *Pandion haliaetus* and White-eyed Gull *Larus leucophthlmus* flew over Line 2, and no bird was observed at Line 4. At Line 5, few birds were observed. At Line 6 which is along mangrove thickets, a warbler sp. was heard; Clamorous Warbler *Acrocephalus stentoreus.* or African Reed Warbler *A. baeticatus.*

Al-Quff, which is outside the Model Area, was surveyed to compare avifauna in different mangrove thickets. The main difference between the avifauna in Duqm Sabq and the one in Al-Quff is doves.

3. Discussion and conclusions

3-1. Species and habitats

Both in February and June, the species composition and number of individuals were different in different habitats. On the mainland, the lines along the shorelines had more bird species and individuals than the ones inland.

The following four habitats are important in the Model Area.

1). Arid area

This habitat is the dominant one in the Model Area. In both seasons, there were very few birds observed in the habitat.

2). Salt marshes

This habitat is developed narrowly along the shoreline at Line 1. Generally there were few species but a relatively high number of individuals were observed.

3). Wadis

The area in which Line 4 was set up is the only place where wadis are observed in the Model Area. Although the wadis are small, the differences from other habitats are obvious regarding species composition and their abundance in winter. It is a very important area.

4). Mangroves

Based on the Inventory Survey, these mangrove thickets in the Model area were expected to support many bird species and individuals. However, it seems they apparently do not support them at this time as expected.

The Mangroves / Coastal Vegetation team conducted a comprehensive survey on mangroves in the Model Area and Al-Quff. The mangrove thickets in Al-Quff are more developed and have a more complex structure than those in any other site, which indicates that the mangroves in Al-Quff are mature and the others are still in a young stage. This may explain why the avifauna of mangroves in Duqm Sabq and Jazirat Qumma'an is less complex than the one in Al-Quff.

The area of mangroves is the biggest in the Study Area and it is very important to monitor the relationship between the mangroves and their avifauna.

3-2. Species and season

Based on the two field surveys in the Model Area, the seasonal difference is very clear. There are many wintering shorebirds and gulls in February, and few of these birds are

observed in June. It is also indicated by the results of the Inventory Survey that the mangroves provide migratory birds with resting places. In order to understand seasonal differences in detail, it is recommended to conduct surveys on these same lines in autumn.

3-3. Conditions for monitoring survey

In order to conduct monitoring surveys, all conditions but season need to be the same at each time. Since the Study has been conducted under many restrictions; e.g. logistical constraints of Japanese members and social conditions of Saudi counterparts, all these conditions were not met.

2.2.9. Ecological transect of the Model Area (Fig. 10)

In the Model Area, many habitats were found along the ashore - offshore transect in harmony with the physical environment. A typical ecological feature is summarised in the following categories. Each zone has its own physical and ecological characteristics.

1. Coastal land area
2. Zone A: nearshore reef flat
3. Zone B: central reef flat
4. Zone C: outer reef flat
5. Zone D: fringing reef

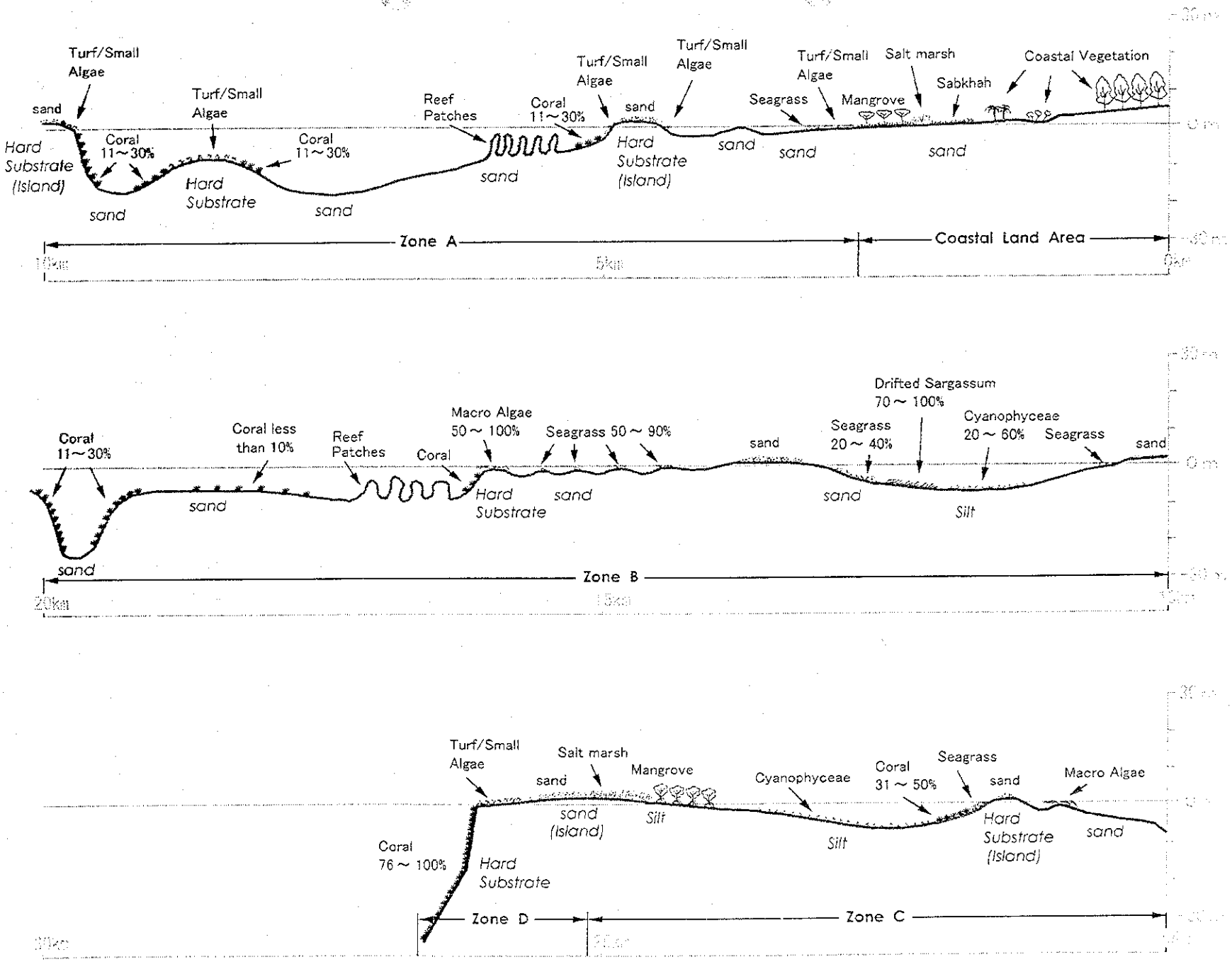


Fig. 10. Ecological transect of the Model Area.

3. SOCIAL ENVIRONMENT

3.1. Introduction

Socio-economic surveys were conducted in the Study Area to determine the present extent and future potential impacts of human activities on the coastal biological environment. Almost all local people in the Study Area are Muslims. They traditionally subsisted on grazing, fishing, and agriculture in wadis. While the local people continue to be engaged in these traditional occupations in this extremely dry and sparsely populated region, the recent influx of oil wealth and large scale development projects has been radically changing the traditional ways of life.

