Studies on the Coastal Ecology and Management Of the Nabq Protected Area, South Sinai, Egypt

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ABSTRACT

The variety and complexity of demands presently placed on coastal environments of the Red Sea has created an urgent need for the establishment of protected areas, which can provide a basis for the conservation of genetic resources and biological diversity.

In the South Sinai, a network of National Parks, Marine Protected Areas, and Managed Resource Protected Areas is established and administered by the Egyptian Environment Affairs Agency (EEAA). This network is managed with major objectives that aim to the protection of renewable natural resources within the Protectorates while allowing for the sustainable use of different habitats. Given the recent establishment of Nabq Managed Resource Protected Area at the south western Gulf of Aqaba, and the rapid pace of development in the surrounding region, the understanding of ecological processes of exploited coastal ecosystems, the threats to their integrity, and the management required to ensure their sustainability, has become an urgent natural resource management priority.

The general aim of this research has been to investigate the ecology and management requirements of the two principal marine resources that are traditionally exploited by the small Bedouin population living within the Nabq area. These are;
(a) intertidal mangrove stands and (b) artisanal coral reef fishery.
Results of this research should provide a broader basis for management decisions made by the conservation authorities.

(a) Study of the mangrove stands in Nabq

Mangrove vegetation was mapped using remote sensing and GIS techniques which allowed for the estimation of the total areas covered by mangrove vegetation in Nabq (approximately 52.5 ha.). Mean tree height, when measured, ranged between 1.42m ± 0.09 (S.E.) to 2.56m ± 0.13 along the four different stands in Nabq. Mean tree density per 100m^2 ranged from 1.86 ± 0.59 to 5.02 ± 0 .91. When tree height, basal area and density were compared in relation to microtopographic elevation, tidal inundation and soil salinity it was found that in the middle and lower intertidal zones, where plants are inundated twice daily by sea-water reducing surface soil salinity to that of surface seawater salinity (41- 42 ppt), dense forests are formed with well-developed trees exceeding 5m tall. However, moving shorewards dwarfed trees (less than 1.5m tall) occur on salt flats where they withstand soil salinity reaching 80 ppt. Yet, a significant input of ground water seepage was detected near most areas were mangrove stands were well

developed. The two sites where the highest levels of ground water input was detected were Marsa Abo Zabad and Shora El Rowaisseya, where salinities as low as 19 & 24 ppt were recorded. Seedling survival has significantly increased at these sites.

Allometric regressions were obtained between the diameter of branches of mangrove trees and the corresponding total dry weight (biomass) upon that branch.
The relationship between total estimated biomass (B) and branch diameter (D) was found to match the equation: $B = 147.9 \times D^{2.06}$
Estimated in this way, the total aboveground biomass was found to range between 5,400 & 47,000 $kg.ha^{-1}$. The mean growth of new leaves was found to be higher during the summer (growth ratio = 0.94 ± 0.19) than in the winter (0.58 ± 0.10). The mean leaf litterfall as a proportion of the initial number of leaves was estimated at 0.83 ± 0.17 per annum. Despite a number of constraints imposed by the need to employ only non-destructive research techniques (with limited exceptions), the methods employed in this study appear to give reliable estimates of total aboveground dry weight and leaf production which could be suitable for the rapid assessment of, relatively similar, small mangrove stands.

The obtained values for over-ground biomass and rates of leaf in Nabq shows that there is good reason to believe that *A. marina* at these locations may be surviving at, or close to, their physiological limits. The results of the present study also supports the view that the pattern of fresh water input from inland to coastal sediments and reductions in soil salinity are two critical factors determining the distribution of mangroves in hypersaline environments (Por *et al.*, 1977; Semeniuk, 1983). Ground water supply was also found to be a critical factor limiting sapling growth and survival. Extensive recolonisation within existing stands or colonisation of new areas may only be possible in rare years when there is much greater rainfall than normal in the Wadi Kid and Wadi Addawy catchments

(b) Status and management of artisanal coral reef fisheries

A pattern of changing abundance with reef zone (depth) was significant for many commercially targeted coral reef fish species.
When the effects of fishing using different gear types upon fish biomass and size structure were investigated, it was found that *L. bohar*, *C. miniata* and *V. louti* all showed a significant decrease in biomass with the increased hook-and-line fishing effort. In addition an apparent reduction in mean population length of larger predatory piscivore species at heavily fished sites was observed (e.g. *C. argus*, *C. hemistiktos*, *L. mahsena* and *P. gaterinus*). By contrast some herbivores (e.g. *Acanthurus nigrofuscus*, *A sohal*,

Scarus frenatus, *S. niger*, *S. psittacus and Siganus rivulatus*) had significantly greater biomass at lightly fished sites than at heavily fished sites.

The current spatial and temporal patterns of fishing effort were quantified for different gear types, and landings have been sampled to investigate catch composition and weight. Three fishing methods are found to be the most commonly employed by artisanal Bedouin fishermen. These are gill nets set on the reef flat or within the lagoon, trammel nets set overnight across the entrance to lagoons, and hand-lining employed in deeper lagoons and over the reef edge and slope. The mean catch per unit effort (CPUE) obtained using gill nets (1.48 kg / net.hr) was markedly higher than that obtained using trammel nets (1.26 kg / net.hr). A significant variation in fishing effort was concluded from effort data for different fishing seasons, with effort being greatest in early summer.

The principal families of fish caught (in term of weight) were parrotfishes (Scaridae), surgeonfishes (Acanthuridae), and rabbitfishes (Siganidae). Parrotfishes accounted for slightly more than 50% of the total landings during the study period. The mean weight of catch per unit effort at lightly to moderately fished sites (1.3 - 2.7 kg / unit gear.ha) was notably less than that at heavily exploited fishing grounds (0.6 - 1.8 kg / unit gear.ha)

The total yield from different fishing grounds in Nabq was found to range between 1.9 and 6.2 $ton.km^{-2}.yr^{-1}$. The highest yields were obtained at three sites, Abu Negailla, Manquatta, and Ghargana, but appeared to decline at sites exposed to annual fishing efforts exceeding 100 - 150 unit gear km^{-2} yr^{-1}. Although the area based relationship between total yield and fishing effort has suggested an approximate range of values for maximum sustainable yield (MSY) in the Nabq fishery, more detailed information about rates of recruitment, mortality and migration of commercially targeted species, as well as data on variation in fish stock abundance and catch from year to year, would allow more confident estimates of MSY to be developed.

The establishment of a network of five small no-take marine fishing reserves in the Nabq Protected Area could achieve the potential benefits as a means of managing fishing effort and protecting fish populations. Approximately 60% of the Nabq Protected Area coastline became effectively unfished since April 1995, taking into account that other sites outside the reserves are typically unfished because of hard access limitations.
A comparison of mean abundance of groupers (Serranidae), emperors (Lethrinidae) and snappers (Lutjanidae) between 1995 and 1997 showed an overall increase in fish abundance in two of the no-take reserves, those at Ras Atantour and South Ghargana. There was also a statistically significant increase in mean length of the serranids;

E. fasciatus and *C. argus*, and the lethrinids; *L. nebulosus* and *M. grandoculus* across the no-take reserves. The mean catch per unit effort within the neighbouring fished areas was observed to increase over the two years from 0.84 to 1.01 kg / unit gear.hr.

In conclusion, the fishery at Nabq may be characterised as a multi-gear, multi-species artisanal fishery subjecting coral reef fish stocks to a moderate level of fishing intensity. The relationship of yield to effort indicates that effort levels do not typically exceed intensities beyond those producing maximum sustainable yields, except at two sites, Ghargana and Manquatta, which are more heavily exploited. While CPUE at these sites appears to have declined, fishermen still exploit these sites more than others because of the smaller cost (vehicle and transport) and time required getting to them. The proximity of these two sites to the village of Ghargana and to the largest fishermen's encampment around Shora Al Manquatta reflects that while the CPUE curve falls off at these sites, an economic evaluation of catch per unit time and resources (costs) against effort would probably not do so. Further, the establishment of marine fishing reserves north and south of these two fishing grounds should essentially facilitate that fish stocks will not collapse due to growth or recruitment overfishing. However, this is not yet clear and will be studied in future fisheries research within the Nabq Protected Area.
Meanwhile, it would be desirable to avoid any present increase in fishing intensity at these sites than the current levels of exploitation.

Finally, the community based management initiatives within the Nabq fishery that have aimed at the integrating of the local Bedouin fishermen within the fisheries management process as well as with other conservation and management activities in the Nabq Protected Area, has proved invaluable to the successful formulation and implementation of management plans. The social acceptability of new regulations and restrictions on exploitation of the reefs was found to be substantially raised by education as well as involvement of the local fishermen into, both formal and informal, meetings to discuss management issues. Several individuals from the fishing community have been employed as full or part-time Community Rangers, which provided local support for conservation efforts and fisheries management plans.
The application of the combination of closed areas, gear limitations and a licensing system for local fishermen should provide a sound basis upon which the sustainability of the fishery can be attained.

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To he who had motivated me to perceiving that scientific advancement,
through genuine and dynamic enterprise,
is vital for the progression of our nation,

to my late father,
Salah Galal

DECLARATION

I hereby confirm that all the research described in this thesis is my own unaided work, save for necessary assistance in field work received as follows: Several undergraduate students assisted as diving partners and observers during collection of UVC data presented in chapters 4 and 7 and Bedouin community Rangers assisted in the collection of fisheries catch and effort data described in chapter 6. In addition staff of the Egyptian Environment Affairs Agency assisted considerably by providing support and necessary facilities. My University supervisor advised on the planning of the research and commented on the manuscript, advising in particular on English language.

Signed

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CHAPTER 1

General Introduction

1.1. ENVIRONMENTAL PROTECTION IN THE RED SEA

Coastal ecosystems represent an extremely valuable resource; one that is increasingly threatened by human interests. Tropical coastal environments, especially those comprising coral reefs, mangrove stands and seagrass beds are among the world's most diverse (Ogden and Gladfelter, 1983) and productive (Lewis, 1977; Smith, 1978) natural habitats. They are however increasingly affected by humans, directly in harvesting food and materials, and indirectly by pollution and unintentional damage (Salm, 1983; Kenchington, 1988;).

1.1.1. Environmental Threats to Red Sea Environments

In the Red Sea damage to coastal habitats has until recently been less than in most other regions, because of the historically low populations levels, difficulty of access to many parts, and consequent slow pace of development. This is now changing and increasing impacts to marine habitats have been reported around the Red Sea linked to rapid commercial development in the region. Influences to marine and coastal habitats have been reported in the Gulf of Aqaba (Fishelson, 1973; Loya, 1975; Walker and Ormond, 1978b; Ormond, 1980; Mergner, 1981; UNEP, 1987).

In the Egyptian Red Sea there has been a rapidly increasing threat of impact on, and degradation of, coastal natural resources, in view of an unprecedented increase in human activities over the last 20 years. Development has taken three general forms:

Urbanisation and general commercial development. The natural growth of towns and ports especially within the Gulf of Suez area has involved increasing coastal construction work that can lead to sedimentation of adjacent sublittoral habitats, and growth of human populations tending to cause increased effluents of sewage and some other general chemical pollution.

Oil exploitation, transport and shipping. Oil pollution was first described as impacting marine habitats in the Red Sea at the northern Gulf of Aqaba, where the coral reef deteriorated during the 1960s at least in part as a result of chronic low-level oil pollution stemming from the near-by oil and phosphate terminals (Fishelson, 1973; Loya, 1975; Walker and Ormond, 1982). With improved operational procedures in the oil fields chronic oil pollution is now much reduced, but another threat has grown in that larger oil tankers now pass by the Egyptian coast, and there is a risk of accidental collision with a reef. Most recently, several cargo ships and other vessels have struck reefs, mostly in the navigationally difficult area of the Straits of Tiran, that join the Gulf of Aqaba to the Red Sea proper. The resulting physical damage to coral communities has been of increasing concern.

Tourism development and related activities. During the late 1980s and 1990s the Egyptian Red Sea has seen an extraordinary growth in international tourism, initially linked to the growing popularity of SCUBA diving on the attractive coral reefs of the northern Red Sea, but increasingly of a more general recreational nature. By 1991 tourism was already the second largest foreign exchange earner and, being potentially the largest source of national income, policies were adopted to attract private sector investment to the development of high-density tourism along the Red Sea coast. This has been centred on two regions, the mainland Red Sea coast stretching south from Hurghada, and the South Sinai coast stretching north from Sharm El Sheikh (Pearson, 1989; Hawkins and Roberts, 1994; Medio *et al.*, 1997). In the Sharm el Sheikh development area hotel capacity has risen from 1030 beds in 1989 to 23,400 beds in 1998; a development ceiling has now been set at 60,000 beds (Pearson, 1998). Commercial dive-operation facilities for diving have expanded correspondingly resulting by 1998 in 42 diving centres (compared to 6 in 1989) and 230 diving vessels (compared to 26 in 1989). There have also been similar increases in other tourist facilities and services in response to this rapidly expanding market. Both tourist development and tourist activities have caused impacts to coastal marine resources. Construction of large numbers of shoreline hotels may cause extensive degradation of coastal fringing reefs and associated habitats, especially if infilling or effluent discharges are permitted. However, these are not permitted throughout the Egyptian coastline confronting the Gulf of Aqaba and only rare few cases are reported. Tourist activities also cause direct damage to reefs: anchoring by dive-boats and other vessels can be very destructive at popular sites; direct physical damage to corals is caused, usually unintentionally by scuba diving, snorkelling and reef walking (Medio *et al.* 1997; Hawkins and Roberts, 1994) and collection of marine organisms by visitors or for sale as souvenirs. Also, any of these activities that could cause damage to the coral reef habitats are forbidden in South Sinai and are strictly managed by the EEAA through its GAP according to the law 102 for 1983.

1.1.2. Protected Areas as Coastal Zone Management Tools

The variety and complexity of demands presently placed on coastal environments, especially of developing countries, has created an urgent need for integrated resource management strategies to replace the traditional sector-by-sector approach. These should strike a balance between the conservation of natural resources on which human welfare depends, and facilitation of economically important development activities. Conflict among different development priorities, as well as between them and conservation demands, can only be resolved by the promotion of integrated zoning plans, rationale resource allocation and co-operation between stakeholders. Ideally environmental impact assessments (EIAs) are undertaken for all activities that might harm renewable natural resources, and decision-makers consider the overall economic value of environmental benefits and resources that might be affected, as well the intended financial gains foreseen from any development project.

The establishment of protected areas, such as nature reserves and natural parks, can provide a sound basis for the conservation of genetic resources and biological diversity, in the sea as well as on land (IUCN, 1984). All marine life may be protected within all or parts of some protected areas; in many cases however National Parks are managed as multiple-use or managed resource areas within which habitats are protected while allowing for the sustainable use of natural resources (Kelleher, 1983). The management of these areas incorporates the separation of conflicting uses and functions by suitable zoning schemes, and research monitoring directed at ensuring the sustainable exploitation of fisheries and other natural resources often in accord with traditional use or below the maximum sustainable intensities (Craig, 1992). Economic development for local populations may be promoted by creating and maintaining employment associated with tourism, recreation and resource management, as well as with traditional resource exploitation.

The definition of a protected area adopted by IUCN is:

An area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means

Although all protected areas meet the general purposes contained in this definition, in practice the precise purposes for which different protected areas are managed differ greatly. The different main purposes of management for which a protected area may be managed are:

- Scientific research
- Wilderness protection
- Preservation of species and genetic diversity
- Maintenance of environmental services
- Protection of specific natural and cultural features
- Tourism and recreation
- Education
- Sustainable use of resources from natural ecosystems
- Maintenance of cultural and traditional attributes

IUCN has defined a series of protected area management categories depending on the principal management objective(s). Definitions of these categories are given in table 1.

1.1.3 Protected Areas in Egypt

Over the last 10 years the Egyptian Government (GOE) has implemented a series of major steps to promote the protection of the country's coastal and marine natural resources, by establishing a network of marine and terrestrial National Parks and Managed Resource Protected Areas along the Egyptian coast. To date Egypt has declared 17 Protected Areas, these include both terrestrial and marine Protected areas as, for example; the Petrified Forest in Maadi; the Zaranik Protected Area in North Sinai; the Omayed Biosphere Reserve in Matrouh; the Wadi Allaqui Biosphere Reserve in Aswan; the Seluga and Gazala islands in Aswan; the Ashtoum el Gamil and Tanis Island in Port Said; the Hassana Dome in Cairo; the Sonour Cave in Beni Suef; the Ras Mohammed National Park, the Nabq and Abu Gallum Managed Resource Protected Areas, the St. Katherine Protectorate in South Sinai; Lake Qaroun and Wadi Rayan in Fayoum and the Gebel Elba and Red Sea Islands Protected Area in the Red Sea Governorate. A full list of these protected areas is given in table 2. Together these Protectorates cover 7.5% of Egypt's territory, or approximately 75,000 km^2.

The first Marine National Park was that established at Ras Mohammed in 1982 while protection measures were effectively implemented in 1987. Subsequently two managed resource protected areas were established on the east coast of the Sinai peninsula, at Nabq and at Abu Galloum, and inshore waters along the remaining Gulf of Aqaba also declared as a Marine Park zone. In addition several adjacent inland areas have also now been given protected status. All the South Sinai protected areas are listed in table 2, which also gives the IUCN, protected area category of each area. Most recently the islands and associated reefs of the northern Red Sea proper, and also a southern section of the Egyptian coastline along the Red Sea proper have been declared as Protected Areas.

Given the recent establishment of these protected areas, and the extremely rapid pace of development in the intervening coastal areas, understanding the natural resources of the protected areas, the threats to their integrity, and the management required to ensure their sustainability, has become an urgent priority. This thesis describes research undertaken within one of the two managed resource protected areas referred to above, that at Nabq. The general aim of the study has been to investigate the ecology and management requirements of the two principal marine resources that are traditionally exploited by the small population of Bedouin living within the area, the intertidal mangrove stands, and the near-shore fishery associated with the coastal fringing reefs.

Table 1. IUCN Categories of Protected Area

Where the site does not meet the internationally recognised definition of a protected area, application of a management category is not appropriate. This is indicated as category unassigned (**UA**) in WCMC protected area lists.

CATEGORY Ia: Strict Nature Reserve: protected area managed mainly for science

Definition: Area of land and/or sea possessing some outstanding or representative ecosystems, geological or physiological features and/or species, available primarily for scientific research and/or environmental monitoring.

CATEGORY Ib : Wilderness Area: protected area managed mainly for wilderness protection

Definition: Large area of unmodified or slightly modified land, and/or sea, retaining its natural character and influence, without permanent or significant habitation, which is protected and managed so as to preserve its natural condition.

CATEGORY II : National Park: protected area managed mainly for ecosystem protection and recreation

Definition: Natural area of land and/or sea, designated to (a) protect the ecological integrity of one or more ecosystems for present and future generations, (b) exclude exploitation or occupation inimical to the purposes of designation of the area and (c) provide a foundation for spiritual, scientific, educational, recreational and visitor opportunities, all of which must be environmentally and culturally compatible.

CATEGORY III: Natural Monument: protected area managed for conservation of specific natural features

Definition: Area containing one, or more, specific natural or natural/cultural feature which is of outstanding or unique value because of its inherent rarity, representative or aesthetic qualities or cultural significance.