3.2. Methods

1. Methods of the comprehensive survey in the Study Area

The Comprehensive Survey focused on three subjects, 1) general information, 2) grazing and 3) fishing. General information consists of a) population, b) large-scale development projects that include oil plants, power plants, desalination plants and cement factories, and c) waste disposal sites.

2. Methods of the in-depth socio-economic survey in the Model Area

The in-depth socio-economic survey focused on two subjects, grazing and fishing. Two survey methods were employed for this study, 1) interviewing local people and 2) collecting information from government offices.

3.3. Results – Study Area

1. Study Area

The Study Area stretches over approximately 1,000 km from Haql to Jeddah. Six cities, Haql, Duba, Al-Wajh, Umluj, Yanbu' and Masturah, were selected as survey sites.

2. General Information

2-1. Population distribution

Based on the distribution of population, two distinct regions are defined in the Study Area (Table 16). The northern region in Tabuk administrative region is sparsely populated, and accounts for two thirds of the Study Area. The southern region in Madinah (including Yanbu') and Makkah (including Jeddah) administrative regions is relatively densely populated. In the northern region where people depend on the traditional industries, there are relatively few migrant workers of foreign nationalities. In the southern region, in contrast, a higher proportion of foreign migrant workers are attracted to one of the most densely populated regions in Saudi Arabia, where manufacturing and the service industries are developed.

2-2. Large scale developments in the Study Area

Large industrial plants, such as oil plants, power plants, desalination plants and cement factories, are located along the coast of Red Sea (Fig.11). Especially large desalination plants are in Jeddah and Yanbu', the surrounding areas of which are densely populated.

3. Grazing

As demand for livestock in Saudi Arabia has been increasing, grazing continues to be an important traditional industry in rural areas. There are two types of grazing observed in the Study Area.

Table 16. Estimated population of the Study Area.

Survey site	Haql	Duba	Al-Wajh	Umluj	Yanbu'	Masturah
Population (persons)	19,323	39,100	32,644	44,091	172,086	5,207
Area (km^2)	5,643	15,750	15,000	16,000	4,250	25
Density persons/km^2	3.4	2.5	2.2	2.8	40.5	208.3
Percentage of foreigners (1)	17.1	19.1	13.3	11.5	22.2	14.6
Administrative region		Tabuk			Madinah	Makkah
Population (persons)		486,134			1,084,947	4,467,670
Percentage of foreigner		17.3			22.8	37.8

1. Masturah is one district of Rabigh city.
2.Percentage of foreigners (1) is from the rate of non-Saudi in public hospital in 1997.
3.The data for Yanbu', Tabuk, Madinah and Makkah are from the population census of 1992.

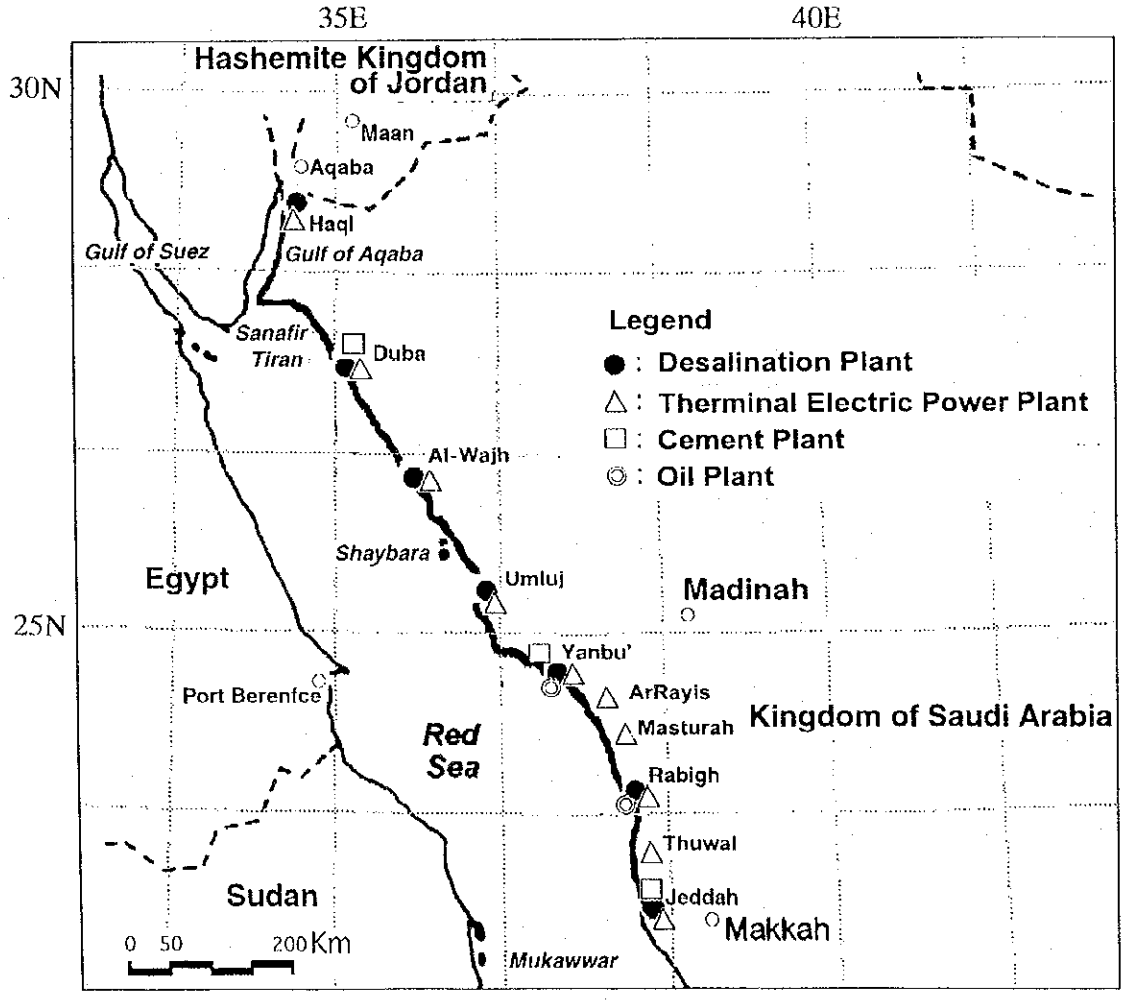


Fig. 11. Distribution of large industrial plants in the Study Area.

Source: Saline Water Conv. Corp. *Annual Report 1996.*

JCCME/JEPIC. 1998. *Survey on Electric Power Generation in Saudi Arabia.*

3-1. Nomadic grazing

Full-scale Bedouins who tend both sheep and camels are nomads. Their camps are pitched in rangelands far from towns. On the other hand, small-scale Bedouins are usually settled in the suburbs of towns, and live in houses, tending sheep and goats. Meanwhile, camels are valued at least five times higher than sheep, thus, wealthy full-scale Bedouins can afford to employ foreign migrant workers.

3-2. Stationary grazing combined with wadi agriculture

A combination of stationary grazing and wadi agriculture causes relatively less impact on the natural biological environment in comparison with nomadic grazing. Nonetheless, the effects of grazing by sheep on the natural vegetation of areas surrounding their farms are inevitable. The typical form of wadi agriculture is a combination of tending sheep and cultivation of date palms. Depending on quality and quantity of available water, wadi farmers can grow additional crops. Supported by a good water well, a farmer can grow varieties of crops, vegetables and fruits, whereas a farmer who depends on a limited amount of water of poor quality can grow few additional crops. With varieties of crops the former tends to depend more on agriculture, while the livelihood of the latter shifts more toward grazing by increasing the number of sheep or by adding camels.

4. Fishing

The Coast Guard oversees all fishing ports and fishing boats in this country.

4-1. Traditional fishing and fishing pressure in the Study Area

Extended coral reefs are found along most of the coast of the Red Sea. The use of hand-held lines on small boats is especially suitable as fishing practice in the coral coastlines. The number of fishermen and boats can indicate fishing pressure. Fig. 12 shows the number of fishermen in the Study Area. Al-Azeczizh is the port of Yanbu', and Al-Gad is located near

Jeddah. In the southern region, the number of fishermen is much higher than in the northern region, thus the fishing pressure is considered higher in the south.

4-2. Participation of foreign fishermen

It is common for a Saudi boat owner and employed non-Saudi fishermen to share their income evenly. A non-Saudi fisherman could earn monthly between 1,500 and 2,000 SR at most, which is a significantly good income for a non-Saudi migrant worker. Many of the migrant fishermen are from Egypt, India and Bangladesh.

5. Assessment of the Study Area

Table 17 summarises impacts of human activities on the natural environment in the Study Area. Two typical traditional occupations, nomadic grazing and fishing, seem to be causing excessive impacts on natural resources (over-grazing and over-fishing). The vegetation situation in the rangeland and the number of animals indicate a significant impact of grazing. The number of fishermen indicates considerably high fishing pressure. As the number of fishery workers increases towards the southern region of the Study Area, from Umluj / Ra's Baridi to Yanbu' / Jeddah, the pressure on fisheries resources becomes more intensified. Furthermore, the southern region hosts a number of large-scale plant projects. Therefore, it is not advisable to plan a marine protected area in the southern region.

3.4. Results - Model Area

1. Model Area

Al-Wajh Bank area was selected as the Model Area, where an in-depth socio-economic survey was conducted, the main focus of which was on grazing and fishing as the traditional industries.

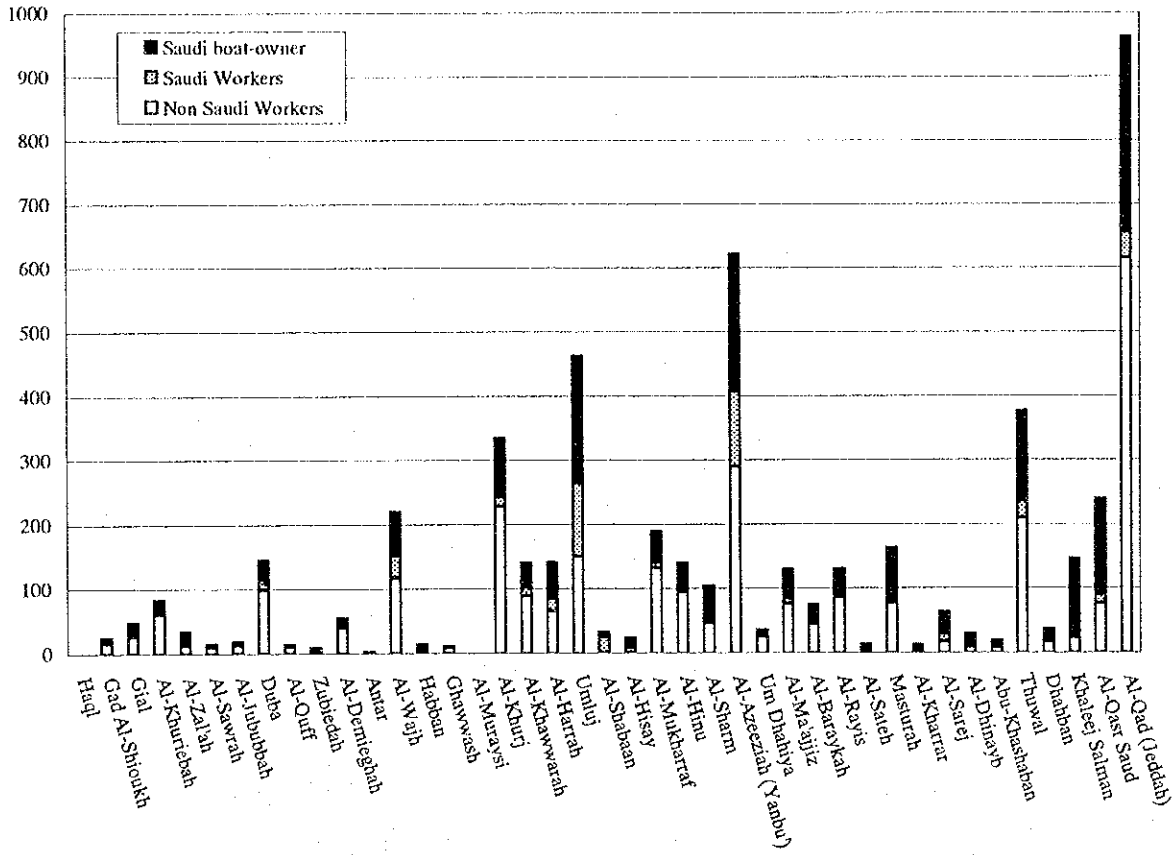


Fig. 12. Number of fishermen by category at each port (1996).

Table 17. Impact of human population and activities.

Impact	Subject	Location					
		Gulf of Aqaba	Tiran	Duba / Al-Wajh	Al-Wajh Bank	Umluj / Ra's Baridi	Yanbu' / Jeddah
Population		1	0	1	1	1	2
Activities							
Development	Desalination	1	0	1	1	1	3
	Power Plant	1	0	1	1	1	2
	Oil Plant	0	0	0	0	0	2
Grazing	Rangeland	1	0	2	2	2	2
	No. of Animals	1	0	2	2	2	3
Fishing	No. of Boats	1	0	1	1	2	3
	No. of Fishermen	1	0	1	2	2	3

*1. Degree of impact : 3: high, 2: medium, 1: low 1, 0: no data.