CATEGORY IV: Habitat/Species Management Area: protected area managed mainly for conservation through management intervention

Definition: Area of land and/or sea subject to active intervention for management purposes so as to ensure the maintenance of habitats and/or to meet the requirements of specific species.

CATEGORY V: Protected Landscape/Seascape: protected area managed mainly for landscape/seascape conservation and recreation

Definition: Area of land, with coast and sea as appropriate, where the interaction of people and nature over time has produced an area of distinct character with significant aesthetic, ecological and/or cultural value, and often with high biological diversity. Safeguarding the integrity of this traditional interaction is vital to the protection, maintenance and evolution of such an area.

CATEGORY VI: Managed Resource Protected Area: protected area managed mainly for the sustainable use of natural ecosystems

Definition: Area containing predominantly unmodified natural systems, managed to ensure long term protection and maintenance of biological diversity, while providing at the same time a sustainable flow of natural products and services to meet community needs.

Table 2. List of Protected Areas in Egypt administered by the Nature Conservation Section of the Egyptian Environment Affairs Agency (MAB, 1995).

1. Ras Mohammed National Park. (South Sinai)
2. Nabq Managed Resource Protected Area. (South Sinai)
3. Abu Galloum Managed Resource Protected Area. (South Sinai)
4. St. Katherine Protected Area. (South Sinai)
5. Taba Protectorate
6. Zaranik Protected Area. (North Sinai.)
7. Ashtoum El Gamil Protected Area. (Lake Manzala)
8. Wadi Assiouty. (Assiut Governorate)
9. Wadi Allaqui. (Aswan Governorate)
10. Omayed Biosphere Reserve. (Matrouh Governorate)
11. Gebel Elba and Red Sea Islands Protected Area. (Red Sea Governorate)
12. Hassana Dome. (Giza Governorate)
13. Petrified Forest. (Cairo Governorate)
14. Seluga and Gazala islands. (Aswan Governorate)
15. Wadi Sunor Cave. (Beni Sueif Governorate)
16. Lake Qaroun. (El Fayoum Governorate)
17. Wadi Rayan. (El Fayoum Governorate)

Table 3. Protected Areas of South Sinai

Areas that are declared under environmental protection by law in the South Sinai, Egypt (Pearson, 1998).

NAME OF AREA	Protection Category	IUCN category	Terrestrial area (km^2)	Marine area (km^2)	Length of coastline (km)
Ras Mohammed	National Park	II	133	327	56
Islands of Tiran	National Park	II	100	271	-
Sharm El Sheikh	Protected coastline	-	-	75	15
Nabq	Managed Resource Protected Area	VI & IB	465	122	47
Abu Galloum	Managed Resource Protected Area	VI & IB	337	121	25
St. Katherine	Protected Area (Protectorate)	VI & IB	4250	-	-
Taba	Natural Monument	III & IB	2800	135	147

1.2. STUDY AREA: THE NABQ PROTECTORATE

The Nabq Managed Resource Protected Area extends along the Sinai coast of the Gulf of Aqaba. It can conveniently be divided into three physiographic zones, arranged roughly parallel to the shoreline: the shallow marine zone dominated by fringing reef formations, including shallow reef flats and four large stands of the mangrove, *Avicennia marina*; a gently inclined coastal plain covered by fluvial sands and gravel and sand dune vegetation; and, occupying the western section of the protected area, the steep-sided mountains of South Sinai, which rise inland towards St. Katherine's and Mount Sinai.

The mountain region is dissected by numerous Wadis (dry seasonally flooded riverbeds) which merge to form two larger valleys, those of Wadi Kid and Wadi Addawy. Most of the wadis experience flooding on an annual or occasional basis, sufficient to allow the periodic growth of scattered vegetation. This vegetation supports grazing by scattered groups of Bedouin livestock (camels and goats), as well as by small numbers of native mammals, such as Desert Hare (*Lepus capensis siniaticus,*), Dorcas Gazelle *(Gazella dorcas)*, and Nubian Ibex *(Capra ibex nubiana)*, and some predators, such as native Fox *(Vulpes zerda)*.

Wadi Kid and Wadi Addawy give onto broad alluvial fans that merge onto the coastal plain that slopes seawards at an angle of about 1° (Gvirtzman and Buchbinder, 1978), and is about 3-7 km across. Formed mainly during the Pleistocene, these fan deltas were presumed by Hayward (1984) to be largely inactive; however, during the last five years, three flooding events have been recorded. Scattered and occasionally dense belts of salt-tolerant shrubs are distributed across the plain in a noticeable sequence of zonation comparable to the successional zonation described by Kassas (1957) as being characteristic of drier salt marsh vegetation.

The inland sand dunes harbour dense stands of *Salvadora persica*, an endangered shrub that forms large tangled clumps up to 3 m. high and 5 m. across. These are believed to be the most extensive known stands of this species (Kassas, pers. comm.). Seaward of this occur distinct zones that are dominated by a number of species of halophyte, such as the commonest Middle-eastern halophytic shrub, *Limonium axillare*, which is significant as a foraging plant for solitary bees, and various succulents including *Suaeda fruticosa* and *Nitraria retusa*. These form zones that roughly extend parallel to the shoreline, which vary in depending upon local topography and hydrological conditions (Gazzar, 1995). In particular vegetation bands are denser, and extend further inland, within wadi beds and drainage channels, where presumably fresh or brackish water is closer to the surface.

The coastal strip is mostly composed of gravelly sand, but in some areas there are clusters of low sand dunes, and in others sediment patches of sabkha (salt encrusted mud flats) that line the reef flat and coastal lagoons. These areas tend to be colonised by mangroves, the Red Sea type locality *Avicennia marina*, which at four sites form extensive thickets or stands.

Beyond almost the whole shore is a shallow reef flat, mainly formed of raised fossilised reef (Por *et al*, 1977), and varying from 100 m. to 800 m. in width, though typically about 350 m. wide. Apparently, the landward part of the reef flat is covered with a thin layer of sandy mud and supports thin algal mats and scattered patches of small macroalgae such as species of *Padina, Caulerpa, Laurencia,* and *Gracilaria*. In many places the central and outer reef flat is broken by scattered small pools (1 - 20 m. in diameter and 0.5 - 3 m. deep) or in some locations more extensive shallow lagoons (up to several hundred meters across and in places up to 10 m. deep. These pools and lagoons provide habitat for larger macroalgae, such as *Turbinaria* and *Sargassum*, various sea-grasses, particularly *Thalassia hemprichii,* and species of *Halophila* and *Halodule*, a wide variety gastropods including *Strombus* and *Lambis* species, echinoderms among which the sea-urchins *Echinometra mathaei* and *Diadema setosum*, and sea-cucumbers (*Holothuria* spp.) are conspicuous, and small colonies of living coral, particularly *Stylophora pistillata*. Moderate numbers of a variety of fish species also occur on the central and outer parts of the reef flat, particularly damselfishes (Pomacentridae), small wrasse (Labridae), parrotfishes (Scaridae), surgeonfishes (Acanthuridae) and rabbitfishes (Siganidae).

As around most of the Gulf of Aqaba, the reef flat is part of a well-developed fringing reef, which is interrupted or becomes broken at a few locations at the back of coastal embayments where freshwater run-off can occur via coastal wadis and drainage channels. At a few sites (e.g. Marsa Abo Zabad and Abo Negailla) shallow channels penetrate from the reef slope into the lagoon to form a number of small shallow sharms or marsas.

The reef edge is exposed to significant wave action generated by the prevailing northeast wind; this has generated a shallow groove and spur system along the reef edge. Below this the reef slope drops steeply to depths ranging between 3 and 20m. On the reef slope coral growth is dominated by the branched hard corals *Acropora* spp. and *Pocillopora* spp., massive hard corals particularly *Porites* spp., *Favia* spp. and soft corals such as *Sinularia* spp. providing a live coral cover typically of between 20 and 50%, but in less frequent sites of up to 100%. Between corals along the reef edge zone are areas of well developed algal turf which provide grazing potential for abundant herbivorous reef fish, particularly parrotfishes and surgeonfishes.

The steeper reef slope gives way to a wide sandy terrace that slopes more gently seawards over some distance to a depth of 50m or more. On this sandy slope are scattered coral rock mounds and pinnacles upon which some sparsely distributed corals, mostly *Favia* spp, *Acropora* spp. and *Porites* spp. could occur. The intervening sandy bottoms are partly covered by dense beds of seagrass, typically either a mixture of *Halodule* and *Halophila* species, or the larger *Thalassodendron ciliatum*.

These different habitats do not occur, or function, independently. There is extensive exchange of organic and inorganic nutrients and of species between them (Sheppard, 1992; Ogden and Gladfelter, 1983). In particular some habitats serve as nursery grounds for species that as adults reside in other habitats. At Nabq the seagrass beds provide habitat for the juveniles of some commercially important species, notably the emperors *Lethrinus mahsena* and *L. obsoletus.*, as well as for various species of wrasse and goatfish (*Upeneus* spp.). And mangroves are widely reported to be important as nursery areas for a number of commercial fisheries species (Robertson and Duke, 1987).

A full species list Is not yet available for corals at Nabq, but in the Gulf of Aqaba about 130 species of hermatypic coral (Head, 1987) have been recorded, and given the well developed reefs within the boundaries of the protected area, it is likely that most of these are present. This contrasts with for example the Gulf of Suez where reefs are much less well developed and the species diversity is suggested to be less than 35% of those from the Gulf of Aqaba (Head, 1987). The fish assemblages within the Gulf of Aqaba are correspondingly diverse, and a large proportion of the approximately 1000 species reported from the Red Sea (Ormond 1980a, and Randall, 1983) are probably present. These include a substantial proportion of those fish species, which are endemic to the Red Sea and the Gulf of Aden.

The diversity of species and the complexity of interactions within tropical coastal ecosystems pose special problems for the sustainable exploitation of biological resources. These must be borne in mind in considering the critical management issues and developing sustainable, management policies for Nabq Managed Resource Area. In particular, given the present exploitation of reef fish by the local artisanal fishery, and the increasing pressures on coastal habitats generated by the rapidly increasing tourist industry, there is an urgent need to determine the sustainable levels of use of the protected area's habitats and resources.

1.3. MANAGEMENT ISSUES AT NABQ

The environmental stresses due to human activities come from two major sources, the local Bedouin population, and a portion of which lives within the protected area, and tourists and other visitors who come for recreational activities. The extent of different impacts and their causes are summarised in table 4.

1.3.1 Residents and users

The local Bedouin population that are permanently resident within the Nabq Protected Area are estimated at approximately 250 individuals and are concentrated around the two villages of Ghargana and Khereiza, while a few live in small non-permanent encampments. Approximately 40% of the observed fishermen during the study period are from those who are permanently resident in the Nabq Protected Area, mostly staying in the two small settlements (Al Gharqana and Khereiza), while others come on short fishing trips for some days, especially during the summer, from the surrounding region (Wadi Mandar, Dahab, Abu Galum, and Sharm El Sheikh).

The number of recreational visitors and tourists has considerably increased during the last few years. These have been observed to exceed 10,000 visitors per year during the study period. They typically visit the area during the day for snorkelling, scuba diving and sightseeing.

1.3.2. Artisanal coral reef fisheries

In the Egyptian Gulf of Aqaba the fishery is predominantly artisanal, incorporating the use of multiple gear which targets a wide spectrum of reef fish species. Most of this is caught using gill nets that are set in shallow water where the seabed is sandy or relatively free from coral growths. Trammel nets, which are also widely used, are set overnight and recovered the following morning. Hand-lining, which is the commonest fishing method elsewhere in the Red Sea, is also used to some extent, either along the reef edge, or from boats anchored over the slopes of coastal or offshore reefs. Trolling is also employed in deeper water by some local and sports fishermen who trail one or more lines and catch small number of skipjack, jack, mackerel, tuna, reef shark and barracuda.

In the Egyptian Red Sea as a whole the realised share of the potential fisheries capture has been estimated at 70%, but this is only a very rough estimate because only a proportion of the catch is marketed while the rest is consumed locally, either eaten by the fishermen and their families, or sold directly to near-by residents or restaurants. Thus prior to this study the catch at Nabq and its relation to sustainable yield was only vaguely known. Hence a principal aim of the present study has been to collect information that would enhance the ability of park managers to determine how the fishery within the protected area should be managed. The management policy needs to consider not only the likely sustainable yields of each of the exploited stocks, but the multispecies nature of the fishery, and the desirability of protecting the biodiversity of both exploited and unexploited species.

A further issue is the probability that those fishing practices may cause direct physical damage to the corals or the marine environment in general. This most obviously occurs to some extent as a result of fishermen trampling over the reef while setting nets, or as a result of the nets becoming entangled with corals or other marine organisms. Small amounts of damage of this type were observed in several areas along the southern portion of the Egyptian Gulf of Aqaba.

1.3.3. Harvesting of other reef organisms

Reef gathering is typically undertaken by Bedouin women over the reef flat at low tides. They harvest Octopus and molluscs (*Tridacna* spp., *Lambis* spp. and *Strombus* spp.) by using sharp sticks. They are quite easily harvested, as they are abundant on the reef flat and simple to find. It is worth noting that such reef gathering causes some considerable physical damage to the reef.

1.3.4. Use of vegetation for fodder and fuel

The cutting of wood from the mangroves and the halophyte *Salvadora persica* is typically undertaken by resident Bedouins to use as firewood for cooking. However, wood collection has considerably increased between 1985 and 1990. This is attributed to the rapid increase of tourism at the nearby tourism centres of Sharm El Sheikh and Dahab and the increasing demand for firewood to make campfires in major hotels. Notable damage to mangrove and Salvadora trees was notable, but since 1991 the commercial wood collection was banned by the Park managers. This has reduced the impacts on coastal vegetation to the local consumption of selective clipping of dry branches.

1.3.5. Tourism development and related activities

Tourists and visitors, even when not resident within the protected area, can generate various negative impacts, including waste and pollution, and damage to both marine and terrestrial habitats, besides visual intrusion into the landscape. However, these impacts may be minimised by appropriate management policies and protection measures. These are listed in table 4.

1.3.6. The need for research

In general, where knowledge is inadequate to be reasonably certain of the best way to ensure that resources are used sustainably, a "precautionary management approach" has been adopted and is supported by the Park managers. That is, where any direct or indirect impacts to natural resources are suspected, activities or uses are kept to a minimum until sustainable levels of use have been established and protective regulations implemented and hence research on the most significant of these issues was required.

Table 4. The significant sources of impact (present and potential) upon natural resources and habitats in the Nabq Protected Area. Also shown is the legal status of each activity. Severity of each impact is shown as: + non-significant; ++ noticeable; +++ marked; ++++ severe.

Impact	Severity	Source	Status	Description
Physical damage to reefs	++	visitors & fishermen	Forbidden by law	Reef walking, snorkelling & diving
Collection of reef organisms	++	Visitors	Forbidden by law	Collection of souvenirs
Fishing	+++	resident & visiting Bedouins	Only traditional fishing permitted. 40% closed as marine reserves	Gill and trammel nets handlining
Harvesting of reef organisms	++	Bedouin families (mainly women)	Only traditional rights. Forbidden inside reserves	Collection of molluscs and octopus for local consumption
Vehicles damaging vegetation etc.	++	visitors and local Bedouins	Tourist vehicles required to keep to marked tracks	4WD vehicles accessing shore areas or taking short cuts
Waste and littering	+	Shipping and Dahab city in the north	Regular clean-up and garbage collection points	Most is washed on shore; some of local origin
Oil pollution	+	Rarely from shipping activities	Source fined	Tar balls on shore
Shipping accidents	+	Ships and tankers	Ship-owners fined	Passing cargo and smaller ships
Collection of shrubs (*Salvadora* spp., etc.) for fuel	++	Local Bedouins	Commercial exploitation forbidden	Local Bedouin for own use;
Coastal construction	+	Local Bedouins	Restricted to villages and encampments by permit.	Light construction
Grazing	++	Goats and camels	Permitted	Owned by Local Bedouin
Cutting of mangrove	++	Local Bedouins	Provisional prohibition	Mostly by local Bedouin for fuel & poles

1.4. THESIS AIMS AND OUTLINE

The inter-related coastal ecosystems of the Nabq area provide a unique habitat within the Gulf of Aqaba. The ecological conservation and coastal zone management of this area was initiated by the inclusion of these habitats within the boundaries of the Nabq Managed Resorce Protected Area. The ecological processes, present exploitation levels and those levels of exploitation to provide sustainability of these coastal resources represented an urgent requirement for the formulation of coastal zone management and zoning plans on a firm scientific basis. The traditional use of coastal resources by local Bedouins focussed upon the mangrove stands in addition to a near-shore artisanal coral reef fishery. The linkages between mangrove stands and fisheries production have been well recorded in tropical coastal environments. The broad intention of the present study was to initiate research and monitoring relevant to one or more of these issues so as to enable the conservation authorities to take management decisions on the basis of scientific evidence. A major principle would be to seek to quantify the extent of impacts upon natural ecosystem structure and the effect of human activities on ecological interactions, with a view to estimating ecologically sustainable levels of use of natural resources. In practice research focused on the two major issues; namely reef fisheries and the exploitation of mangroves.

Research on mangrove stands at Nabq was undertaken with a view to:

1. Describing the character and zonation of the mangrove stands.
2. Assessing the productivity and regenerative capacity of the mangroves.

This work is described in chapters 2 and 3 respectively

Research on the local fish stocks and fisheries was undertaken with the aims of:

1. Determining the abundance, distribution and diversity of the existing reef fish populations.
2. Determining the current fishing effort and catch of artisanal fishermen.
3. Determining the effect if any of local fish populations of this level of fishing.
4. Determining the likely optimal level of fishing effort.

5. Investigating the potential benefits of establishing no-take reserve areas as a means of managing fishing effort and fish populations.

The research done undertaken on fish abundance and distribution is described in chapter 4, that to investigate effects of fishing on fish biomass and size structure in chapter 5, that to determine catch and effort in chapter 6, and that to assess the value of no-take reserves in chapter 7.

In chapter 8 some general conclusions are discussed, and conservation and management recommendations presented with respect to the sustainable levels of exploitation of natural resources at Nabq.

It should be emphasised that the research undertaken was constrained by the requirement to use either entirely non-destructive methods, or ones which would cause minimal damage to plants and animals within the protected area.

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CHAPTER 2

The Sinai Mangroves, *Avicennia marina* (Forsk.): Vegetational Patterns Under Extreme Environmental Conditions

2.1. ABSTRACT

Variation in abundance and size of mangrove trees was assessed in four monospecific stands of *Avicennia marina* (Forsk.) Vierh. at Nabq, in the southwestern Gulf of Aqaba, Egyptian Red Sea. Located between latitudes 28^0 07' and 28 ^{0}12' N, these are considered the most northerly stands of mangrove in the Western Indian Ocean region. These stands are now included within the boundaries of Nabq Managed Resource Protected Area established in 1992. Tree height, basal area and density were compared in relation to microtopographic elevation, tidal inundation, soil salinity, and other environmental factors. The extent of the stands was mapped using remote sensing and GIS techniques.

In the middle and lower intertidal zones, where plants are regularly flushed by tidal inundation of seawater, there are dense growths of well-developed trees up to 5m or more at some locations. But moving shorewards trees become smaller and bush-like, the most inland bushes actually protruding from low sand dunes 1 - 2m high. These trees experience soil-surface salinity values that can exceed 80 ppt due to occasional inundation by spring tides followed by rapid evaporation. In the same areas, however, ground water with salinities down to 24 ppt was found at depths of about 2m beneath ground level, indicative of underground fresh water seepage from inland wadis. Air temperature was observed to range between as high as 45°C and as low as 14°C. New saplings of *A. marina* were found to be abundant at middle and lower intertidal stations with reduced soil salinities, supporting the view that microtopographic elevation and ground water influx are two of the major influences mangrove to development in this area.

2.2. INTRODUCTION

Globally the highest extent and diversity of mangroves is found in tropical regions between latitudes 20° S and 20° N, where mangrove forests are typically best developed around the shores of rivers and estuaries. However, mangrove communities do occur at some sub-tropical locations outside this latitudinal range including China (Tam *et al.*, 1995), Florida (Snedaker, 1989), Southern Australia (Clarke and Hannon, 1970), and New Zealand (Burns and Ogden, 1985; de Lange and de Lange, 1994). Mangroves also occur as coastal fringes on arid shorelines, as in the Arabian Gulf (Abdel-Razik, 1991; Sheppard *et al.*, 1992; Fouda and Al-Muharrami, 1995) and Red Sea (Kassas, 1957; Kassas and Zahran, 1967; Por *et al.*, 1977; Price *et al.* 1987; Saifullah *et al.*, 1989).

At higher latitudes or in more arid locations species diversity is notably reduced with typically only one or two species present. The species that is most tolerant of low temperatures and high salinities is *Avicennia marina* (Tomlinson, 1986; Hutchings and Saenger, 1987). Globally this species has the broadest latitudinal range of any species and in the Red Sea they occur up to latitude 28 ° 12' N along the south-western Gulf of Aqaba (Kassas and Zahran, 1967; Por et al, 1977). Five stands of *A. marina* grow along the Egyptian coastline of the Gulf of Aqaba. One, first recorded by Aschersohn (1887), is a small stand in a narrow channel that bisects the headland of Ras Mohammed, at the southern tip of the Sinai peninsula; this site is now incorporated within the Ras Mohammed National Park. The four other stands, which are the subject of this study, occur at approximately 55 km. to the north, within the Nabq Protected Area (see Figure 1). As described by Por et. al. (1977), these relatively well-developed stands are considered the most northerly mangrove vegetation in the western Indian Ocean region.

The degree of development of the Nabq mangroves is additionally surprising because of the dry desert conditions (annual rainfall < 10 cm. yr^{-1}), which the stands experience, and the above normal salinity of the Gulf of Aqaba (> 40 ppt). Further soil salinities in the upper intertidal zone reach much higher values than mean surface

sea-water salinity due to the high evaporation rates that prevail in the Gulf of Aqaba, recorded at over 210 cm. yr^{-1} by Morcos (1970) and over 300 cm. yr^{-1} by Assaf and Kessler (1976).

While most mangroves within the Red Sea occur on soft bottomed areas (sand or mud) within sheltered bays or creeks, or in the lee of off-shore islands (Price *et al.* 1987), most of the northern Red Sea stands, including those in Sinai, occur in lagoons or on reef flats behind fringing reefs (Por *et al.*, 1977). These fringing mangroves are spread along the shoreline on the inner parts of the back reef where they typically grow on a discontinuous layer of soft sediment that covers hard fossil reefs. Such stands have been distinguished as 'hard-bottom mangals' or 'reef mangals' (Por *et. al.*, 1977) by comparison with the much more widespread 'soft-bottom' or 'peat-mangals'.

A study of the Nabq mangroves was therefore undertaken (1994-1998) with two general aims: to understand those factors, which permit or control the distribution of mangroves in the area, and, given these ecological constraints, to develop a management strategy for the mangroves.

In the first part of the study, described in this chapter, it was intended:
(a) To characterise the mangrove stands by direct field measurements of tree size so as to obtain a picture of forest structure and the spatial variation in tree height and development;
(b) To measure the basic environmental parameters on a seasonal basis, such as soil and water salinity, and air and water temperature and ground water run-off so as to identify factors which could limit tree growth and development;
(c) To map, by interpretation of satellite images and aerial photographs, the extent of the mangroves so as to calculate the total area of the resource available.

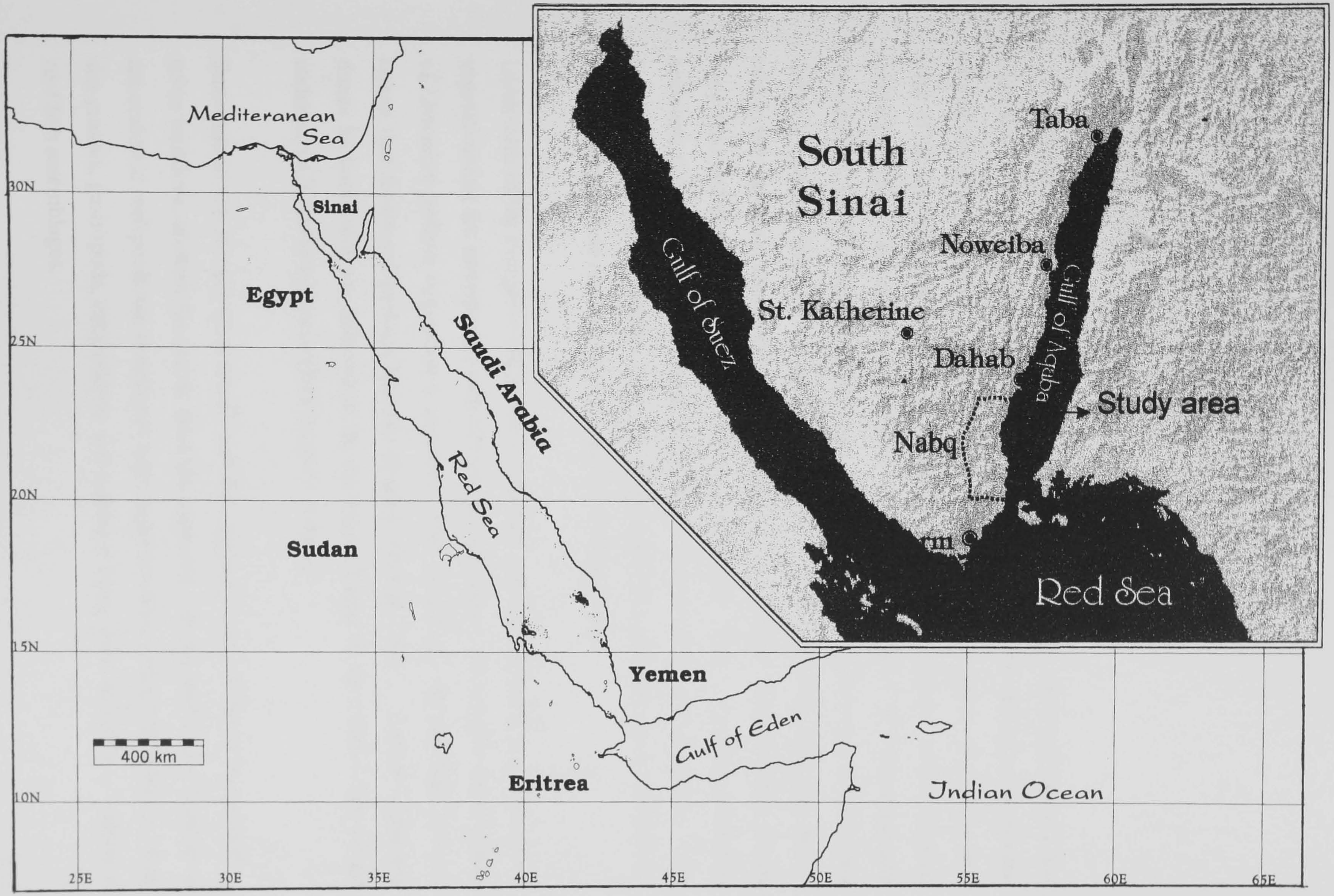


Figure 1. Map shows study area where the most northern mangroves in the Western Indian Ocean occur. The dotted line represents the boundaries for the Nabq Protected Area.

2.3. METHODS AND STUDY AREA

2.3.1. Study Area

The area of the present study is a coastal belt at Nabq (figure 1) about 1 km wide and 20 km long within which four well-developed stands of *Avicennia marina* extend along a significant portion of the shore. These stands grow on the seaward edge of the merging alluvial fans of Wadi Kid and Wadi Addawy, which form an inclined plain, 3-7 km across, that slopes seawards at an angle of 1^0 (Gvirtzman and Buchbinder, 1978). Formed mainly during the Pleistocene (Hayward, 1984), the fan deltas are largely inactive though they do flood very occasionally following heavy rain in the mountain catchment area. During the study period, three flooding events were recorded (between November 1994 and December 1996). On these occasions sediment rich flood waters reached as far as the inland salt marsh vegetation. Less frequent surface water reaches the shore where it deposits sediment on the littoral salt flats (sabkha) before running on to the lagoon or fringing reef.

Landwards of the mangrove are zones of scattered tropical salt marsh and arid coastal vegetation that are interspersed with hillocks of sand dunes. On smaller dunes a zone of *Limonium axillare* vegetation is apparent. Also abundant is the salt-bush *Nitraria retusa* that forms and protects hillocks of sand (Gazzar, 1995). Further inland low dunes harbour what are believed to be the largest stands in the Middle East of the endangered *Salvadora persica* (Kassas, *pers. comm.*).

Seawards of the mangroves a raised reef flat, typically some 350m or more wide at some locations, shelters the stands from the open sea. On the reef flat in these areas are scattered reef-pools and occasional large lagoons which provide habitats for algae, sea-grasses, gastropods, echinoderms and scattered living coral as well as a variety of reef fish assemblages.

2.3.2. Methods

2.3.2.1. Size structure and abundance.

Sampling was undertaken between October 15th 1994 and May 10th 1995. Trees were surveyed along eight 10m wide band transects positioned at right angles to the shore, so that the effect of environmental gradients related to varying degrees of tidal inundation could be investigated. Each transect extended from the seaward edge to the landward margin of the mangrove vegetation, which at some sites extended landwards well above the intertidal zone. Sites of transects were selected so as to be representative of the dominant vegetational growth form of the surrounding mangrove trees. The location of each transect was permanently marked with metal stakes, driven into the substrate, to allow relocation for further surveys. In addition the latitude and longitude of the landward end of the transect was recorded using a hand-held GPS (Global Positioning System).

The positions of all trees (*A. marina*) growing inside the band transects were mapped with reference to a series of 10m x 10m quadrats into which each band transect was sub-divided. Tree reference number, height, basal trunk diameter and crown diameter were all measured directly and recorded on pre-printed data recording sheets. Because *A. marina* typically branches from close to ground level, trunk diameter was measured at the interface between the tree trunk and the soil substrate rather than at breast height as in standard practice in tropical regions with most other mangrove trees. However, even this measurement was not feasible in the most landward quadrats, where typically most of the trunks were buried beneath the sand and soil, and only the canopy was accessible above ground.

2.3.2.2. Physical factors.

Along one transect at each of the two largest stands (Marsa Abo Zabad and Shora Al Rowaisseya) three quadrats were selected for quarterly measurement of physical / environmental factors. (Available time and resources limited the number of sites that could be monitored). On each of these transects one quadrat was selected in each of the upper, middle and lower intertidal zones and was permanently marked for repeated future measurements. At each station (monitoring quadrat), the following parameters were measured:

- Water level with reference to a number of fixed points
- Air temperature was measured using mercury thermometers (sensitive to +/- 0.5°C) suspended in the shade from a larger tree.
- Maximum and minimum temperature was measured using a max. / min. mercury thermometer, suspended at the same locations over 24 hours.
- Soil temperature was measured using a mercury thermometer inserted to a depth of 10 - 20 cm. deep with the aid of a protective tube.
- Seawater salinity was measured using a hand-held refractometer with a range 0-100 ppt and sensitive to 1 ppt; before use it was manually calibrated using deionized water.
- Soil salinity was measured using the same hand held refractometer after extracting sufficient drops of soil water by squeezing them out from a soil sample with the aid of a syringe fitted with a pad of filter paper below the aperture
- Soil acidity (pH) of the surface sediment (5-10 cm deep) was measured using a hand held digital pH meter (Horiba).
- Dissolved oxygen of surface water samples was measured using a hand-held digital dissolved oxygen meter.
- Soft sediment depth above the hard-bottom fossil reef was determined using a manual 1.5 meters long soil corer.

Measurements were taken in August and November 1995, and in February and April 1996, every 3 to 4 hours, over two full 24 hr periods, one on a spring tide, and one a week later on neap tide. This arrangement was adopted in order to observe the extremes in conditions, e.g. in temperature or salinity that were expected to occur, either on a spring or neap tide, by day or night and in summer or winter.

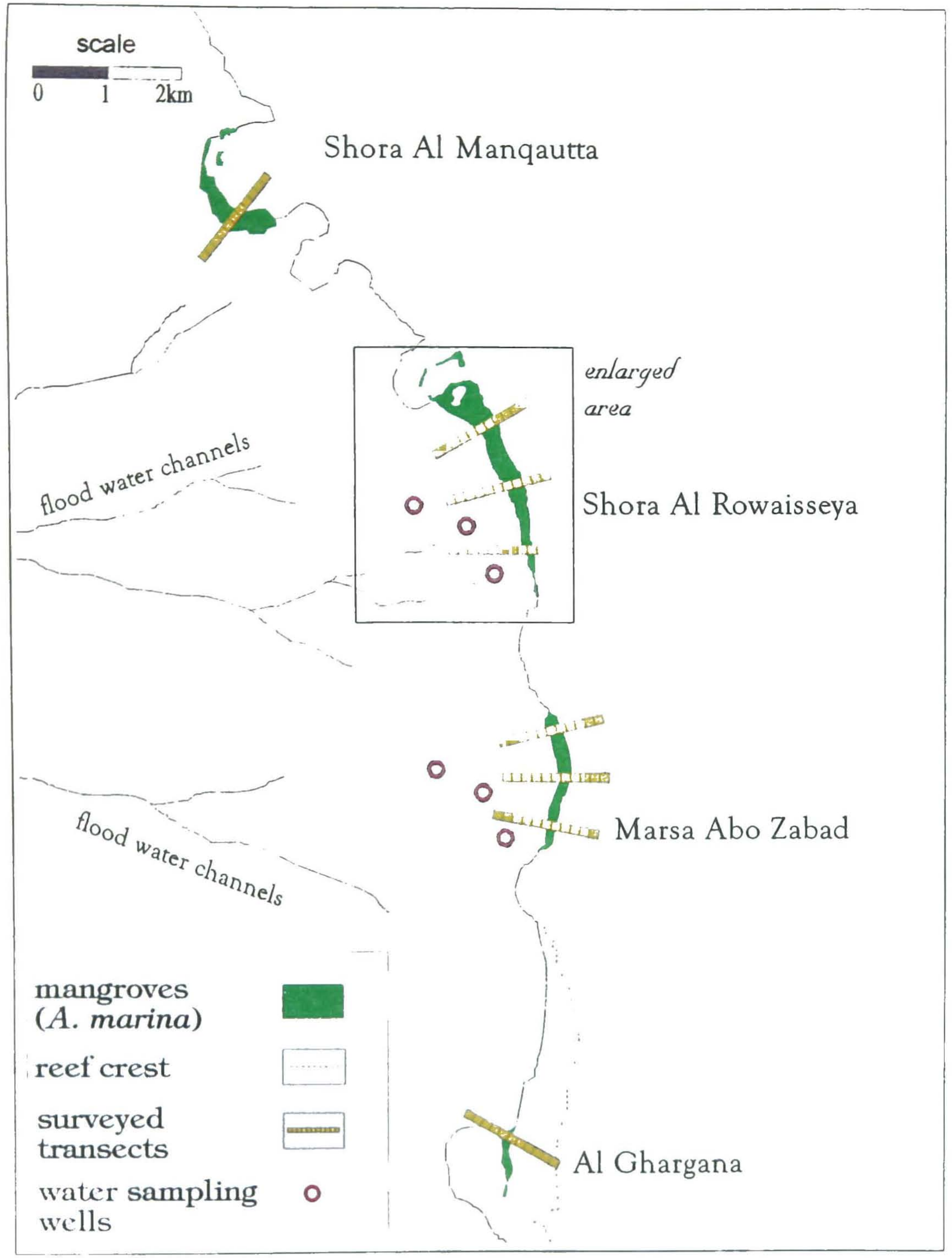
2.3.2.3. Mapping and area estimation.

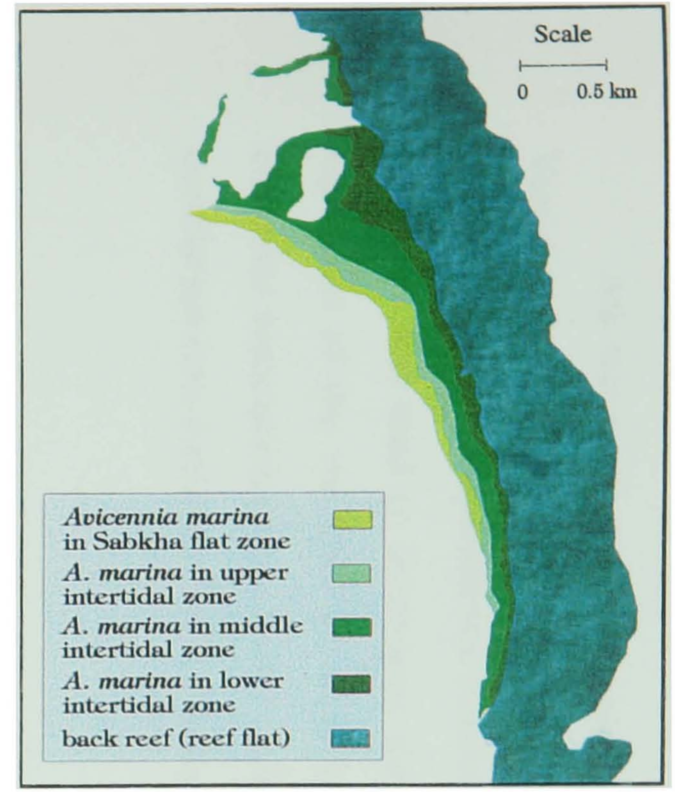
The interpretation of satellite images for mapping and area estimation of mangrove vegetation at Nabq was carried out in the GIS Unit of the Gulf of Aqaba Protectorates as follows:

- A digitised Landsat MSS TM image of the Nabq area was geo-referenced and rectified to a topographic map of the Egyptian Geological Survey acquired via the Department of Protectorates, Egyptian Environmental affairs Agency (EEAA).
- Ground truth surveys of training areas of mangrove vegetation were undertaken in December 1994 using a hand-held Global Positioning System (Magellan 2000 GPS).
- The co-ordinates of these training areas were applied to the TM image in order to estimate the spectral signature of mangrove vegetation at Nabq, following which spatial classification, colour coding and area estimation were obtained.