2. Grazing

2-1. Nomadic grazing

Five families of full-scale and six families of small-scale Bedouins were interviewed (Table 18). Groups of nomadic Bedouins who were significantly affecting the natural vegetation in the Model Area were active in the area between Al-Khurj and Umluj. There are three specially important ranging lands, Abar Umm Nitash, Al-Harrah and Umluj. The small-scale Bedouins were based in the town of Umluj and its suburbs, Al-Harrah. In contrast, some full-scale Bedouin groups were based in Abar Umm Nitash, which is sparsely populated, and is located as far as 60 km north from Umluj. Two major changes in the life style of Bedouins were observed:

a) As it was found in the comprehensive survey that families of small-scale Bedouins were settled in suburbs of towns and lived in houses, while the families of full-scale Bedouins also had been settled down. Even though they were living in tents away from towns, the families had not moved for over 20 years.
b) Four out of five heads of the families of full-scale Bedouins were engaged in regular cash-earning jobs in towns. Some of them were settled by highways in houses for the convenience of the long commuting by automobile to the towns for work and for children's schooling.

Despite the changing practice of grazing that has been shifting more toward purchasing fodder for their animals, the impact of grazing on natural vegetation will continue to be a serious concern. Although their scales of operations is small, a number of Bedouins settled in the suburbs of towns will significantly modify the surrounding vegetation, while large-scale grazing operations in remote areas will affect the coastal biological environment,

including the mangrove forests. Stationary grazing practice with wadi agriculture were not observed in the Model Area as a significant part of its economy.

3. Coastal fishing

There are eight fishing ports along the 165-km coastline from Al-Wajh to Umluj. Al-Khurj is the only one port where fishermen can fish inside Al-Wajh Bank. Al-Harrah and Al-Khawwarah are important fishing ports which are bases for fishermen to go to the main fishing area outside Al-Wajh Bank.

There are two types of fishing practices, self-employed independent fishermen and fishing businesses. A self-employed fisherman practices traditional fishing with one boat, fishing daily alone or with another worker to sell fish at local markets in Al-Wajh and Umluj. A typical fishing business owns two or three boats, hiring foreign migrant workers. They sell fish at markets in large cities such as Jeddah, Yanbu' and Madinah where fish prices are considerably higher.

Business owners share the income from the catch evenly with their foreign workers. The practice of income sharing gives foreign workers an incentive to go on fishing trips as long as four days to catch as many fish as they can. The growing fish demand in large cities is pushing these fishing businesses to expand their fishing operations rapidly.

Out of twenty Saudi boat-owners who were interviewed, five from Al-Wajh, twelve from Umluj and three from Yanbu', eight were self-employed independent fishermen, and twelve were fishing business owners (Table 19). Nine of them were selling their catch at local markets, and twenty-one at markets in large cities, thus some of them were selling at local markets and in cities. Fishing business owners were selling almost all their fish caught at the Al-Wajh Bank coast in large cities. The study also indicated that the practice of fishing businesses in the densely populated southern region causes a significant impact on the

Table 18. Types of grazing (Phase III).

Type	Saudi-owner Regular job	Sheep	Camel	Living in Tent /House	Location	Latitude (N)	Longitude (E)
Full-scale	Petrol station	300	15	House	Abar Umm Nitash	252835	371012
	Officer	65	45	Tent	Abar Umm Nitash	252825	371220
	C.G. soldier	80	18	Tent	Abar Umm Nitash	253003	370929
	IMARA officer	40	20	House	Al-Harrah	251417	371401
	No	100	3	Tent	South of Umluj	245215	371947
Small- scale	Desali. plant staff	30	12	House	Al-Harrah	251417	371401
	No	40	3	Tent	Abar Umm Nitash	253000	370930
	C.G. soldier	50	0	House	South of Umluj	245711	371650
	No	50	0	Tent	Al-Harrah	251351	371835
	No	20	2	Tent	Abar Umm Nitash	252741	371126
	No	10	0	Tent	South of Umluj	245214	371955

1. The border between the two scales is 100 sheep.
2. One camel is evaluated as 5 sheep.

Table 19. Interview data on fishing, by type (Phase III).

Type	Saudi owner Address	No. of boats	Fishing workers	Fishing day per 1time	Fishing port Location	Selling Market
Employer = Fish businessman	Umluj	4	5 E. 5 I.	4 day	Al-Khurj	no data
	Yanbu'	3	6 B.	4 day	Al-Harrah	Y.
	Yanbu'	3	6 B.	no data	Al-Harrah	Y. M.
	Umluj	2	2 B. 3E.	no data	Al-Khurj	no data
	Al-Wajh	2	2 B. 2E.	4 day	Al-Khurj	Y.
	Umluj	2	2 B. 2E.	4 day	Al-Khurj	Y. M. J.
	Umluj	2	4 Saudi(family)	5 day	Al-Khawwarah	Y. M. J.
	Yanbu'	2	3 P.	4-6 day	Al-Harrah	Y. M. J.
	Umluj	1	3 B.	4 day	Al-Harrah	Y. M.
	Umluj	1	1 I. 1 Saudi.	1 day	Al-Khurj	Y. M. J.
	Umluj	1	2 Saudi	5 day	Al-Khawwarah	Y. M.
	Umluj	1	2 Saudi	1 day	Al-Muraysi	Y. U.
Self-employed	Al-Wajh	1	No (brother)	1 day	Al-Wajh	W.
	Al-Wajh	1	No (son)	1 day	Al-Wajh	W.
	Al-Wajh	1	No (son)	1 day	Al-Wajh	W.
	Al-Wajh	1	No	1 day	Al-Wajh	W.
	Umluj	1	No	3 days	Al-Harrah	U.
	Umluj	1	No	1 day	Umluj	U.
	Umluj	1	No	1 day	Umluj	U.
	Umluj	1	No	(3 days)	Umluj	U.

1. Nationality of foreign workers: B.= Bangladeshi, E.= Egyptian, I.= Indian, P.= Pakistani. Number indicates number of workers.
2. Selling Market: J.= Jeddah, M.=Madinah, U. = Umluj, Y.=Yanbu', W.=Al-Wajh
3. Under fishing workers,( ) indicates the hiring of family members as a temporary worker.

fisheries resources. The participation of a number of foreign migrant workers in the fishing industry is partially responsible for the fishing pressure in the south.

3.5. Conclusion

In the northern region of the Study Area including the Model Area, that is sparsely populated and where there are a limited number of large-scale development projects, impacts from development projects on the natural biological environment along the coast of northern Red Sea, from the Gulf of Aqaba to Umluj, are insignificant. In this region, however, grazing and fishing continue to be major causes of significant human-induced impacts on the natural resources.

The changing life style of full-scale nomadic Bedouins, who have become more or less settled, can be a serious environmental concern since it could cause over-grazing in the areas surrounding their settlements. The traditional practice of setting grazing land aside as "hima" should be re-evaluated and implemented by local communities to avoid major impacts from grazing. Stationary grazing combined with wadi agriculture seems not to create serious environmental problems at the present time.

The growing demand for fish in large cities has been encouraging fishing businesses to expand their operations. While impacts from the traditional fishing practices on fisheries resources are relatively limited, the modern fishing businesses practice more indiscriminate and intensive operations. If the trend of expanding fishing businesses continues, the resulting over-fishing may become a serious threat to the marine natural resources in the Model Area.