2.3.2.4. Assessment of fresh water seepage.

Ground water seepage was assessed in a two-stage process. First, rectification and digital image subtraction were applied to two SPOT panchromatic images of the Nabq area recorded in 1992 and 1994. This was done in order to enhance the visual interpretation of flood water channels seawards of the Wadi Kid and Wadi Addawy alluvial fans along which ground water or surface water might reach the mangroves. Subsequently six wells were dug to a depth of 2-3m at locations within these channels a little landwards of the main mangrove stands (see Figure 2). Water samples were taken from these wells in May 1995, September 1996 and May 1997, and salinity and water temperature recorded.





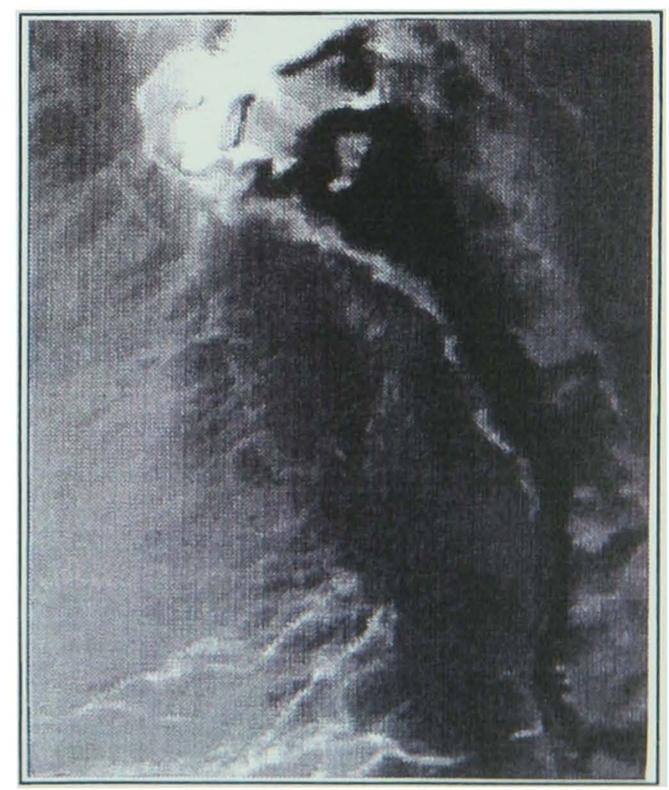


Figure 2. The mangrove stands in Nabq are mapped (above) by the aid of SPOT panchromatic satellite image (bottom right). Ground truth surveys revealed, however, that more mangrove vegetation occurred as compared to those detected by remote sensing. The GIS layer of mangrove vegetation at each stand (e.g. Shora Al Rowaisseya) shown at top right figure was enhanced by ground-truthing.

2.3.3. Statistical analysis

All statistical analysis was performed using SPSS 8.0 statistical software. Variation in tree structural development parameters between different locations was tested using the non-parametric Kruskal-Wallis test for the analysis of variance. The same test was used to investigate the statistical significance of spatial or temporal variations of the recorded environmental parameters at replicated sites. Between character associations were tested using bivariate two-tailed Pearson product-moment correlation tests (unless otherwise stated in the text).

2.4. RESULTS

2.4.1. Size Structure and abundance

2.4.1.1. Extent and character of stands

The four mangrove stands at Nabq fringe protected shorelines and are best developed along shores where there are extensive areas whose elevations are somewhat above mean sea level. Descriptions of the stands follow. The names of the stands are the traditional ones used by the local Bedouin population.

Ghargana. This is the smallest of the four stands where *A. marina* are present in the north-eastern section of the Ghargana lagoon (see Figure 2) which has a depth range of 1.5-4m. Scattered, low-density mangrove shrubs also occur for 600m along the coastline to the south of the lagoon, and extending inland to approximately 40m beyond the normal high tide line. These shrubs are generally dwarfed trees that do not exceed 1.2m in height. However, individual trees with well-developed crowns that reach approximately 4m high are apparent at the seaward margin of this stand.

Marsa Abo Zabad. This stand extends for about 1.4 km along to the shoreline and for approximately 150m seawards from the upper intertidal zone to the lower intertidal zone. In the upper intertidal area, a zone of dwarfed trees extends inland from the shoreline for about 80m. These shrubs grow in highly saline soils, which are only inundated by seawater at spring high tides, and are characterised by the apparent absence of aerial roots. The seaward margin of the stand is protected from the open sea by a stretch of raised fossil reef that dries out at low tides.

Shora Al Rowaisseya. This is the largest of the stands. Mangroves extend for more than 3.5km along the shoreline in a band, which at some locations exceeds 250m in width. The middle and lower intertidal zones are characterised by fully-grown healthy trees exceeding 5m in height. The upper intertidal zone by contrast is occupied by abundant dwarfed trees no more than 1.5m tall. Towards the northern end of this stand is a large lagoon surrounded by a band of dense trees. The lagoon ranges in

depth from 0.5 to 3m but is only fully connected to the open sea at high tide. Other subtidal pools occur also among the mangrove vegetation and are surrounded by some of the largest trees (6.2m) along the Gulf of Aqaba. The largest of these subtidal pools, known as the 'Caulerpa pool', is connected to the open Gulf at high tide when water exchange over the reef flat is observed while at low tides, the reef-pool gets disconnected from the sea.

Shora Al Manquatta. This is the most northern of the stands and hence the most northerly in the Western Indian Ocean region. Trees here are well developed and especially dense towards the protected western edge of a sandy lagoon that is separated from the open sea by a strip of fossilised reef.

The mean tree density and height on transects in each stand are shown in table 1. There was found to be a highly significant variation in tree height between stands (χ^2= 20.36, P < 0.0005), but variation in total basal area was less significant (χ^2=3.13, P < 0.05), probably linked to the fact that no notable variation in tree density was apparent.

Stand location	Position (lat. / long.)	mean tree height meters (+/- S.E)	mean tree density $100m^{-2}$ (+/- S.E)
Ghargana	28 07` N 34 27` E	1.93 (+/- 0.11)	1.86 (+/- 0.59)
Marsa Abo Zabad	28 09` N 34 26` E	1.42 (+/- 0.09)	3.73 (+/- 0.64)
Shora Al-Rowwaysia	28 09` N 34 27` E	1.81 (+/- 0.64)	5.02 (+/- 0.91)
Shora Al-Manquatta	28 12` N 34 25` E	2.56 (+/- 0.13)	2.64 (+/- 0.59)

Table 1. Mean tree height and density of *A. marina* along transects at each of the main mangrove stands. Measurements from both transects within each stand are pooled. N >150 for mean height, and >40 for mean density. Positions were recorded by GPS at the landward ends of each transect.

2.4.1.2. Topography and zonation

The mangrove transects were most conveniently sub-divided into four zones at different elevations compared to mean sea level, corresponding to different inundation classes as described by Watson (1928) (see table 2).

The sabkha (salt flat) zone: The least inundated zone is characterised, typically, by sabkha flats that are completely dry for most of the year except at the highest spring tides (table 2). In this Sabkha zone the pneumatophores (aerial roots) typical of *A. marina* were not obviously present and digging carefully beneath plants to approximately one meter deep revealed that the roots extended downwards to deeper than this. At many locations in this zone, *A. marina* are completely surrounded by hillocks of sand so that only the tree canopy protrudes above substrate level, i.e. no trunk is apparent. Dried fruits were abundant under mangrove trees in this zone: their mean density was estimated at 5.5 (S.E +/- 0.86) seedlings per square meter but in some locations, notably at northern Marsa Abo Zabad, exceeded 20 fruits m^{-2}.

Upper intertidal zone: This zone is flooded by the high spring tides: much of the seawater then evaporates, concentrating salt within the flat. The zone is characterised by a dense scrub of dwarfed trees, hardly exceeding 1.5m tall, growing on soft sediment composed of anaerobic mud intermixed with sand and alluvial sediment.

Middle intertidal zone: This zone is characterised by the presence of small lagoons or pools, which, although lacking mangrove growth, were surrounded by dense, well-formed trees growing on soft anaerobic sediment typically over one meter deep.

Lower intertidal zone: In this zone trees possess well-developed crowns forming a dense canopy. The trees grow on an exposed porous hard fossilised reef covered by only a thin layer of mud, that does little more than fill crevices and depressions in the substrate, but the decrease in depth of sediment did not significantly influence their growth or development. The root system, when carefully checked, was found to penetrate the porous hard-bottom reef substrate. In many locations the stand ended in

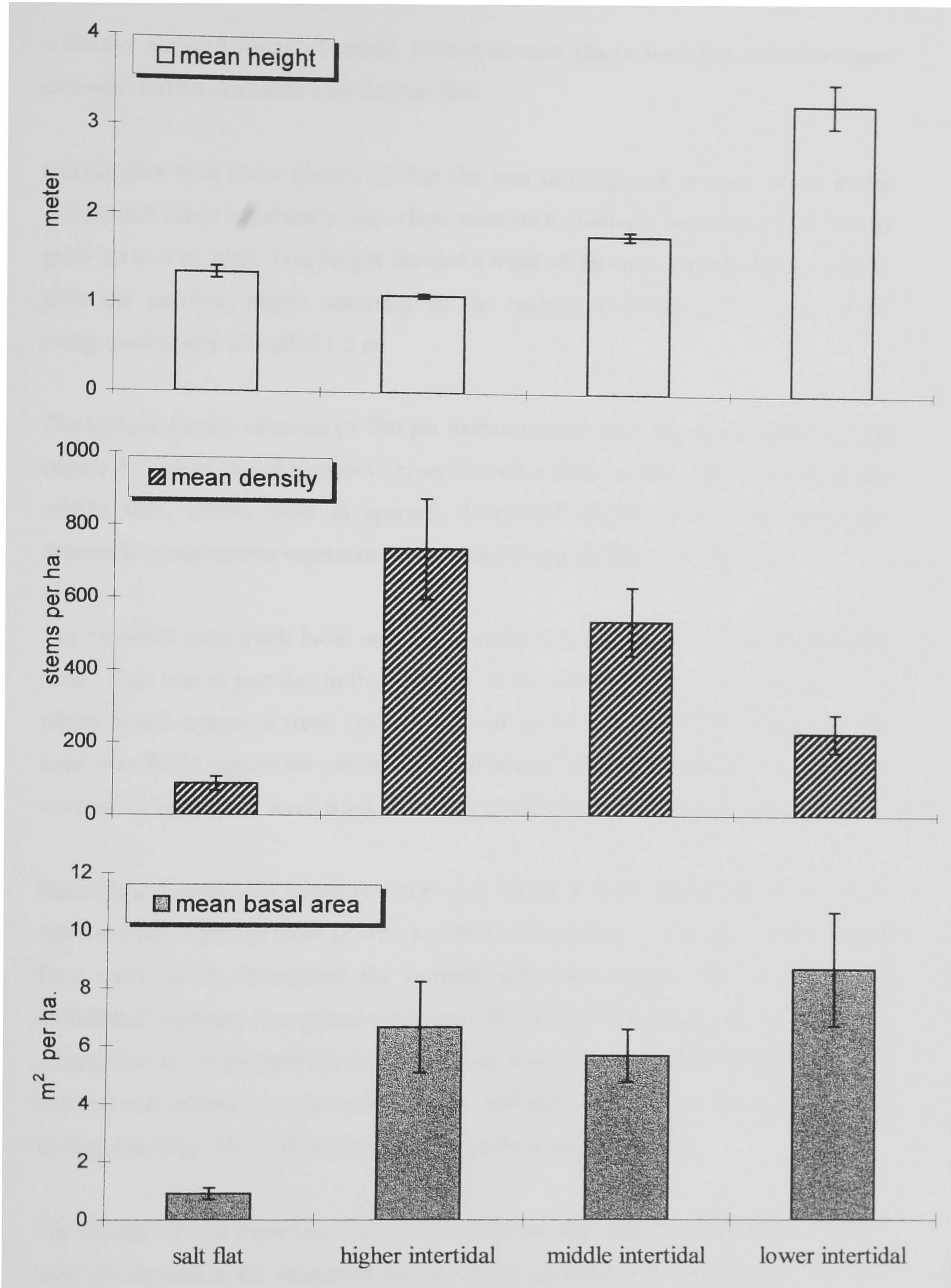


Figure 3. Variation in structural development parameters of trees between tidal inundation zones. Error bars represent standard error of the mean.

a distinct seaward fringe of stands, though in most places scattered individual trees extended further seawards over the reef flat.

Quantitative data show (figure 3) that the best developed *A. marina* occur in the middle and lower intertidal zones where trees with relatively well developed crowns grow up to 6 m. high. Tree height showed a trend of decreasing gradually landwards, with the smallest plants occurring in the highest intertidal zone where dwarf mangroves hardly exceeded 1.5 m.

The highest density of stems (> 700 per hectare) occurred in the upper intertidal zone (figure 3), where dwarf mangrove trees formed a dense scrub. By contrast on the sabkha flats, shrubs were so sparsely distributed (figure 3) that they were not detectable as mangrove vegetation by remote sensing applications (figure 2).

The recorded total trunk basal area by contrast was lowest in the middle intertidal zone. This was in part due to the presence of the reef flat lagoons, described above, within which mangrove trees, typically, did not occur. Also this pattern ignores total basal area of the uppermost sabkha flat zone where, because the mangroves are partly covered by hillocks of sand, trunk diameters could not be directly recorded.

Phenological events of mangrove trees was found to peak during the period from April to June, although some flowers and fruit were produced over an extended period from early spring throughout the summer until late autumn. The abundance of established saplings was greatest between the middle and higher intertidal zones. Abundance of well-established saplings was also notably greater at stations with reduced soil salinity i.e. where salinity was influenced by ground water or rarely by surface flooding. This will be discussed in more detail in chapter 3.

The cutting of tree branches, for use of timber as fuel, was observed to be or have been widespread in the mangrove stands. Trees growing in the sabkha flat zone had the highest rate of human associated damage, and in a few easily accessible sites within this zone approximately 70% percent of the trees present showed signs that one or more branches had been cut from the tree. By contrast mangroves in the less accessible lower intertidal zones showed few signs of damage. Overall there did not appear to have been any recent reduction in extent of living mangroves as a result of the observed levels of use, although some local people described that there used to be an additional small stand of mangroves adjacent to the Bedouin village of Ghargana, and that this may have been depleted as a result of excessive use for fuel wood.

2.4.2. Physical parameters

Recorded tides of the Gulf of Aqaba were semi-diurnal. High water level ranged from as little as 15cm above the reef flat at neap tides, to 55cm at spring tides. Measurement of topographic elevation along the mangrove transects, together with the recording of the frequency and duration of tidal flooding, allowed the quantification of flushing frequency for each quadrat (table 2).

Mean surface seawater salinity of the Gulf of Aqaba in areas confronting Nabq ranged from 41.5 to 42.5 ppt (mean value 41.8 +/- 0.23). Measurements of water salinity in different zones (figure 4) confirmed that salinity increased and was highly correlated with elevation in relation to mean sea level ($r^2 = 0.91$, $P < 0.005$). By contrast the salinity of ground water (2m deep) at the inland margin of the mangrove was always lower than ambient seawater salinity. At two of the wells, Marsa Abo Zabad and Shora Al Rowaisseya, ground water salinity was much lower, at 24 and 19 ppt, respectively. By contrast, soil-surface salinity in the inland zones was higher than open seawater salinity, with highest values of >80 ppt occurring at neap tides (figure 4).

Soil surface temperature ranged from a minimum of 14 °C in February, to a maximum of 37.5 °C in August, but did not vary significantly between sites. Diurnal variation was greatest in autumn with a temperature amplitude reaching 14°C, and, as would be expected, was much greater than that observed (Anati, 1976) in surface seawater temperatures in the Gulf of Aqaba.

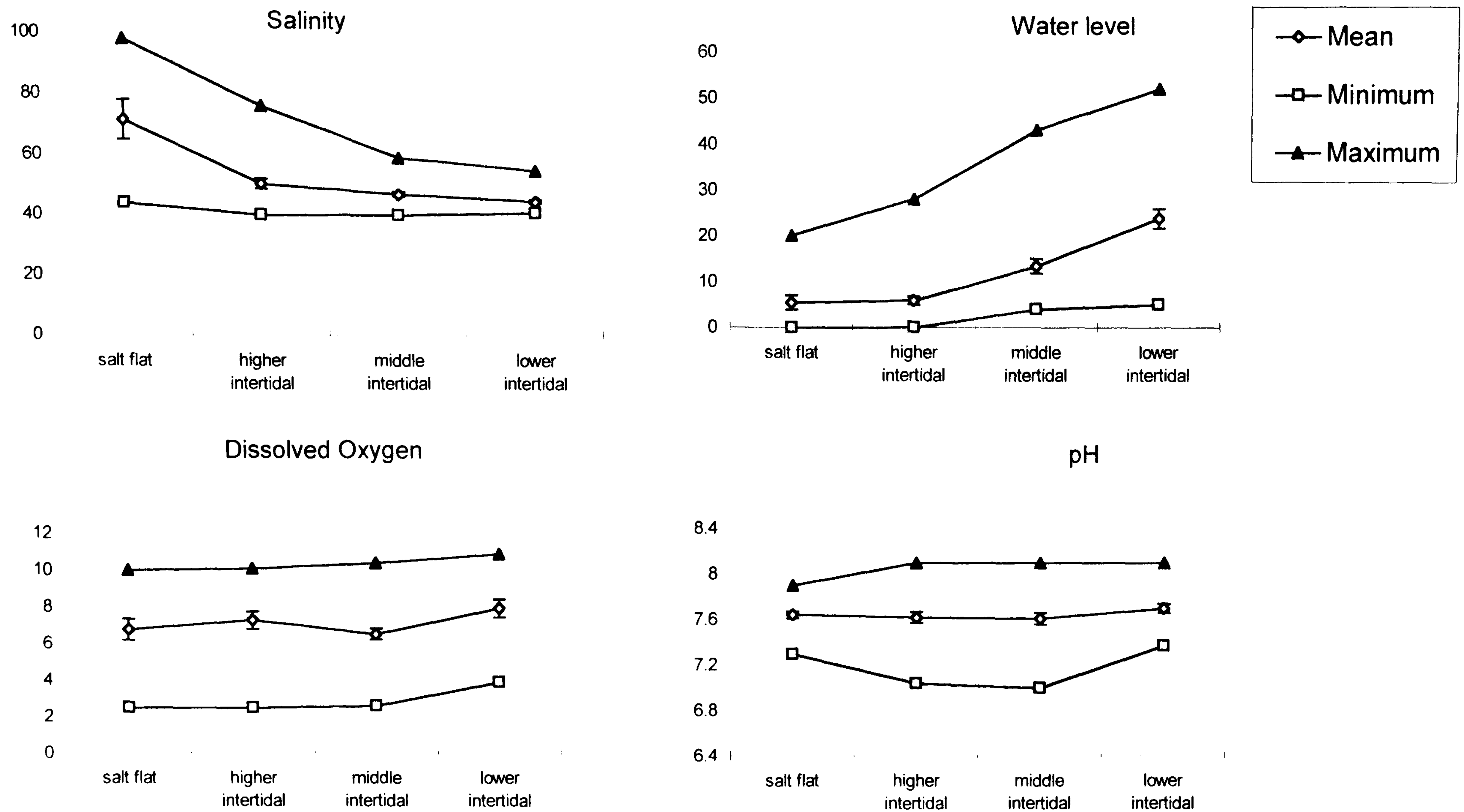


Figure 4. Physical factors within the Nabq mangal and variation between inundation zones (see table 1). Values are those from all measurements during 1995 / 96. Error bars represent standard error of the mean.

Dissolved oxygen levels of soil surface water varied diurnally between 2.5 and 10.4mg. lt^{-1}, but again there was no significant variation between stations. Similarly recorded pH ranged between 7 to 8.1, but did not vary significantly between stations.

zone	tidal inundation regime	inundation class	topographic elevation	relative zone area	flushing rate
sabkha flats with sand dunes	inundated only by extreme tides	5	> 65 cm	16%	Occasional (< 10 times per year)
upper intertidal	inundated by spring tides	4	45-65 cm	24%	3-6 times/wk.
middle intertidal	inundated by normal tides	3	20-45 cm	32%	7-9 times/wk.
lower intertidal	inundated by neap tides	2	< 20 cm	28%	12-14 times/wk.

Table 2: Tidal regimes of intertidal zones. Microtopographic elevation is shown relative to mean sea level. Relative zone area is calculated as the mean proportion of the zone area as determined for each band transect. Inundation classes shown are according to Watson (1928).

2.4.3. Mapping and area estimation

The TM digital satellite image was classified for mangrove vegetation by the aid of ERDAS image enhancement and classification software. The mangrove layer was colour-coded, copied then rectified to the topographic map of Nabq as previously stored on a GIS system (MAPINFO software). The resulting map is shown in figure 2. The area of the different mangrove stands (table 3) was determined from the digitised GIS layer representing the mangrove stands.

Mangrove stand	Mean basal area (m^2 / ha)	Total cover area (ha)
Al Ghargana	0.179 +/- 0.07	3.4
Marsa Abo Zabad	0.044 +/- 0.008	14.4
Shora Al Rowaisseya	0.072 +/- 0.012	27.6
Shora Al Manquatta	0.133 +/- 0.03	7.1

Table 3. Total area of each mangrove stand as calculated from the GIS map layer. Also shown are the mean basal areas for each stand expressed as m^2 (+/- S.E) per hectare.

2.4.4. Assessment of fresh water seepage

A notable reduction of ground water salinity than that of the seawater salinity was detected. The minimum measured salinity of the samples that were taken from the pits at varying distances landwards of the mangrove stands ranged between 14-38 ppt. This reflects that seepage of fresh ground water into the coastal zone and consequently the mangrove soil is not only limited to the apparent rare events of flooding and fresh surface water run-off, but to more frequent underground seepage as well. This will be discussed in more detail in chapter 3.

2.5. DISCUSSION

The effect of microtopographic elevation of the substrate on tidal inundation regime is one of the main factors affecting the spatial distribution and abundance of mangroves at Nabq. These mangroves are, in general, less well-developed than stands of *A. marina* that are reported to grow under the most favourable conditions, such as those found around the mouth of estuaries in tropical regions (McNae, 1966; Blasco, 1977, Bunt *et al.*, 1982). They are more comparable to the mangroves found at higher latitudes, for example, around the Red Sea (Kassas, 1957; Kassas and Zahran, 1967; Fouda and Al-Muharrami, 1995, Abdel-Razik, 1991; Saifullah *et al.* 1989; Price *et al.*, 1987), Taiwan (Tam et al, 1995), New Zealand (Burns and Ogden, 1985; de Lange and de Lange, 1994) and in south western Australia (Clough *et al.*, 1997). The limited structural development of Gulf of Aqaba mangroves has been attributed to the high salinity levels, low winter temperatures and relatively low nutrient levels of seawater in the Gulf of Aqaba (Por *et al.* 1977). However, *A. marina* in the middle and lower intertidal zones form denser growths with better developed crowns and attain greater height even though they are more exposed to the open sea, suggesting that it is principally the higher salinity levels and low tidal flushing rates of the upper shore which restricts growth rates along the higher intertidal zones.

The initial hypothesis that mangroves stands at Nabq occur principally where fresh or brackish ground water, and occasionally surface water, reaches the coast have been confirmed. Ground water that slowly percolated into almost all the wells dug on the inland side of the stands was less saline than the open water of the Gulf of Aqaba. In particular, values down to less than 20 ppt were recorded in wells adjacent to the best-developed stands. The flood events during the study period, though involving relatively low volumes of water, were in fact the largest for the last two decades. Ground water salinity in the wells was at its lowest recorded values shortly after the last flood in November 1996, supporting the view that this water percolates to the coast down the Wadi Kid and Wadi Addawy catchments following rain in the mountains which was previously suggested by Por *et al.* (1977).

The growth of new saplings at Nabq was also observed to be related to the pattern of fresh water drainage; many more seedlings survived, and saplings had grown taller, where surface water reached the coast after flooding. This matches the findings of Downton (1982) and Clough (1984) that optimal growth of *A. marina* occurs at reduced seawater salinity levels (25% seawater treatments). This will be discussed in more detail in chapter 3. The better development of both mature and immature mangroves in areas influenced by groundwater supports the view that *A. marina* are able to survive, and even thrive, in coastal areas at Nabq, despite the high salinity sea water, and the hypersaline intertidal soils, because of the dilution of soil water by this supply of freshwater.

The variation of soil acidity and dissolved oxygen levels within the mangrove stands did not seem to influence the spatial distribution or structural development of the mangrove trees. The low winter temperatures especially during the winter (December to February) were recorded to reach as low as 14° C in the early morning. These low temperatures, together with the high salinity levels within these stands are presumed to significantly contribute to the limiting of mangrove development in Nabq and further extension towards the north where lower winter temperatures and higher salinity levels prevail. These influences of low temperature stress have been reported in the Red Sea by Zahran (1975) as well as in other regions (McNae, 1966; Lugo and Zucca, 1977). They have also suggested that other environmental stressors at high latitudes include low rainfall and wider temperature amplitudes, which are reported for the Nabq area.

A. marina growing at the innermost sabkha / sand hillock zone of the mangrove had developed only ground, rather than aerial, roots and yet developed well-formed crowns. The pneumatophores (aerial roots) of *A. marina* are widely recognised to be important in supplying oxygen to the below ground roots (Hutchings and Saenger, 1987; Tomlinson, 1986); thus it seems probable that the lack of aerial roots is a response to the fact that the soil there is formed of coarse alluvial and calcareous sands that dry out between rare events of extreme high tides when they get flushed by seawater. Further, the presence of underground fresh water that was detected to seep into the mangrove soil could suggest that the substrate in which the roots are growing is not anoxic like typical mangrove muds in other locations. This has allowed growth in these inland locations that are rarely flushed. Also, the apparent production of moderate amounts of leaf and twig litter and seeds was found to dry out under the trees before being transported to other zones by rare flushing events or occasionally strong winds. These inland mangroves are important to the wildlife of Nabq: both terrestrial insects and small rodents find food and shelter among this litter.

Compared to other coastal environments within the Gulf of Aqaba, the mangal in Nabq and the inter-related coastal ecosystems of coral reefs and seagrass beds suggests a relatively highly productive ecosystem that supports economic benefits such as fisheries production as well as biological and genetic diversity of this unique environment within the Gulf of Aqaba.

Traditionally timber from *A. marina* has been exploited by local Bedouin. They collected firewood for their cooking requirements and special occasions, and in addition made occasional selective use of branches as poles for light construction. By 1994 there appeared to have been a noticeable increase in the rate of physical damage to mangroves. Further there was concern that the amounts being taken were increasing due to a growing demand for firewood from the neighbouring tourism centres around Sharm El Sheikh and Dahab. This was being used for cooking or making campfires in hotels, in addition to which increasing numbers of tourists were visiting the mangrove stands and their lagoons, and also sometimes using timber for fuel.

The expansion of the boundaries of the Egyptian Gulf of Aqaba protectorates in 1992 to include the Nabq and near-by Abu Galloum Protected Areas increased the area of protected coastal land from 185 to 460 km^2 (South Sinai Parks, 1997). These protected areas are managed and administered by the Egyptian Environmental Affairs Agency (EEAA) through its Gulf of Aqaba Protectorates Department in Sharm El Sheikh. Area managers held long discussions with resident Bedouin who stated that they personally were opposed to the heavy exploitation of the mangrove stands for timber by a few individuals for sale to the nearby tourist centres. Consequently, a community-based conservation and management scheme, incorporating a precautionary approach, was formulated by Park managers and has been accepted by the local population. They have conceded to refrain from using mangrove timber for

commercial activities and to use so far as possible, only dry and dead branches (< 15 cm) for basic cooking requirements. The supply of gas stoves by the GAP was also promoted as a possible option. In return all fishing rights and most tourism activities were reserved by the EEAA to the local Bedouins and their families.

In addition several local Bedouin have also been employed as Community Rangers within the National Park and protected areas. Their duties include patrolling the mangrove areas in support of environmental regulations. This has also facilitated the spread of environmental awareness amongst the local inhabitants. Through this approach, the conservation of natural resources is benefiting resident Bedouin, both directly through the provision of wages, and indirectly through an increase in nature-based tourism to the area.

The quantitative determination of the extent of the mangrove stands, and collection of data on tree height and structural development, is a first step towards assessing the sustainable levels of utilisation of the local mangrove resources. Subsequently work was initiated to monitor standing above-ground biomass, leaves productivity of trees and rates of colonisation by new saplings, which is described in chapter 3.

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CHAPTER 3

Estimation of Biomass, Leaf Production, Litterfall and Recruitment of Mangroves, *Avicennia marina* (Forsk.) Vierh., at Nabq, South Sinai

3.1. ABSTRACT

Studies were undertaken at sites within the Nabq Protected Area of the biomass, rates of leaf growth and litterfall, and rates of sapling survival and growth, of the mangrove *A. marina* in Nabq, South Sinai. These were investigated by taking repeat measurements of the diameter and length of tagged branches and twigs, and of the number of marked leaves present on tagged twigs. The dry weight of leaves, twigs, and timber varied with branch diameter, although the weight of reproductive components did not. The relationship between total estimated biomass (B) and branch diameter (D) was found to match the equation: $B = 147.9 \times D^{2.06}$.
Timber biomass matched the equation: $T = (3.141 \times D^2 \times L) / 4 W$; where L is branch length (in cm.), and W the weight of timber per unit volume (kg. cm^{-3}). Estimated in this way, the total above-ground biomass was found to range between 5,400 & 47,000 kg.ha^{-1}. The mean growth of new leaves was found to be higher during the summer (growth ratio = 0.94 +/- 0.19) than in the winter (0.58 +/- 0.10). The mean leaf litterfall as a proportion of the initial number of leaves was estimated at 0.83 +/- 0.17 per annum.

There was significant input of brackish ground water to most areas were mangrove stands were well developed. The two sites where the greatest ground water input was detected at Marsa Abo Zabad and Shora El Rowaisseya had ground water salinities as low as 19 & 24 ppt.
Seedling survival varied significantly between sites (Kruskal-Wallis, $\chi^2=4.74$, $P < 0.05$), depending on ground water input (Spearman correlation coefficient = 0.74, $P < 0.005$). The heights and leaf numbers of mangrove saplings was also highly correlated with fresh water drainage, but there were no significant differences between seasons and years.

3.2. INTRODUCTION

Mangrove forests still cover extensive intertidal areas of sheltered coastlines and estuaries in many tropical regions (Lugo and Snedaker, 1974). They also extend to subtropical areas like south-eastern China and Taiwan (Tam *et al.*, 1995), southern Australia (Clough *et al.*, 1997), southern Florida (Snedaker, 1989) and the northern Red Sea (Kassas and Zahran, 1967). However at these higher latitudes survival or growth of mangrove plants appears increasingly limited by their lack of tolerance to low temperatures (Burns and Ogden, 1985), and stands generally show a marked reduction in species richness, tree density and tree size, as described for southern Australia by Macnae (1966), for the northern Gulf of Mexico by Lugo and Zucca (1977), and for the Red Sea by Zahran (1975), and Price *et al.* (1987).

In the northern Red Sea stands frequently consist of only smaller shrub like trees, although in some locations, dense areas of taller mangrove are also present (see chapter 2). On the southern Egyptian Gulf of Aqaba coastline mangroves are frequently growing under hypersaline conditions, both as a result of the dry arid climate, with little if any rainfall, and because of the associated increase in open water salinity which within the Gulf of Aqaba reaches > 41 ppt. At Nabq, soil salinities at some locations have been reported to reach as high as 70ppt (Por *et al.* 1977), due to a combination of water-logging and evaporation in the higher intertidal zones. Such hypersaline environments have been found to result in both an increase in respiration required to meet the energy demands of retaining water balance (Tomlinson, 1986) and a decrease in net productivity (Lugo *et al.* 1975). Thus mangroves at Nabq, subject to both hypersaline soils and occasional low winter temperatures at this high latitude may be expected to show a level of productivity somewhat less than those reported for multispecies tropical mangrove forests.

Usually it is only one or more species of *Avicennia* which are able to tolerate the most extreme conditions. *Avicennia marina* (Forsk.) Vier. in particular is recorded globally in a wider range of environments than any other mangrove species (Clough, 1982). It occurs locally in extensive patches fringing the shore of arid and semi-arid coastlines in both the Arabian Gulf (Abdel-Razik, 1991; Sheppard *et al.*, 1992; Fouda and Muharramy, 1995) and the Red Sea (Kassas & Zahran, 1967; Zahran *et al.* 1983; and Price *et al.*, 1987), which is a type locality. In the southern Red Sea *Avicennia* stands are in some sheltered lagoons mixed with stands of *Rhizophora mucronata*, both on the Sudanese coast (Kassas and Zahran, 1967), and in Saudi Arabia (Price *et al.*, 1987). However, at Nabq, where the most northerly mangroves in the Indian Ocean region occur, only monospecific stands of *A. marina* are present.

During the last two decades, it has been increasingly appreciated that mangrove forests constitute a very valuable renewable resource (Lugo and Snedaker, 1974). Not only do the trees provide timber and fuel, but it is now recognised that a large proportion of their production enters the shallow water marine environment as litter-fall that is broken down to particulate organic matter and detritus which fuels near-shore secondary production (Callimeri and Ribi, 1986; Alongi, 1989; Alongi *et al.* 1989; Fleming *et al.* 1990). This process is accomplished by a complex detritivore food web in which micro-organisms (bacteria and fungi) and shredder crustacea (especially sesarmid crabs) play a key role. This trophic web in turn supports a range of commercial species including penaeid shrimps and a variety of demersal fish for many of which the mangrove habitat is believed to serve as a critical nursery ground (Lindall, 1973; Bell *et al.*, 1984; Robertson and Duke, 1987; Thayer *et al.*, 1987). Mangroves have a further importance for coastal zone management in that the ability of their roots to trap and retain sediments (Furukawa *et al.*, 1997) has made them important shore stabilisers, contributing to shoreline accretion and controlling coastal erosion (Blasco *et al*, 1996).

Despite this economic and ecological value, mangrove forests have increasingly been impacted and destroyed on a global scale. In south-east Asia, in particular, a very high percentage (>>50%) of the original mangrove forests has been either felled for direct use (for timber chip-board production) or transformed into other land uses such as building, agriculture, oil palm plantation, or shrimp culture.
Management and conservation measures have been introduced into many regions (e.g. Malaysia, Australia, Philippines), including establishment of protected areas and replanting, but considerable threats to the mangrove still persist. In the Red Sea, although historically human impact on the scattered mangrove stands was probably small, and low level use for timber, firewood and fodder probably sustainable, this is suspected to have caused the loss of *Rhizophora mucronata* from some more northerly stands where it previously occurred. More recently, not only has traditional use been intensifying with the rapidly expanding human population, but other threats have materialised including oil pollution, commercial felling for fuel and fodder, and in particular clearance in the process of extensive coastal construction work linked to urbanisation and tourism related development.

In the south Sinai, all mangrove vegetation has been afforded a degree of protection by being included within the boundaries of either the Ras Mohammed National Park (one stand) or the Nabq Managed Resource Protected Area (four stands). Although effective management of these protected areas has been implemented (Pearson, 1998), the Nabq Protectorate is considered a multiple-use managed resource area within which sustainable use of renewable resources by local populations (predominantly Bedouin) may be permitted. Thus it is the expectation that restricted harvesting of mangrove products by Bedouin may at some time in the future be allowed, in keeping with the traditional rights they exercised before a moratorium was introduced when the protected area was established. Knowledge of the productivity, turnover rates and sustainable yield of the mangroves at Nabq, and of the factors affecting them, is thus required to enhance the decision-making capacity of the park managers in relation to potential zoning and exploitation.

The flora and fauna of the Nabq mangroves have been described by Por & Dor (1975), Por *et al.* (1977), Gazzar (1995) and Abou-Zeid *et al.* (1995). There have however been few studies of their ecophysiology and ecology. Their anatomical and physiological adaptations for survival in extremely saline conditions were reviewed by Leshem and Levison (1972), and leaf litter detritic decomposition processes in the area were studied by Reice *et al.* (1984). However no study has quantified the biomass and leaf litter production of these stands. In 1995 therefore a study was initiated to investigate the standing over ground total biomass of mangrove trees in Nabq, and their growth rates and annual leaf litter production. In addition the recruitment, survival and growth of new seedlings was examined, as a way of assessing the potential for replanting in either new or harvested plots.

3.3. METHODS AND RESULTS

For convenience, since this chapter describes results obtained using a series of different methods, the methods and results are subdivided into 3 separate sections with the description of the results following the description of the respective methods. Section I focuses on the estimation of standing above-ground biomass, and section II upon leaf turnover rates, while section III investigates seedling survival and sapling growth.

3.3.1. Section I: Estimation of above-ground standing biomass

3.3.1.1. Materials and methods

(i) Tree structure and branch measurements.

The two largest stands of mangrove, Marsa Abo Zabad and Shora Al Rowaisseya (see map, figure 2), were selected for these studies. At each of the two stands, three 10 x10m quadrats were demarcated and arranged along a transect perpendicular to the shoreline, with one quadrat in each of the higher, middle and lower intertidal zones. The positions of all the trees (height > 60 cm from ground level) in each quadrat were then mapped and the following measurements were recorded;

- Diameter at base (just above ground level).
- Trunk height (from ground level until branching occurs).
- Diameter of all first orders branches (d > 2cm) originating from the trunk, categorised in terms of four size classes (table 1).
- Lengths of all first order branches (from base until further branching occurs).

All measurements were made using 3m water-resistant tape measure and callipers.

Size class	diameter in cm.
I	(2.0 <D < 4.0)
II	(4.0 < D < 8.0)
III	(8.1 < D < 12.0)
IV	(12.0 < D)

Table 1. The ranges of branch diameters in each size class used to classify the size of first order branches.