To conserve the coastal biological environment and to implement sustainable practices of traditional industries in local areas, therefore, the following recommendation is made:

1) the changing life style of Bedouins should be continually monitored;

2) practice of the 'hima' system should be studied to sustain the grazing industry;

3) operations of fishing businesses and the marketing/distribution systems should be monitored; and

4) marine protected areas should be established upon consideration of sustaining the traditional fishing practices.

4. HABITAT MAPS

4.1. Introduction

All habitats in the Study Area are identified and categorised into simplified habitat types. They are represented in different colours to make it easy to understand how each habitat type is distributed and exactly where it is. It provides NCWCD with a very clear idea on the marine environment of the Study Area.

4.2. Methods

1. Categorisation of habitats

All aerial photographs were examined one by one to establish the discrepancy levels in such aspects as colour shifts until they were satisfactorily printed as 1:10,000 scale aerial photographs.

They were carefully analysed, and the habitats in the Study Area were classified into the categories as shown in Table20.

The habitat maps include data on important information on the social environment, such as factories, farms and fishing ports.

Table 20. Classification of habitat categories and their characteristics of colour and pattern.

Terrestrial Habitats		Marine Habitats	
D	Desert (yellow, orange, brown systems)	S	Sand (pale ocher, white, pale yellow)
Is	Island (yellow, orange, brown systems)	Md	Mud (brownish gray)
Tf	Tidal flat (brown, dark brown, moss green)	Rp	Sand with Reef Patches (Coral less than 10%) (scattered gray, brown)
Ro	Emerged rock (dark orange, dark brown)	C-1	Coral (coverage 11-30%) (white, gray, brown)
M	Mangrove (dark green, brown)	C-2	Coral (coverage 31-50%) (white, gray, brown)
V	Coastal vegetation (brown, greenish brown)	C-3	Coral (coverage 51-75%) (white, gray, brown)
Sk	Sabkhah (with Cyanophyceae and Salt marsh) (black, brown, gray)	C-4	Coral (coverage 76-100%) (white, gray, brown)
Sm	Salt marsh (scattered brownish green based Sabkhah)	T/Sa	Turf/Small algae (scattered pale or dark brown, black)
Fm	Farm (confirmed by forms)	Ma	Macro algae (patched pale or dark brown, black)
Lv	Fence of livestock (confirmed by forms)	Sg	Seagrass (patched dark bluish greenish black)
Fp	Fishing port (confirmed by forms)	Cy	Cyanophyceae (blue-green algae) (patched dark brown or true black)
Tw	Town area (confirmed by forms)	Sc	Sea (blue, green)
Fc	Factory (confirmed by forms)		

2. Summary of the process

The entire process of drawing habitat maps was shown in Fig.13.

1) A index list of the photographs was made in order to find whichever photograph needed for analysis in the most efficient and easiest way.

2) Coverage of each habitat zone was hand-traced onto tracing papers.

3) The traced habitat map was reduced to the scale of 1:50,000, and then traced onto a topographical map of the same scale.

4) Supplemental data and information based on the spot ground truth surveys and aerial verifications were used to reinforce aerial photography analysis.

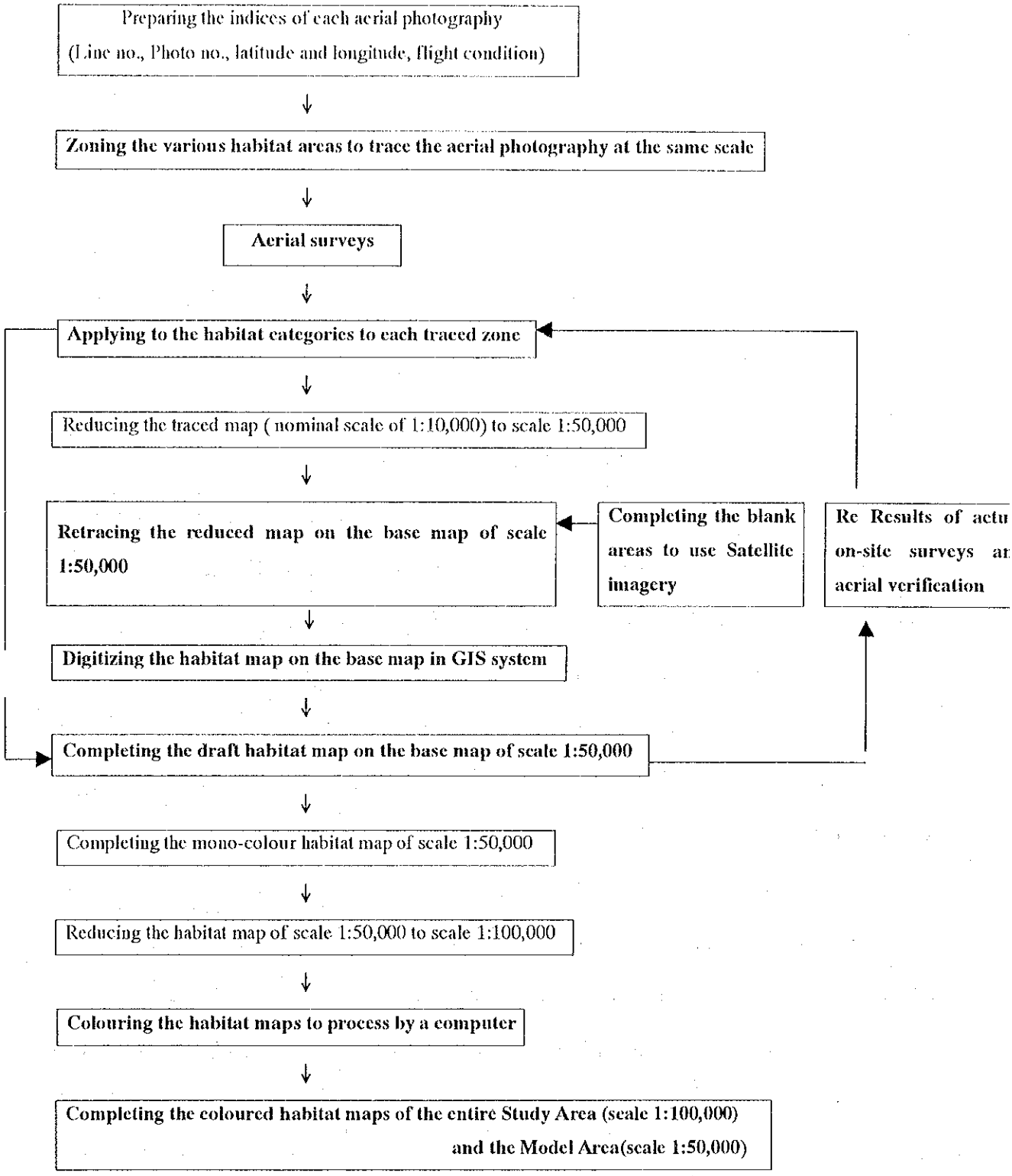


Fig. 13. Flow chart on drawing up process of the habitat maps (cells with bold letters are important steps).

4.3. Results

1. Habitat maps

The habitat maps of the Study Area (1:100,000) and the Model Area (1:50,000) were presented separately.

In the areas of the Gulf of Aqaba and south of Rabigh of which habitat maps were completed by satellite imagery, the category of coral is represented as only one category as the coral coverage was not capable of being analysed in detail on the prints of the satellite imagery.

Varied, large expanses of habitats are found at the entrance to the Gulf of Aqaba and the area from Al-Wajh Bank to Jazirat Jabal Hassan and the area from Masturah to Rabigh.

At the entrance to the Gulf of Aqaba, the variety and expansiveness of habitats are ranked at the middle level because of the absence of a mangrove habitat.

In the northern part of Al-Wajh Bank, the variety of habitats is ranked the same as that at the entrance to the Gulf of Aqaba. There are mangrove habitats, and the coverage of coral is monotonous compared with that of the southern part. The expanse of habitats is ranked at the high level in the northern part.

In the southern part of Al-Wajh Bank, the variety of habitats is ranked as the highest level because of its complex geomorphic features. The expanse of habitats in this area is ranked at the higher level next to the northern part.

Considering both variety and expanse of habitats, the southern part of Al-Wajh Bank is evaluated as the most important and interesting site in the Study Area.

2. Improvement of the habitat maps

The habitat maps made in this study were mainly based on the aerial photographs taken in summer from 3rd June to 12th July 1998, at an altitude of about 5,000 feet a.s.l. The

information from the ground truth surveys in winter (February 1999) and early summer (June 1999) in the Model Area was also taken into the habitat maps to improve the precision of the aerial photograph analyses. As the information of the ground truth surveys was limited due to lack of time, only two seasons and several parts of the Study Area were covered in a hurry, so complementary studies will be needed covering the entire Study Area in the future to upgrade the precision of the habitat maps.

The habitats gradually change their quality and quantity. After a large-scale flood, the organisms in the inter-tidal zone and the shallow water area will be strongly affected by lots of soil sedimentation and freshwater discharged from land: consequently, the habitats of these organisms are expected to change. Therefore, aerial surveys and ground truth surveys should be conducted at least once every 5 years, or immediately after a large scale flood, if any.

5. GEOGRAPHICAL INFORMATION SYSTEM (GIS) / DATABASE

5.1 Introduction

An advantage of using GIS is that data from dozens of sources can be consolidated on GIS overlays and the various relationships between factors such as social environment and biological resources can be examined. It is also possible to monitor changes in these factors over time. This enables the Study Team members to understand environmental issues affecting the target area.

The other advantage is that it can present very complex and technical data in a visible way which is very easy to understand not only by professionals but also by non-specialists.

5.2 Structure of the database

1. Preparation of GIS database (digitising base maps)

Preparation for the base maps to make the GIS database was arranged by digitising the 1/150,000 maritime charts. The area is from Jeddah to the Gulf of Aqaba near the border of Jordan. The base maps were digitised in vector format for storage. It is recorded as distinct points, lines, or areas (polygons). Information on points, lines, and areas is encoded and stored as collections of x-y coordinates.

The Meteorology & Environmental Protection Administration (MEPA) provided NCWCD the digital data which include the Red Sea coastal area. Mainly, 1:50,000 marine charts were used for digitising. –5m, -10m and -15m sea depth data from MEPA was used in this project.

2. Data conversion

The data conversion process is to collect, coordinate, and clean up the data before it can be converted to a digital format. When the data is compiled and all source records are complete, these data will be attached to the corresponding graphic data features. Then graphic data and attribute data are explicitly linked, so that there is 1 to 1 correspondence between map features and attribute data records. After this process is finished, GIS can quickly search through map data, looking for features with certain characteristics or inspecting spatial relationships among features.

3. Structure of the database

In order to use GIS, the database structure must be established. The database format is shown in Fig. 14.

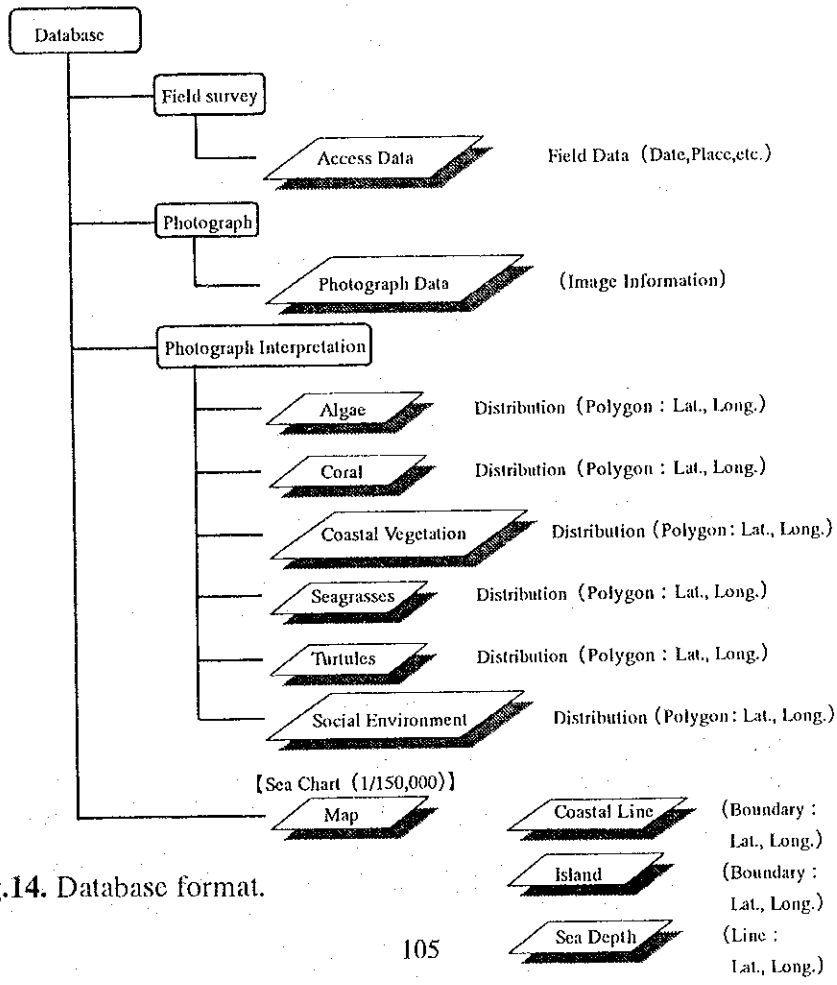


Fig.14. Database format.

5.3. GIS software

For this project, GIS software ArcView (Ver.3.0) has been purchased. ArcView is a desktop geographic information system made by Environmental Systems Research Institute, Inc.(ESRI). ArcView is designed to meet the needs of the largest possible number of users for many purposes and it has the capabilities for many types of applications. In order to obtain the maximum capability of GIS, customising the software is necessary. Customisation allows a user to operate the GIS by single easy command. Examples of customisation include an interactive front-end driver programme, which uses a menu type system to control each programme module.

The items in the customisation procedure are as follows.