In addition, within each quadrat, three trees were selected for estimation of biomass. These were chosen to represent the vegetational architecture typical of three different size classes of tree, small (90-150cm overall height), medium (160-250cm) and large (> 250cm). Their location of these trees within each quadrat were mapped, and the trees permanently tagged to further aid relocation. For each of these trees further detailed measurements of branch number and size were made as follows:

- Diameter and length of all second order (i.e. sub-branches) originating from two randomly selected first order branches.
- Diameter and length of all third order branches originating from the selected second order branches.

When, as sometimes happened, a swelling occurred at the base of a branch, the diameter of the branch was measured immediately above the swelling.

(ii) Dry weight estimation

Care needed to be taken so as to minimise any physical damage that would be caused to the mangrove stands by biomass estimation work, both in order to conserve the mangal ecosystem generally and to conform with the management regulations of the Nabq protected area. With this in mind, biomass estimation was undertaken as follows:

A second order branch was selected from each tagged tree at random, cut and taken to the laboratory for drying and weighing. Leaves, twigs, reproductive components (fruits and flowers) and timber were separated, and the total harvested fresh weight measured for each different component from each cut branch.

Sub samples were then taken of leaves, twigs, timber and reproductive components, and these oven-dried (60 °C for 24 hour or longer) until completely dry (i.e. until no further weight loss was detected). Fresh / dry weight ratios were obtained in this way for at least 12 sub-samples of each component, except for the reproductive elements, which varied in occurrence and were not present on all sampled branches.

3.3.3.2. Results

The dry weight / fresh weight ratio of sub-samples of the different components (leaves, twigs, reproductive components, and timber) did not significantly vary between the different branches, except for the reproductive components. The dry weights for each component of all the sampled branches could thus be estimated from the appropriate mean dry / fresh weight ratio. Table 2 gives the mean dry weight of each different component present (except reproductive components) on four different size classes of second order branch.

Table 2. Mean dry weight in gm of different components (excluding reproductive components) present on second order branches of different basal diameter. Values represent means +/- standard error of the mean.

Diameter range	Leaves	Twigs	Timber
> 0.3	1.78	1.63	4.32
0.31 – 0.6	4.70	8.51	29.24
0.61 – 0.9	8.95	20.72	49.01
0.91 – 1.2	28.26	41.81	108.52

Figure 1 shows the dry weight of each component plotted against sub-branch basal diameter for all the sub-branches sampled. The dry weights are each positively correlated with sub branch diameter, in each case the plot could best be described by a power relationship of the form:

$$B = a \times (D)^{b} \quad - \quad - \quad - \quad \{\text{equation 1}\}$$

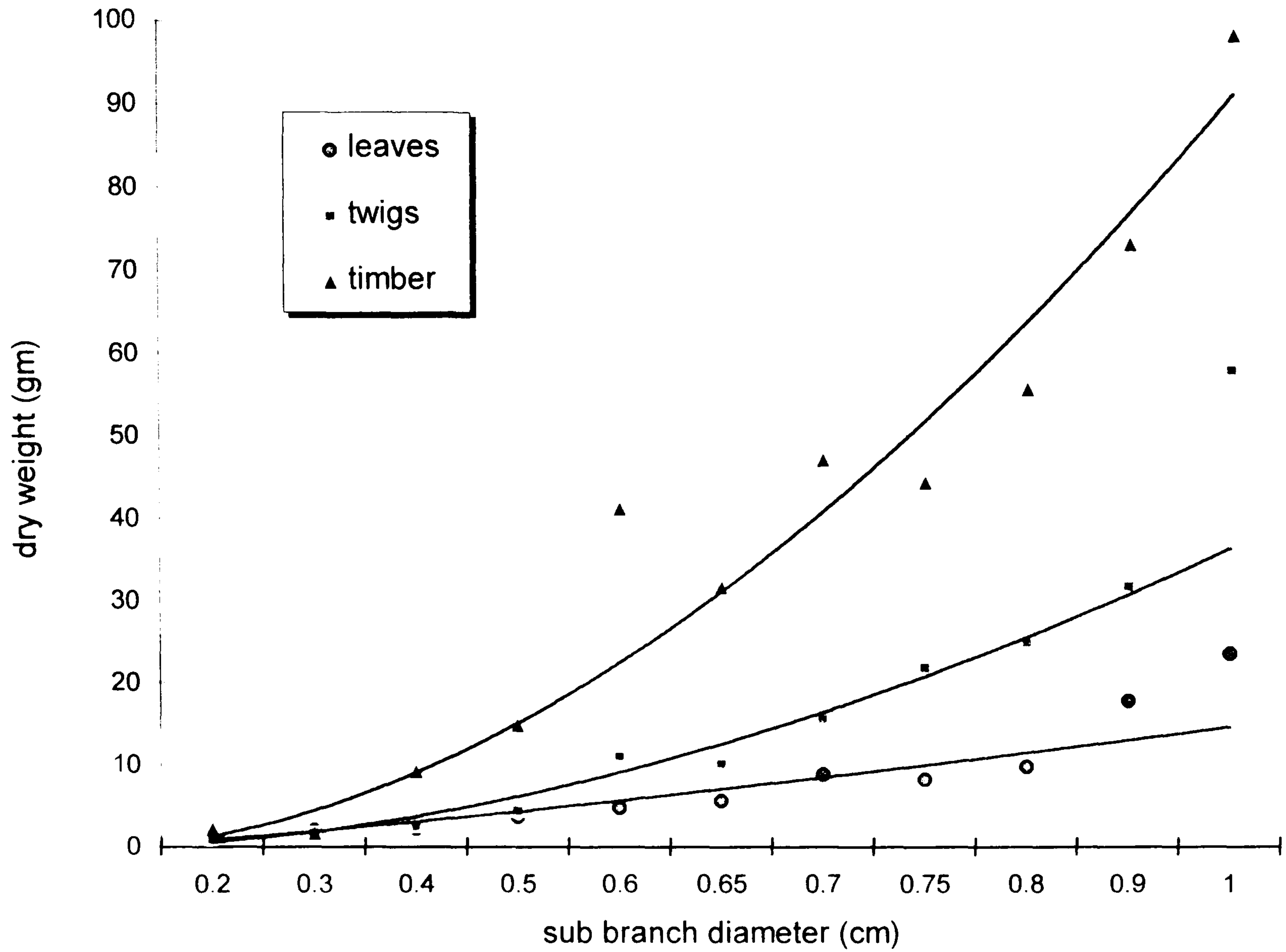
where ***a*** and ***b*** are the regression constants
B is the biomass (dry weight)
D is the diameter of sampled branch

The values of the regression coefficients (r^2), the regression constants (***a*** & ***b***) and the levels of significance are shown in table 3. Only the weight of the reproductive components was not significantly correlated with branch diameter. Instead, marked variation in occurrence of reproductive components was apparent, as might be expected from the known temporal variation in phenological events (Lugo and Snedaker, 1974; Seanger and Snedaker, 1993).

	r^2	***a***	***b***	Significance.
Leaves	0.913	21.42	1.98	$P < 0.0005$
Twigs	0.981	42.41	2.36	$P < 0.0005$
Timber	0.929	107.01	2.39	$P < 0.0005$

Table 3. regression coefficients and equation constants for different branch dry weight components

Figure 1. Allometric relationships between sub branch diameter and dry weight of different components



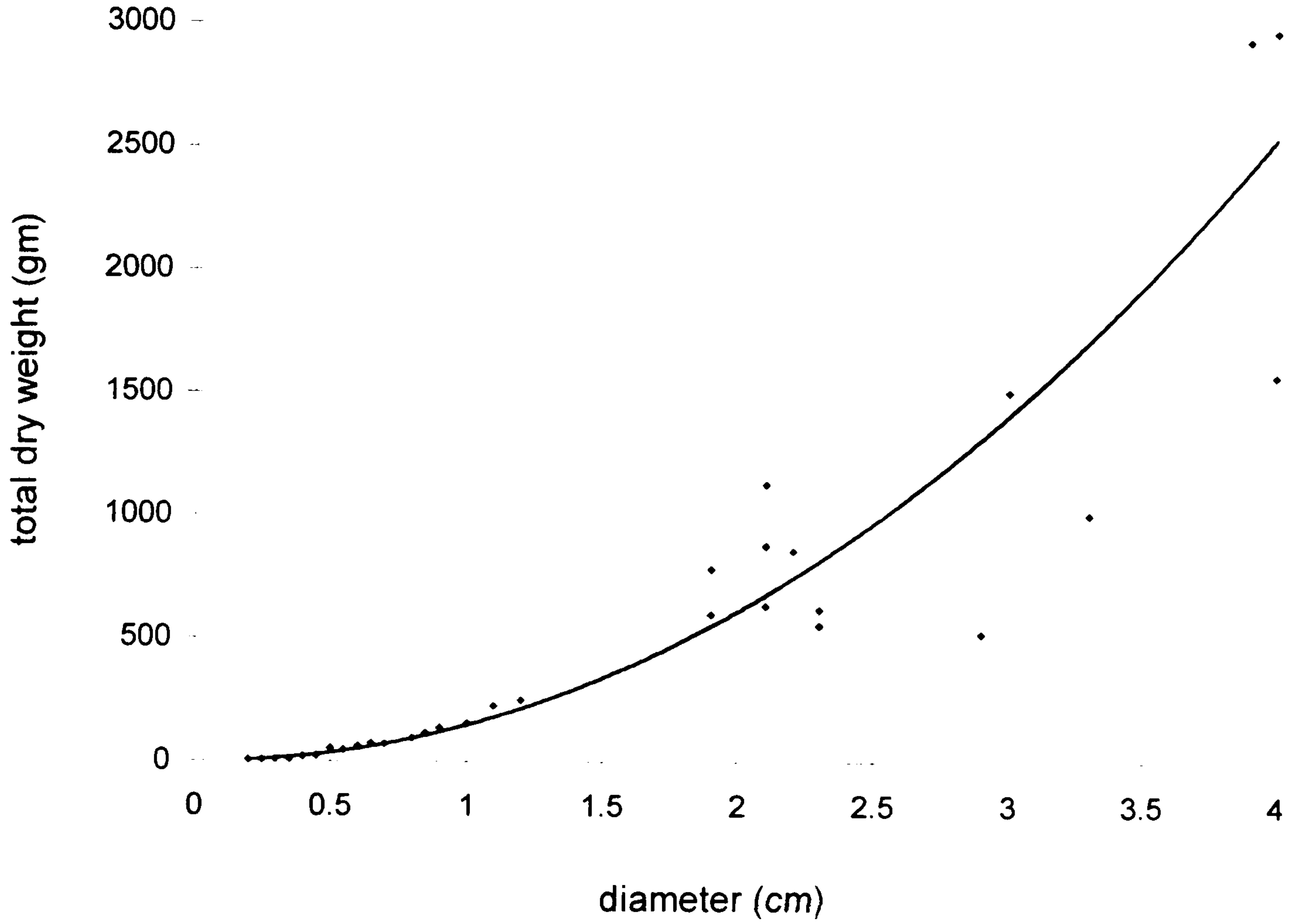


Figure 2. The least squares best-fit line showing the allometric relationship between total biomass of all components and the corresponding second order branch diameter.

When the total estimated biomass (excluding reproductive components) of all sampled branches (oven dried and these estimated from dry / fresh weight ratio) was plotted against the second order branch diameter (figure 2), the following allometric regression was obtained.

$$\mathbf{B = 147.9 \times D^{2.06}} \quad \text{- - - - (equation 2)}$$

The total biomass of first order branches was estimated by summing the biomasses of all its second order branches estimated from the above relationship. However, the estimation of first order total biomass by adding the biomasses of the second order branches does not include the timber biomass of the first order branch itself. This was allowed for by adding the timber biomass calculated (equation 3) from the measured volume of each first order branch.

$$\mathbf{Branch\ timber\ biomass = (3.141 \times D^2 \times L) / 4 \times mean\ T.d.} \quad \text{- - \{equation 3\}}$$

where D is the branch diameter in cm

L is the branch length in cm

T.d. is the mean timber dry weight per cm^3 in kg/cm^3

This equation assumes a cylindrical shape for first order branches. Although the most typical morphological shape would be a truncated cone, the cylindrical shape was selected for simplicity and because it also compensated for the various nodes and bulges present on a branch. The biomasses of first order branches determined in this way are plotted against branch basal diameter in figure 3.

The internal consistency of the allometric regression used to estimate biomass values was checked by comparing the biomass values for first order branches estimated by applying equation 2 (derived from second order branches) with the corresponding values obtained by summing the biomasses of all the second order branches growing on each first order branch (figure 3). Both methods yield regressions which are statistically highly significant ($P<0.0005$) and have regression coefficients greater than 0.9. However the

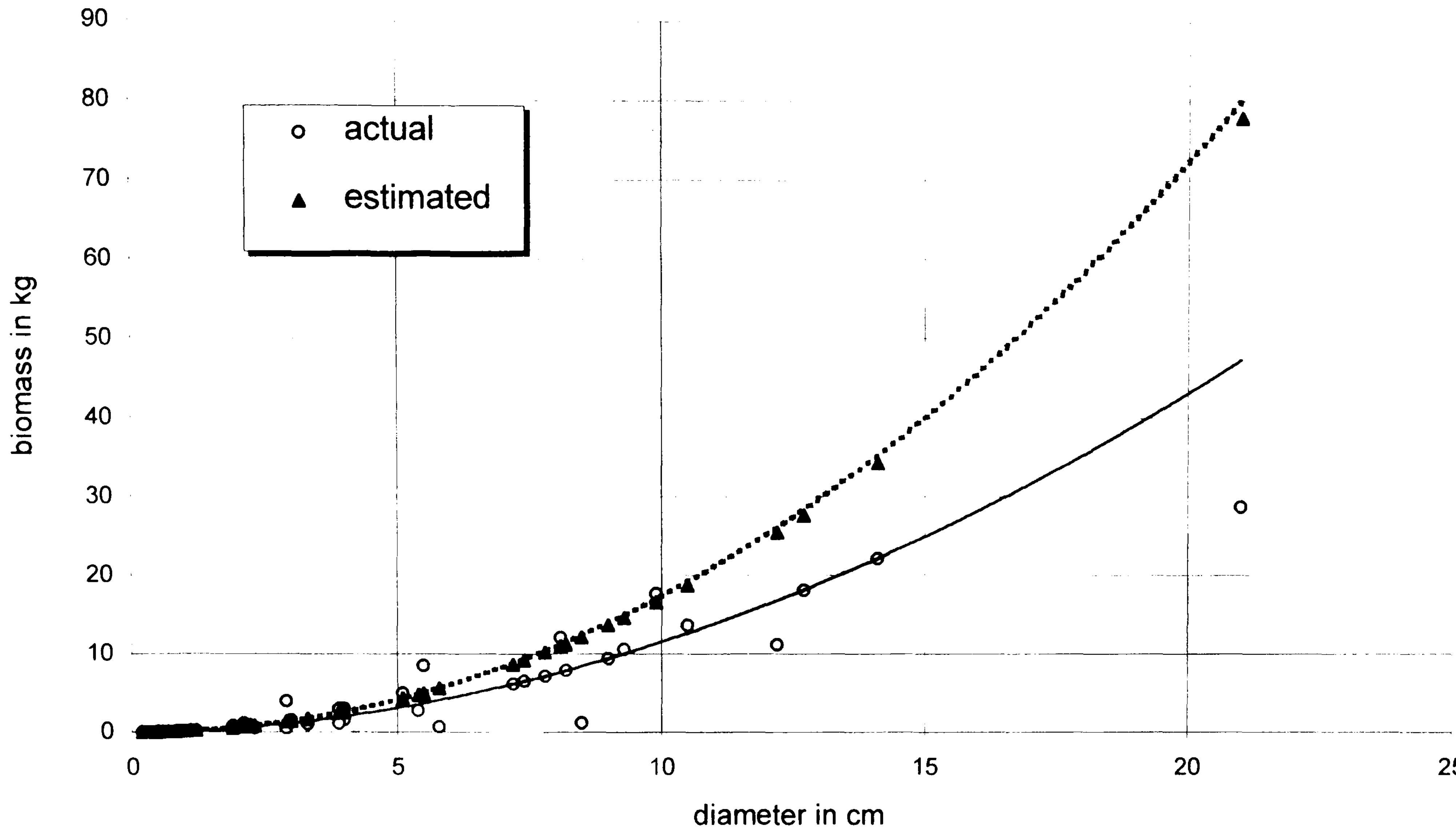


Figure 3. Accuracy ranges of the estimated allometric relationship between branch diameter and the corresponding total biomass The projection of the least squares best-fit line for estimation of larger diameters is shown together with that from actual values obtained directly by harvesting.

estimation of first order branch biomass from the second order branch regression equation tended to over-estimate the biomass values of the first order branches. Consequently, the allometric regression derived by summing the biomasses of second order branches (figure 3) was used to estimate the biomasses of different size first order branches (table 1). This enabled the total above-ground biomass of each tree growing in each quadrat could be estimated using the following equation

$$\text{biomass} = \Sigma_{i=1 \, .. \, n} (\boldsymbol{B.b}) + \boldsymbol{T.b} \quad - \quad - \quad - \quad \{\text{equation 4}\}$$

where **n** = total number of individual branches originating from the tree trunk

B.b = total first order branch biomass

T.b = estimated trunk timber biomass (equation 5)

Estimated in this way the total above-ground standing crop of the quadrats was found to range between 5,400 & 47,000 kg per hectare (table 4). The variation in biomass reflected the visually obvious differences in density, size and structure of the mangrove trees in the different locations, differences which may be explained by site-specific differences in microtopographic elevation, tidal inundation, water salinity and soil drainage.

Table 4. The estimated total above ground biomass (kg) of mangrove growing in each of the study quadrats.

Site	Intertidal location	Biomass(kg / 100m^2)
Marsa Abo Zabad	High intertidal (salt flat)	54
Shora al Rowaisseya	Middle intertidal flat (dwarfed trees)	151.4
Marsa Abo Zabad	Middle intertidal	222.1
Shora Al Rowaisseya	Middle intertidal (flat with lagoons)	100.6
Marsa Abo Zabad	Lower intertidal (flat with lagoons)	342.3
Shora Al Rowaisseya	Lower intertidal	470.3

3.3.2. Section II: Leaf growth and litterfall.

3.3.2.1. Materials and methods

The same six 10x10m quadrats (three at Shora El Rowaisseya and three at Marsa Abo Zabad) used for estimation of above-ground biomass were used to study leaf growth and litterfall. In each quadrat three trees were selected typical of the general vegetational architecture of the trees in that area, one in each of three size classes: small (90-150cm overall height), medium (160-250cm) and large (> 250cm). For each tree the following parameters were recorded:

- Tree height
- Basal diameter
- Number of first order branches
- Diameter of all first order branches
- The number of second order branches originating from two randomly selected first order branches

On each of the two selected first order branches, two second order branches were selected to monitor leaf litterfall and growth of new leaves. The position of each second order branch was recorded and each was also securely tagged for future identification using colour-coded cable ties. On each of these second order branches the following were counted:

- The total number of twigs.
- The number of leaves growing on each twig.

Further, on each selected second order branch, three twigs were securely tagged with colour coded cable ties. On these twigs all leaves longer than 1cm were also tagged. Initially (March 1995) leaves were tagged using heavy-duty staples that were stapled at the leaf edge in order to minimise physical tissue damage. Nevertheless it was found that this method tended to cause a degree of necrosis around the staples. Subsequently, therefore (from April 1997), leaves were marked by using a hole puncher to produce a small hole in the leaf. Again this was positioned towards the edge of the leaf in order to minimise risk of more extensive damage.