- Update Data: Icon to update data.
- Grid: Icon to overlay mesh on the map.
- Search: Icon to search inventory data (using inventory code, classified name, scientific name, observed date, and location).
- Area Analyze: Icon for estimating area.
- GPS locus (location): Icon to draw a line using GPS data.
- MakeLayout: Icon for making layout automatically.
- ZoominMesh: Icon to zoom.
- Information: Icon to shows inventory information.
- Search with Mouse: Icon to search items using mouse.

5.4 Counterpart training

GIS is a new technology which represents different ways of manipulating geographic information. Introduction of the GIS is necessary for users to become knowledgeable about

this technology. Even people who are familiar with computer commands and keyboard instructions, may be very unfamiliar with computer mapping concepts and computer-based geographic information handling. Therefore, a series of GIS counterpart training sessions was planned to improve counterparts' skills and to make better use of this system.

Major exercises conducted are listed below.

① Classifying features based on their attributes

② Measuring distance and area in a view

③ Managing scale

④ Managing tabular data

⑤ Analysing spatial relationships

⑥ Presenting information

After the basic training is finished, it is also important to offer advanced training, which provides counterparts with the opportunity to improve their skills and to make better use of the GIS. The key goals of the advanced training are as follows.

- Understanding techniques for making database for GIS.
- Learning how to use GIS in various fields.
- Learning how to use GIS software, especially ArcView.

6. EVALUATION OF THE STUDY RESULTS

6.1 Introduction

The Study Area extends 1,000 km long and has a width of 1 km from shoreline to land and up to 15 m depth of marine environment. The present data is limited within this area. Species identification is conducted by conventional techniques within the Study time frame. New scientific classification technology using genetic analysis might bring different results in future. The Study is primarily targeted to understand the structure of the ecosystems, not their functions and linkages as these may be done in future. The habitat maps show mosaics of habitats of the land and sea in the Study Area. Interaction and/or intervention among the habitats could not be evaluated due to the lack of physical data such as the oceanographyical ones. Thus, the Study results evaluate the present status within these limitations.

6.2. Summary map (Fig. 15)

Compilation of appropriate data from the Study into one map is the easiest way for decision makers or protected area planners to understand the current natural environmental status visually. The following data are indexed into summary data sheets by compilation of natural and social environment data;

Extent of areas shallower than 20m depth, numbers of habitat categories, extent of habitat {(Extent of areas shallower than 20m depth)x(Numbers of Habitat categories)}, extent of coral { Σ (Coral coverage of rank(1-5)x(Coral extent of rank 1-5)}, extent of colonies of seagrasses, extent of colonies of algae, extent of mangrove communities, extent of colonies of Cyanophyceae, extent of tidal flat, existence of industrial plants, number of fishing boats.

The natural environment of the Study Area is ranked into five categories in the

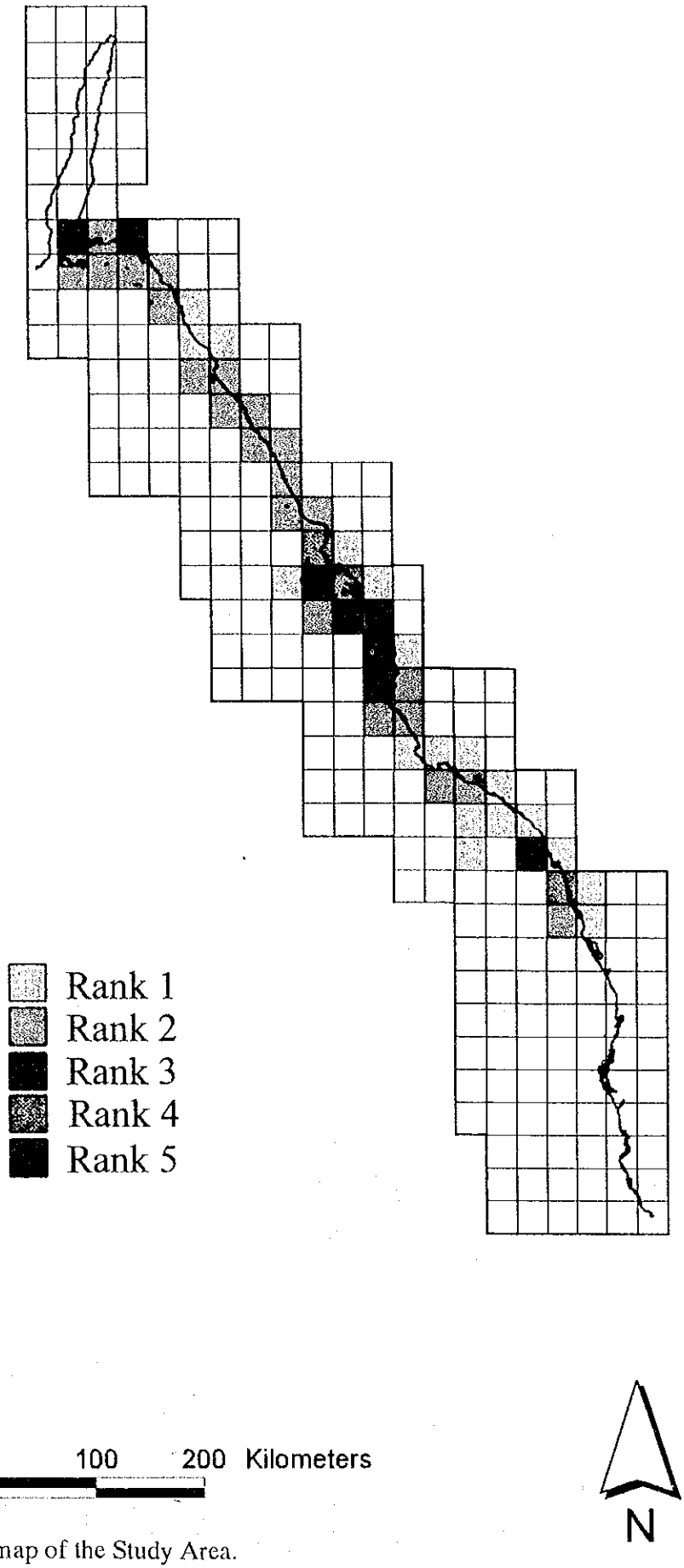


Fig. 15. Summary map of the Study Area.

summary map. The mouth of the Gulf of Aqaba, Al-Khuraybah, Al-Wajh Bank, Umluj to Sharm Shabaan and Al-Hajir (north of Ra's Masturah) areas are evaluated as high rank (3-5) areas. The following three statuses can be considered from a management point of view.:

1. Priority conservation area (Rank 3-5);
2. Strategic environment management area (Rank 2); and
3. Multiple area (Rank 1).

Based on these rankings, comprehensive regional marine resources and environmental management policies and plans could be drawn. The comprehensive approach to the regional environment can assure a healthy regional ecosystem and continuation of its productivity. The regional environment management is to be cored by establishment of marine protected areas.

6.3 Priority conservation areas

The Study results provide sufficient understanding of the current status and characteristics of the environment using the latest scientific technology. Priority areas which can represent the Study Area are identified by the summary map. Considering the connectivity of the areas, the priority conservation areas may be considered as three; 1) Tiran area (the mouth of the Gulf of Aqaba – Al-Khuraybah), 2) Al-Wajh Bank plus surrounding (Sharm Habban – Sharm Shabaan), 3) Al-Hajir (north of Ra's Masturah).