Rates of leaf production and leaf longevity were then investigated by checking quarterly in 1995, and subsequently annually (until May 1998), the numbers of marked leaves surviving and the number of new unmarked leaves which had appeared since the last check. These new leaves were then marked in the same way as the others. Leaf litterfall could be subsequently estimated by subtracting the number of surviving tagged leaves from the number tagged leaves which had been left on the twig at the end of the previous check.

During the regular field checks data was also collected on any natural apparent die back or physical breakage and other similar impacts. From this data it was possible to estimate the mortality rates of twigs and branches. Natural mortality was regarded as having taken place when twigs with tags were still present, but the twig was completely dry with no leaves.

3.3.2.1. Results

(i) Leaf abundance

The initial mean number of leaves on the twigs being monitored did not vary significantly between sites or with tree or branch size. This is explained by the observation that typically increase in total number of leaves on larger branches and trees was achieved through the growth of additional twigs rather than through continuous growth of, and production of larger numbers of leaves on, existing twigs. On the other hand, as might be expected, the total number of leaves present on second order branches increased with branch diameter. The regression was highly significant with $P < 0.001$ and r^2 greater than 0.9 ($r^2 = 0.916$, $a = 103.9$ and $b = 1.53$).
The least squares best-fit line could be best described by the power regression equation.

$$N = a * (\delta)^{b} \quad - - - - \text{(equation 6)}$$

where N represents the total number of leaves growing on all twigs on specific branch diameter.

δ represents second order branch diameter (ranging between 0.4 – 2.5 cm).

a & b are the constants for the least squares best-fit power regression line.

When the internal consistency of the allometric regression used to estimate the number of leaves on larger branches was tested, the number of leaves predicted from back-substitution in the regression equation 6 did not differ significantly from the number estimated directly by summing the numbers of leaves estimated for the component sub-branches. There was no significant difference between r^2 for the two regressions. Consequently, the allometric regression was used to estimate the total number of leaves upon all branches of all trees (whose branch diameters had already been measured) in each study quadrat.

(ii) Growth of New Leaves

To check for possible differences in leaf production between sites and seasons data were analysed as the number of new leaves on each twig expressed as a proportion of the previously recorded number of leaves on the twig. During 1995 the mean proportion of new leaves was greatest in the higher intertidal zone (mean = 1.06 +/- S.E = 0.38), and successively smaller in the middle and lower intertidal zones (mean = 0.73 +/- S.E = 0.12 and mean = 0.55 +/- S.E = 0.16 respectively). However these differences were not statistically significant

Leaf growth results were pooled across the three inundation zones in order to investigate any temporal variation patterns of leaf growth. However, mean leaf growth during the summer months in 1995 did not differ significantly from that in the winter months. Similarly the mean proportions of leaf growth for the same trees did not differ significantly between the different years 1995, 1996 and 1997, means = 0.94 +/- S.E. 0.18; 0.63 +/- 0.1 and 0.66 +/- 0.13 respectively), although leaf growth during 1995 was noticeably greater.

(iii) Leaf litterfall

The mean annual values of presumed leaf litterfall in the different intertidal zones at each of the two mangroves stands (Marsa Abo Zabad and Shora Al Rowaisseya) are shown in table 5.

Table 5. Mean values of leaf litterfall expressed in gm / m2 / yr +/- S.E. of the mean

	Marsa Abo Zabad	Shora Al Rowaisseya
Higher intertidal zone	332.8 +/- 29.5	405.3 +/- 47.4
Middle intertidal zone	199.7 +/- 12.3	78.6 +/- 8
Lower intertidal zone	264.6 +/- 88.2	481.9 +/- 24.3

Variation of leaf litterfall was also analysed in terms of the proportion of leaves lost in relation to initial leaf biomass. This proportion was observed to be notably higher during the summer months (mean = 0.94 +/- 0.19) during 1995-1996; than in the winter months (mean = 0.58 +/- 0.10) for the same trees, although again, given the small number of trees, this was not statistically significant. Like the growth of new leaves, the proportions of leaf litterfall did not vary significantly between different years. Consequently values could be pooled to give an overall mean annual leaf litterfall proportion which was calculated as 0.83 +/- 0.17.

(iv) Mortality of tagged branches and twigs

From the data collected on regular field checks an estimate was made of the percentage mortality of marked twigs due to either physical damage (twigs that had been physically broken due to external impact such as human access, camel grazing, and wind) or apparently natural die back. The relative significances of the different specific causes of impact were also assessed. As may be seen from table 6, physical damage was slightly more significant than mortality due to apparent dieback.

Zone (site)	Physical damage	Natural mortality	Camel grazing	Human access	Wind exposure
Marsa Abo Zabad - High	33.3	5.6	++	++	+
Marsa Abo Zabad - Middle	5.6	33.2	+	+	+
Marsa Abo Zabad - Low	25.0	25.1	++	+	+++
Shora Al Rowaiysseya - High	26.3	21.3	+++	+++	++
Shora Al Rowaiysseya - Middle	35.3	35.3	++	+++	+
Shora Al Rowaiysseya - Low	23.5	17.6	+++	++	+++

Table 6. Percentages of the total number of tagged branches affected by either natural die back or physical damage. The extent of different apparent causes of impacts is indicated on a scale ranging from (+) indicating only slight or rare, to (+++) indicating extensive or frequent.

3.3.3. Section III: Re-colonisation and growth of new plants

3.3.3.1 Materials and methods

(i) Assessment of ground water run-off

The coastline of the study area, from Ras Tantour in the north to Ras Nasrani in the south, was divided into a series of sections within each of which the coastal form, shore structure and ground conditions were comparable. In each section the likely frequency of surface and ground water run-off was assessed by observing the extent and degree of vegetation of surface water drainage channels that took the form of slight depressions in the ground running perpendicular to the coast. Their extent and degree of vegetation was recorded using the following qualitative 4 point scale:

1 = no evidence for any run-off at any time and no ground water found
2 = some surface drainage channels with sparse vegetation (soil salinity 35 - 42 ppt)
3 = surface drainage channels with dense vegetation (soil salinity 30 - 35 ppt)
4 = actual surface water run off observed during the study period (soil salinity 15 - 30 ppt)

Visual inspection of coast was supported by visual interpretation of digitally stored SPOT satellite images of the area for 1992 and 1994. These assisted in identification and tracing of flood water channels across the merging alluvial fans of Wadi Kid and Wadi Omm Adawy, and guided field inspection.

In addition, at some sites, salinity of suspected ground water was measured after digging on site with a mechanical digger until ground water was visible. At each site where moisture was observed three water samples (a few drops each) were then collected by pumping from the soil using a siphonette pipe. The salinity of the samples was then determined using a handheld refractometer. At two sites, one behind each of the mangrove stands being investigated, deeper holes were excavated and periodic measurements made of groundwater salinity made, especially following any rain in the catchment area.

(ii) Seedling dispersion and survival

Regular checks on the mangrove stands revealed on several occasions seasonally high densities of seedlings. In April 1996 large numbers of seeds were present and the opportunity was taken to observe the fate of seeds falling from trees. Many seeds were seen to be transported to neighbouring sites by tidal water movement and coastal currents. The number of seeds arriving on each of the sections of shore into which the coast had been divided were counted within 10 x 10m quadrats on the upper shore (between middle and higher intertidal zones) where seeds were typically stranded. Each quadrat where significant numbers of seeds were found was demarcated by colour-coded stakes placed at each corner. Subsequently, in November 1996, the numbers of seeds that had germinated successfully to produce small saplings (height > 10cm & leaves > 2) were counted inside each quadrat.

(iii) Growth of saplings

Populations of *A. marina* saplings were observed to have recruited, mainly between the middle and higher intertidal zones, within various sheltered embayments and lagoons along the study area, not all of them fronting developed mangrove stands. Eight sites where selected to monitor survival and growth rates of these saplings. At each site, a 3 x 3m quadrat was demarcated and permanently marked using colour-coded metal stakes.

In each quadrat all saplings between 10 and 90 cm in height were measured and mapped on a pre-prepared waterproof forms. To further assist future relocation each sapling was tagged with a colour-coded plastic cable tie.

For each sapling the following variables were recorded, initially in October 1996 and subsequently in April 1997 and May 1998:

- Total height measured from the surface of the substrate to the tip of the terminal shoot
- Total number of leaves
- Number of branches
- Number of visible aerial roots (pneumatophores)

The increase in size (growth) of mangrove saplings during the period October 1996 to April 1997 was related to initial sapling height according to the following equation:

Growth index(i) = [*Present record(i) - initial record(i)*] / *initial record(i)* (equation 7)

A comparable index was calculated for the increase in total number of leaves on each sapling. As these indices do not have a unit, they could be pooled for different quadrats.

3.3.3.1. Results

(i) Assessment of ground water run-off

The results of the assessment of surface and ground-water run-off are summarised in table 1. Two sites were categorised as category 4 on the 1-4 scale; these were Marsa Abo Zabad and the shore south of Shora El Rowaisseya, at which minimum underground water salinity values of 19 & 24ppt were recorded respectively. Between the first two monitoring visits, the mountain catchment area behind the Nabq coast was exposed to very heavy rain, and flooding occurred in the inland Wadis with surface water run off actually reaching the highest category sites above the ground. This event was presumably responsible for these very low ground water salinities. It is also notable that both these sites are adjacent to existing large mangrove stands.

Category 3 sites with recorded salinity values of 20-35ppt included South Manquatta, the Shrimp Farm, the Lighthouse, South Abo Zabad, Nakhlet Al Tal and South Checkpoint. Even category 2 sites (North Rowaisseya, Middle Rowaisseya, North Abo Zabad, North Manquatta and the Checkpoint) showed soil salinity slightly below 41ppt, which is the surface seawater salinity of the Gulf of Aqaba.

(ii)Seedling survival

The distribution of seedlings from existing mangrove stands to other coastal sites could clearly be attributed to prevailing hydographic conditions and tidal regimes, together with the fact that *A. marina* seeds are positively buoyant in local sea water. Seeds and germinating seedlings mostly lodged and stabilised themselves through the growth of the primary radicle into the sediment on the upper shore between middle and higher intertidal zones.

Sector Name	seedling density October, 1996	seedling density April, 1997	seedling density May, 1998	surface & ground water
	scale (0-4)	scale (0-4)	Scale (0-4)	scale (1-4)
North Ghargana	-	+	+	1
Manquatta	-	+	++	1
North Rowaisseya	-	-	+	2
Rowaisseya	++	-	+++	2
North Abo Zabad	+++	-	-	2
North Manquatta	+	+	+	2
South Manquatta	-	-	+++++	3
Shrimp farm	++	+	+++	3
Lighthouse	+	+	+++	3
South Abo Zabad	-	++	++++	3
Nakhlet Al Tal	-	++	+++++	3
South Ghargana	+	-	+++++	4
South Rowaisseya	+	+++	+++++	4
Ras Tantour	-	-	-	1*
Wadi Kabila	-	-	-	2*
Wadi Ghorabi	-	-	-	1*
Center	-	-	-	1*
Kotayeb	-	-	-	2*
Ghargana	-	-	-	1*
Checkpoint	-	-	-	2*
Sandy beach	-	-	-	1*
South checkpoint	-	-	-	3*

Table7. Seedling density per 0.01 ha (10x10m quadrat) categorised on a **0 - 5 scale** with the following ranges; (-) no seedlings evident; (+) 1-20 seedlings; (++) 21-40; (+++) 41-60; (++++) 60-80 (+++++) > 81 seedlings. The fresh water input levels are categorised on a 1-4 scale as described in the text. (*) represents these estimates of ground water that were obtained from direct observations and satellite imagery rather than direct salinity measurements. Sites are listed in ascending order with respect to drainage categories, which are described in the text.

The survival of the newly beached seedlings was found to be influenced by various site characteristics, in particular the probable occurrence of freshwater run-off producing a reduction in ground salinity levels at or near the shore. Thus seedling survival between October 1996 and April 1997 varied significantly between sites found to experience different levels of ground water drainage (figure 4) (Kruskal Wallis non-parametric test, $\chi^2 = 4.74$, $P < 0.05$), and seedling survival was highly correlated with the level of fresh water drainage category of the site (Spearman correlation coefficient = 0.74, $P < 0.005$).

By contrast, during the subsequent period from April 1997 to May 1998 the fresh water drainage category of the site did not significantly influence seedling survival. In fact survival rates were significantly higher during this latter period, mean = 0.287 +/- 0.051, than during the earlier one, mean = 0.165 +/- 0.032 (S.E) (Kruskal Wallis test for variance, $\chi^2 = 19.5$, $P < 0.005$).

(iii) Sapling growth

(a) Initial sapling size

The heights and total numbers of leaves of mangrove saplings (height 10 - 90cm; number of leaves > 2) inside quadrats with different levels of exposure to fresh water drainage are shown in figures 5 and 6. Both were correlated with site water drainage category as follows (for height increase : Spearmann two-tailed correlation coefficient = 0.73, $P < 0.005$; and for leaves: Spearmann two-tailed correlation coefficient = 0.81, $P < 0.005$).

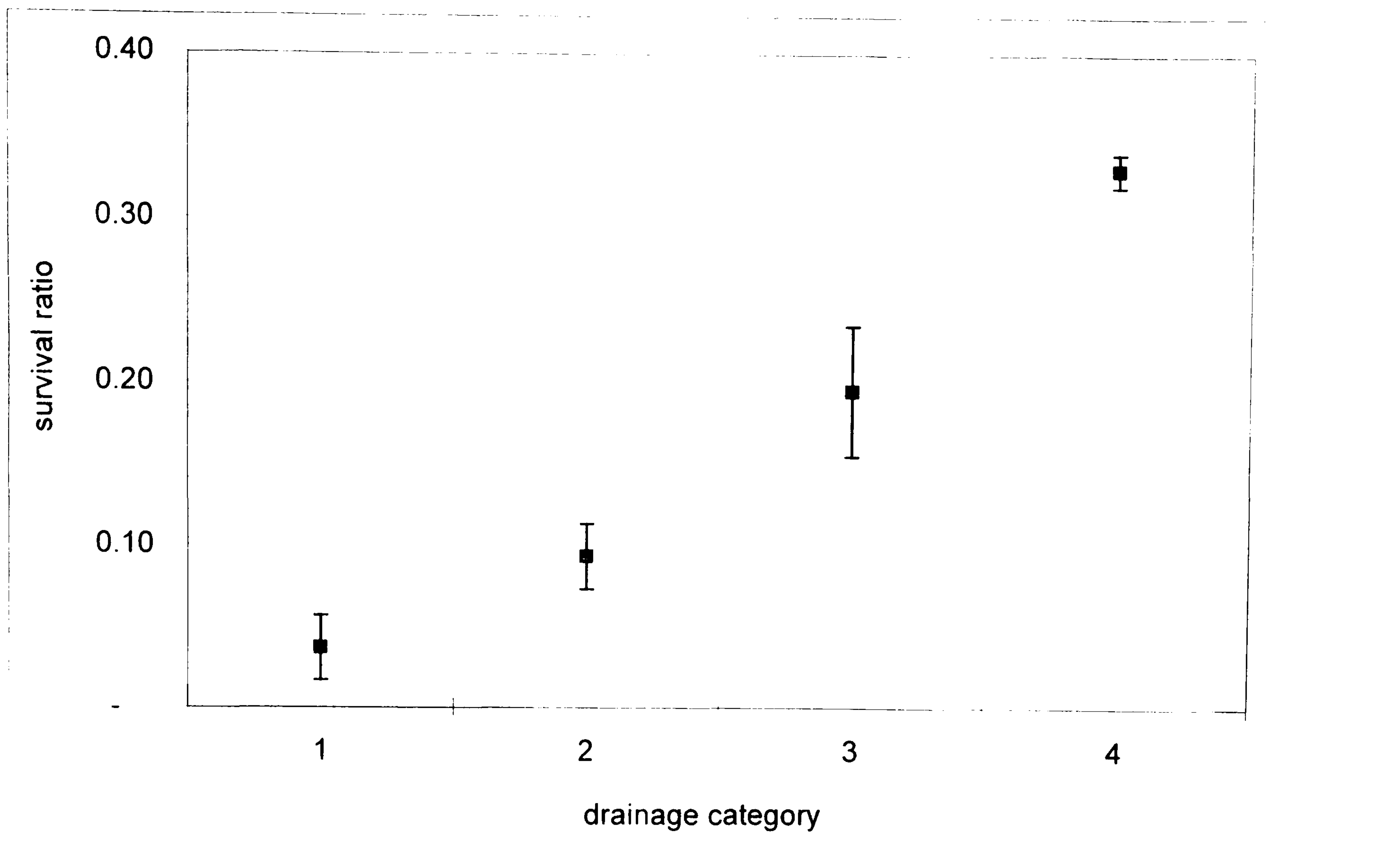
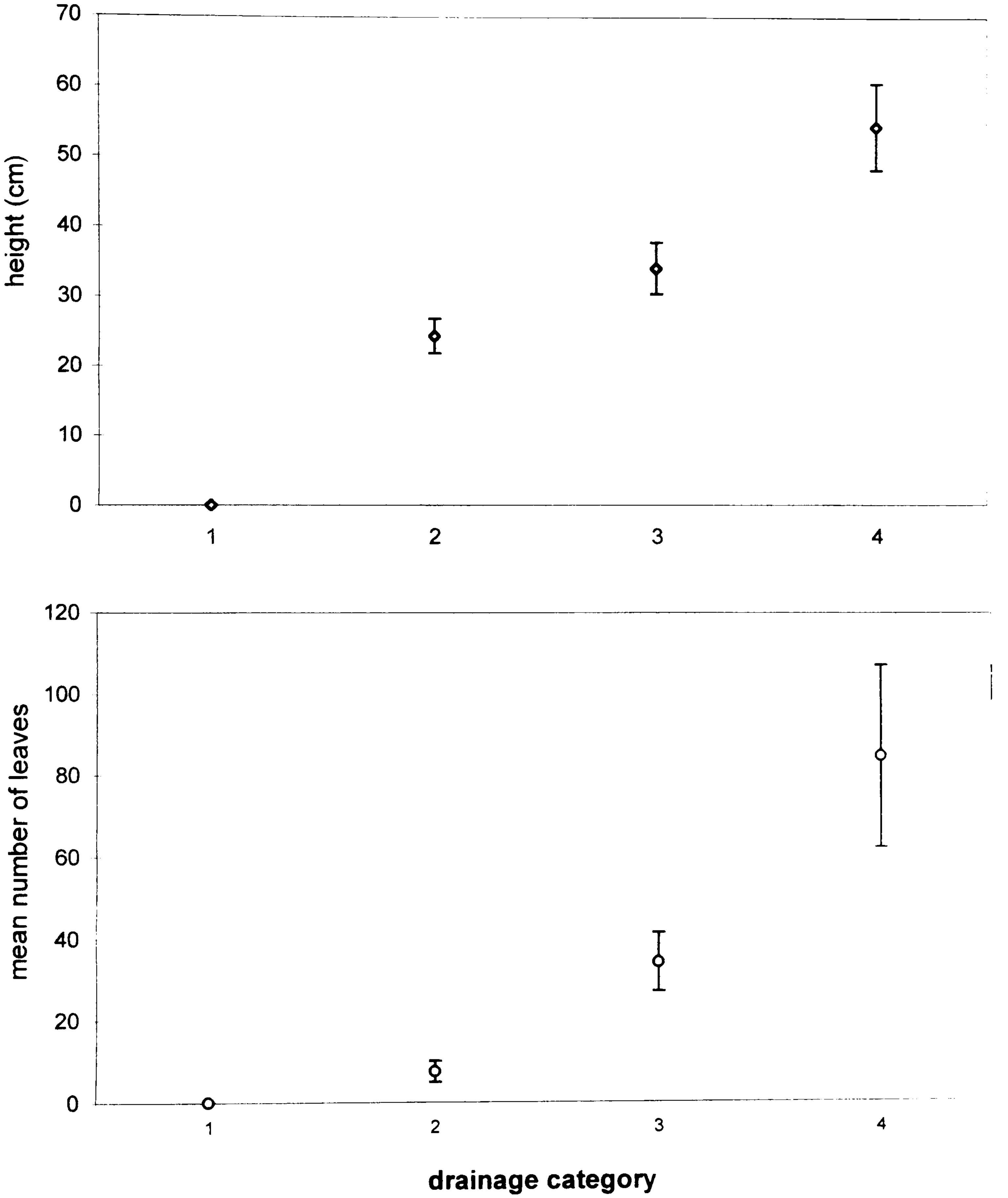


Figure 4. Mean proportion of seedlings that survived and successfully established in a period of six months in relation to the total number that were present in the study quadrats. Different drainage categories represent reduced salinity levels (see text). Error bars represent standard error of the mean.