The three priority conservation areas have significance and potential for establishment of marine protected areas. A network of marine protected areas in the northern part of the Red Sea is the key component in comprehensive coastal and marine environment management programmes.

1. Delineation

The delineation of the marine protected area needs to be based on the true ecological boundary with ecosystem structure and functions. Therefore, in order to make precise delineation for marine protected areas, key function areas and linkages are to be identified. The seasonal variations (time components of the functions) of these areas are also to be evaluated. With this information, precise ecological boundaries will be drawn for the delineation of marine protected areas.

2. Objectives and zoning

Objectives and goal of conservation management need to be determined by the Kingdom in the process of establishment of marine protected areas. The clear objectives are the basis for clear management zoning.

3. Management implications

Science-harnessed management plans are the most effective and efficient. However, the sciences in this field develop quite quickly and might bring different results. Results from monitoring surveys might require different management programmes. The habitats in the priority conservation areas are unique and rather sensitive. The important feature of conservation management is that both research and management programmes have enough flexibility to accommodate new findings, survey results and knowledge on the habitats.

Fine balance is found to be the key for survival of many species in the harsh natural environment, not only the terrestrial but also in the marine environment. This sensitivity of species and habitats in the priority areas is to be fully taken into consideration to develop effective management programmes. Monitoring programmes need to be conducted in a systematic manner. Monitoring methodology must be simple, practical and applicable in local conditions of the areas. Monitoring programmes on critical habitats and species need to be carefully planned. The isolation levels of the endemic species are important key factors in

biodiversity conservation and should be specially focused in conservation management programmes. Information-gathering systems, cooperation among responsible authorities and communities are essential for effective conservation management and need to be established.

6.4. Strategic environment management areas

The strategic environment management area is essentially the surrounding area of priority conservation area, excluding city / town. The important habitats in the areas are benthic communities in enclosed or open bays which are more vulnerable than other areas. Offshore pinnacles and bedrock areas sometimes provide key ecological functions such as breeding and courtship areas for many animals. These scattered important habitats are to be focused on in the strategic environment management areas since their ecological functions are not studied.

6.5. Multiple use areas

A multiple-use area is basically the vicinity of cities or towns where coastal development takes place. Linkages between terrestrial and marine habitats in the area are weaker than in tropical and subtropical areas due to the physical environment. However, the impacts from cities, especially coastal development, desalination plants, sewage and solid waste, cause certain effects to the marine environment. In order to provide a healthy living environment for the city dweller and to control human impacts to priority conservation and strategic environment areas, impacts from human activities have to be monitored and managed.

6.6. Recommendations

1. Establishment of marine protected areas in the priority conservation areas identified.

The Study provides sufficient information on the habitat structure with precise maps. All information is integrated into GIS database for efficient conservation management. Three priority conservation areas are identified; Tiran, Al-Wajh Bank and its surroundings, and the Al-Hajir area. In order to establish marine protected areas, the critical and important ecological functions and linkages are to be identified in the priority conservation areas. The delineation of marine protected areas is to be drawn up from the identification of these. Feasibility of establishment of marine protected areas is assessed in the social conditions of the Kingdom.

2. Establishment of management programmes, including management zoning and guidelines for marine protected areas in the priority conservation areas

First define objectives and goal of a marine protected area. A zoning plan with guidelines is the primary document that defines the strategic framework for management. Management programmes need to contain the following items;

- Objectives of management
- Boundary and area description
- Resource description (area and location, geographic and habitat classification, conservation status, access and regional context, history and development)
- Physical and biological features (landforms, bathymetry, tide, salinity and turbidity, geology, currents, precipitation, temperature, wind, terrestrial and marine fauna and flora)
- Management issues (conflict, pollution and future demand)
- Management policies (objectives, zoning and guidelines)
- Biological, environmental and usage monitoring
- Education and information

- Enforcement
- Maintenance and administration (budget and staffing)
- Plant species, animal species, special features, past, present and proposed use.
- Zoning map

3. Establishment of management programmes of strategic environment management areas

It is important to identify habitats which have important ecological functions and linkages such as open and enclosed bays and offshore pinnacles. Focusing on the conservation of the functions of these habitats, management programmes of the strategic environment management areas are to be prepared and established.

4. Further studies and monitoring surveys

- Monitoring survey of coral habitat with methodology in Reef Check and Global Coral Reef Monitoring Programmes.
- Study on predator-prey relationship with coral habitats (fish, coral and crown-of-sea-starfish) in Al-Wajh Bank especially in the south.
- Study on macro benthos such as Polychaeta or Amphipoda for precise understanding of the ecosystems of Al-Wajh Bank.
- Genetic or DNA study on Hawksbill Turtle in Al-Wajh Bank to understand isolation level from the Indian Ocean population.
- Study on distribution and abundance of sponges as a primary food source for Hawksbill Turtle in Al-Wajh Bank.
- Study on migration routeof Green Turtle nesting population in Al-Wajh Bank.
- Study on reproduction status of Dugong population in Al-Wajh Bank
- Survey on the permanent quadrats for vegetation dynamics and/or succession.
- Survey on seasonal changes of avifauna.

- Survey on interactions between the mangroves in Al-Wajh Bank and their fauna including birds.
- Evaluation of the habitat changes by comparison with existing previous aerial photos.
- Monitoring survey on fishing (fishermen, boats, fishing yield, sampling data of monitoring species)
- Monitoring survey on fish in Al-Wajh Bank with Reef Check methodology.
- Monitoring survey on grazing (number of livestock, herders, output and others).

5. International cooperation for coral reef monitoring

The Red Sea is becoming of more and more international interest in the global coral reef conservation. International monitoring programmes have been implemented with participation of many countries. The monitoring data of coral reef in the Red Sea have an international significance. An important aspect of the monitoring survey is the continuity and the systematism. The results of coral reef monitoring surveys will provide significant information for global monitoring and the international linkage will bring up-to-date knowledge and skills for effective coral reef conservation in the Red Sea. Therefore, international cooperation of coral reef monitoring for marine environment conservation in the Red Sea should be established.

6. Education and public awareness programme

Nature conservation can only be achieved with public participation, especially community support. The success of marine protected areas is largely dependant on participation of local communities. The Study provides sufficient knowledge of habitat structure (what biological resources they have) and the specimens of their inhabitants. Two books targeted at public awareness are produced by the Study; Marine Wildlife of the Northern Saudi Arabian Coast of the Red Sea (in Arabic and English) and Wonderful Nature of the Red Sea (in Arabic). Many photographs on the biological resources were taken in the

Study. These outputs are an ideal tool for public education and awareness. In order to promote public understanding and support for coastal and marine environmental conservation through establishment of marine protected areas in the northern part of the Red Sea, educational and awareness programmes should be established and implemented centrally and locally. These programmes will harness the public and governmental support on coastal and marine environment conservation programmes.