Figures 5 & 6. Mean height and number of leaves of newly established saplings at different sites that are exposed to different levels of fresh water input. Drainage categories are expressed by levels of reduction of soil salinity (see text). Error bars represent standard error of the mean.

(b) Comparison of sapling growth in consecutive periods

A comparison of growth indices for the two successive intervals revealed a difference between seasons and years. The mean height growth index (0.43 +/- 0.08) during the first six month period was considerably higher for all site categories (paired samples t-test t=5.66, N=76, P<0.0005) than that for the subsequent 12 months (mean index = 0.13 +/- 0.03). By contrast the leaf index of saplings was significantly greater (t=-2.7; df=76; P<0.005) during the second period. Further, leaf growth index was negatively correlated with height growth index over the two intervals (Spearman rank two-tailed correlation coefficient for period 1 = -0.41, P<0.005 and for period 2 = -0.43, P<0.005)

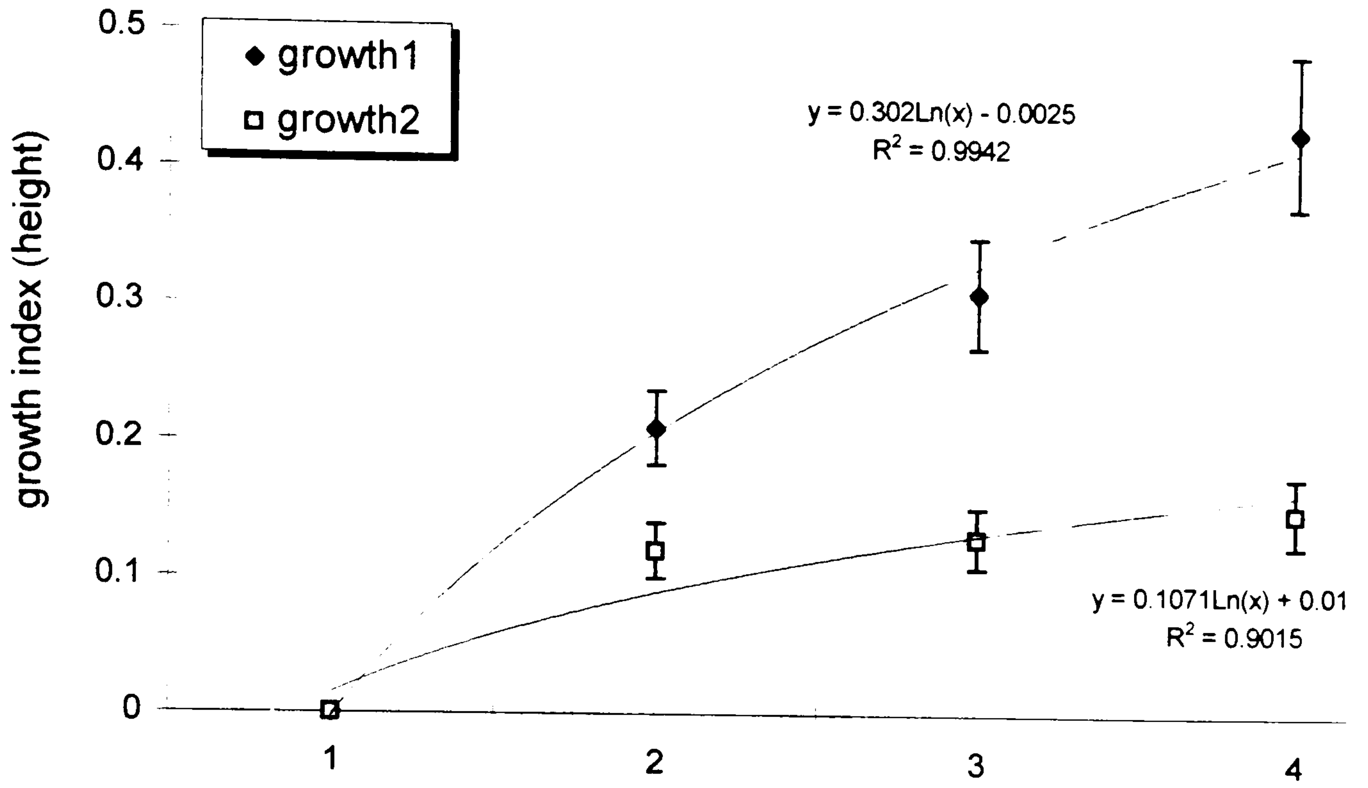
The mean heights and mean numbers of leaves on marked saplings after different periods of time are shown in figures 7 and 8. It was found that the relationship between the growth height index and initial height of *A. marina* saplings could be described by the *inverse* regression equation:

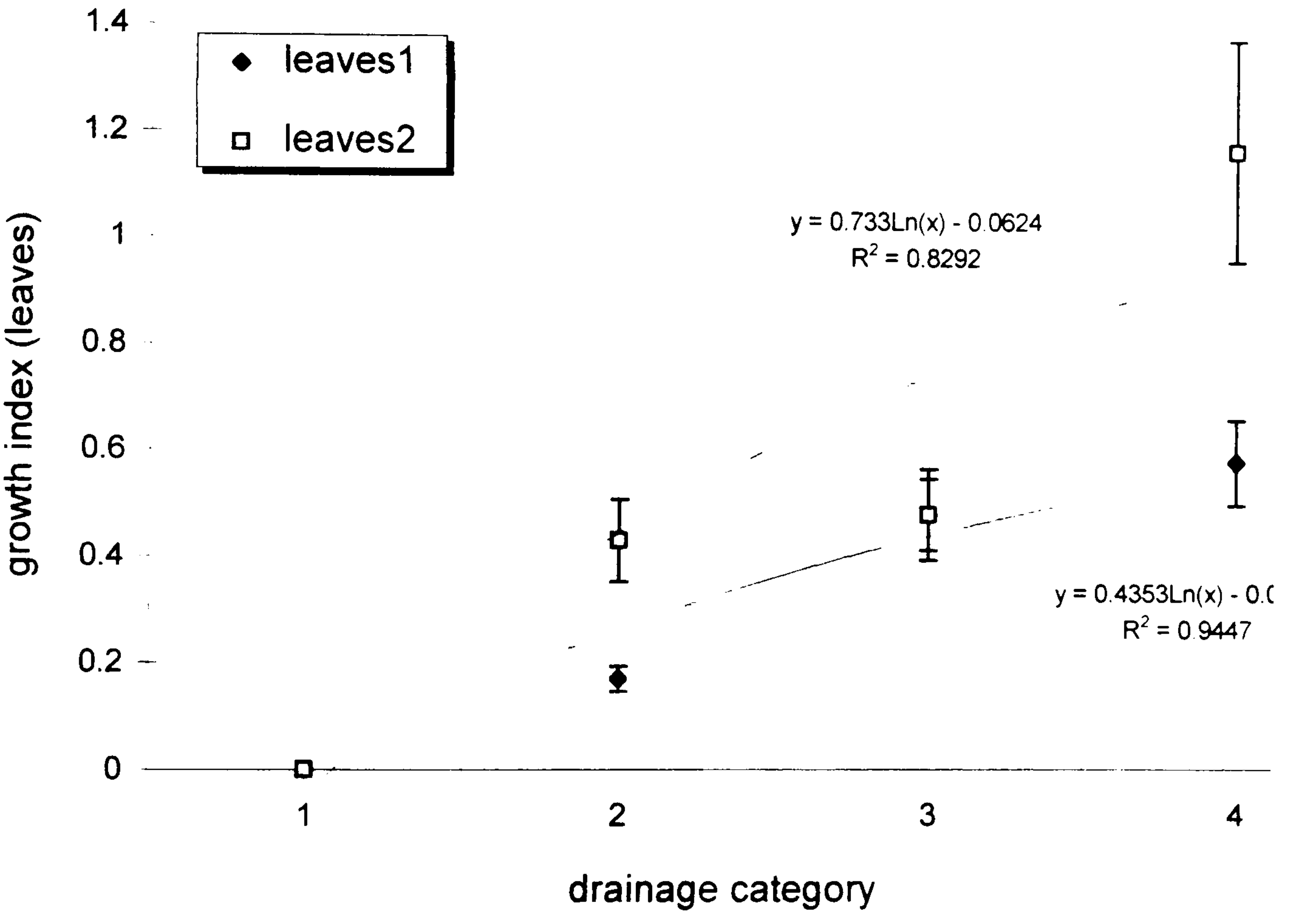
$$\text{growth index} = (20.43 / \textit{height}) - 0.314$$

where the regression coefficient $r^2 = 0.72$, N = 74 and P < 0.0005.

(c) Sapling mortality

During the initial winter period (October to April, 1997) mean sapling mortality within the study quadrats was 14% +/- (1.1 S.E). Over the subsequent longer period (April 1997 to May 1998) mean sapling mortality percentage was notably lower at 8.3% +/- 0.97.





Figures 7 & 8. Variation in growth index for both the height and the numt leaves of mangrove saplings at sites that are exposed to different levels of water input (drainage category, see text). Growth (1) & (2) for height anc leaves (1) & (2) represent proportional increase during the first and secon sampling periods (see text). The least squares, best-fit, regression lines arc Error bars represent standard error of the mean.

3.4. DISCUSSION

It is increasingly proclaimed that biomass and productivity of mangroves vary considerably between sites, depending upon a wide spectrum of influences, including salinity (Cintron *et al.*, 1978; Downton, 1982) and patterns of variation in salinity (Ball, 1988), nutrient supply (Boto, 1983), and other soil characteristics. It was thus of academic interest, as well as important for management, to investigate the biomass and productivity of the mangroves at Nabq, being the most northerly in the Indian Ocean region.

3.4.1. Biomass estimation

The use of allometric regressions to estimate above ground biomass from directly measured values of tree parameters, as first used by Whittaker and Marks (1975), provides a method that causes minimal structural damage to trees and was hence appropriate for use in the context of the Nabq Protectorate. Other workers have described allometric relationships, derived from linear regression on a log-log scale with DBH, which they used to estimate total above-ground biomass of different mangrove species (Putz and Chan, 1986; Clough and Scott, 1989), and some have similarly measured tree height in order to obtain a relationship between volume and biomass of the tree trunk (Causton, 1985). However, this approach is more difficult to employ with *Avicennia* spp. because of the way in which they often, especially *A. marina* in the northern Red Sea that have several (3 - 10) branches diverging from close to ground level, rather than a single upright trunk. Hence in the present study allometric regressions were produced through measurement of the diameters of each branch of each tree, treating each branch as a separate unit. A similar approach has recently been adopted by Clough *et al.* (1997) to investigate multi-stemmed trees of *A. marina* in Western Australia. It seems that the method probably gives reasonably accurate estimates of biomass of mangroves in Nabq, in that the present data show that the value of the above-ground biomass, as measured by direct cutting, drying and weighing, differed by only 2 to 17% from the values predicted by the allometric regression.

The total above ground biomass of the study quadrats ranged between 54 and 740 kg, equivalent to 5.4 and 74 mt. ha^{-1}. The smallest values were obtained on salt flats in the higher intertidal zone which are only inundated by the highest tides. Here the ground is hypersaline due to waterlogging coupled with evaporation, hence the stunted growth of *A. marina* occur in these locations. By contrast the highest biomasses were estimated for quadrats in lower intertidal zones which are inundated by all tides, essentially at those locations where mangroves grew on more than 1.5m of soft sediment surrounding mangrove lagoons or reef flat pools.

These above ground biomass values (equivalent to 0.54 to 7.4 kg m^{-2}) are notably less than those obtained for *A. marina* in some other tropical regions such as Queesnland, Australia, where values ranged between 11 to 34.1 kg m^{-2} (Mackey, 1993). The values do however conform to the trend of reduced structural development and biomass in *Avicennia* stands at higher latitudes (Duke, 1990). The most comparable value is of 8.7 kg.m^{-2} reported for Futian Nature Reserve, Shen Zhen, China (Tam *et al.*, 1995). This may be a maximum value, i.e. one obtained for one of the best-developed parts of the mangrove stands there, and hence comparable to the upper figure of 7.4 kg.m^{-2} obtained in the present study. But the finding that the best-developed zone of the Nabq stand has an even lower biomass is not surprising in view of the fact that the site experiences, in addition to low winter temperatures, very low rainfall and high rates of evaporation together with the already high salinity waters of the Gulf of Aqaba.

Below ground or root biomass of the mangrove trees was not estimated in the present study, but several other studies have recently estimated the below ground / above ground (root / shoot) biomass ratios of *A. marina*. These ranged between 0.9 and 1.5 in New South Wales (Saintilan, 1997) and between 0.68 and 1.1 in Queensland, Australia (Mackey, 1993).

3.4.2. Leaf litterfall

The litter traps, bags or baskets commonly used for estimation of litter fall in mangrove forests were found to be impractical for use at Nabq where typical growth could be represented by low dense crowned shrubs. This was principally because of the shrubby nature of the trees whose lower canopy was often covered at high tide. In addition the canopy was incomplete, and indeed in some zones trees were relatively scattered, so that traps could not easily be positioned in locations that would be representative of mean litter fall. In a similar way litter traps have proved impracticable for studies in some other regions, such as south-eastern Australia (Duke *et al.*, 1981; Bunt and Williams, 1981) and Florida (Pool *et al.*, 1974). By contrast the low canopy of most trees provided access to representative branches and twigs so that these could be tagged as an aid to monitoring twig growth and leaf production.

Leaf litterfall values at Nabq were estimated to range between 78.6 and 481.9 $g.m^{-2}.yr^{-1}$); these were notably lower than values obtained for the same species in Florida of 2.4 $g.m^{-2}$.day (Heald, 1971) and in New Zealand of 3.6 - 8.1 $t.ha^{-1}.yr^{-1}$ (Woodroffe, 1982). Moreover, The leaf litterfall production is considerably less than those values obtained from Saudi Arabia in the Southern Red Sea where Saifullah *et al.* (1989) have estimated total litter production to range between 1.21-1.79 $g.m^{-2}.day^{-1}$.

By contrast, annual leaf turnover rates for the Nabq mangroves did not differ appreciably from those estimated in Florida by Snedaker and Lugo who estimated a mean annual leaf turnover rate of 88%. However, Pool *et al.* (1974) recorded a rate of 140% in mangrove forest in Puerto Rico. Nevertheless this suggests that lower leaf fall at Nabq is primarily a consequence of the lower leaf biomass, not of lower rates of leaf replacement. These rates of leaf replacement may however vary during the year, even though almost all mangroves are evergreen. At Nabq there appeared to be a significant increase in leaf fall during the summer; this can be linked to the very high ambient temperatures and incident light levels that both of which reach an annual maximum at this time.

3.4.3. Leaf growth and productivity

The rates of leaf production could provide a broad estimate of above ground annual productivity that ranges between 20-200 $gC.m^{-2}.yr^{-1}$ as a means for comparison with those estimates made by various methods in different regions. This would only depend upon the validity of the assumption that the dry matter production: carbon ratio is 10:1. As the typical primary productivity of mangroves has been considered to be in the range 350 - 500 $gC.m^{-2}.yr^{-1}$ (Lugo and Snedaker, 1974), this estimated range of productivity for the mangroves in Nabq match the assumption of lower productivity in extreme environments as discussed by Lugo and Snedaker (1974).

One possible source of underestimation of production in the present study is that a number of the heavy duty plastic ties used to tag twigs (varying between 4 and 18% in different quadrats over the whole course of the study) disappeared between checks. This loss was allowed for in that these twigs and branches were excluded completely from the analysis. But this may have resulted in a slight under estimation of production since in most cases loss of the tags was due to the fact that marked twigs turned out to be vigorous juvenile sub-branches, that just looked like twigs, but grew very rapidly and produced abundant leaves, during the study period. It was the rapid increase in diameter of these new sub-branches, which caused the tags to break.

Leaf growth and presumable primary productivity did show significant seasonal variation at Nabq, but the principal source of variation was the much greater values of leaf growth observed in 1995 as compared to 1996 and 1997. This seems probable to be linked to the fact that during the winter of 1995 inland rain resulted in flooding of some of the neighbouring wadis which, for a short period, discharged surface water into the mangrove stands. At some locations, including Nakhlet Al Tal and southern Shora Al Rowaisseya, flood levels approaching the shore reached 25cm. No such flooding event occurred in either of the following two years, although as a result of inland rain minimal surface water run-off and some ground water seepage were recorded.

3.4.4. Seedlings Dispersal

The seedlings and germinating seeds that were washed ashore were mostly found at sites located towards the south of existing stands. This drift is readily explained by the north to south direction of the prevailing winds and surface water currents. In fact only low densities of seeds were found inshore of existing mangrove areas, suggesting that seeds from trees in the lower intertidal zones could not so easily penetrate on the tide through the dense pneumatophore growth in the higher zones. A higher density of seedlings was observed to beach in sheltered embayments to the immediate south of existing stands. These tended to accumulate in the higher intertidal zones which, due to the only slightly higher microtopographic elevation, are inundated only by the highest tides. Observations suggested that local *A. marina* employ a strategy of persistent colonisation resulting in substantial seed banks and high densities of seedlings and saplings of different ages being dispersed to the upper intertidal zone of potential colonisation sites. This was observed in particular at the sheltered bays of Ghargana and Shora al Manquatta. A similar strategy has been described for *A. marina* in Western Australia by Lugo and Snedaker (1974).

Seedlings were found at locations up to 3km south of different mangrove stands. This falls within the ranges reported by Clarke (1993) in south-eastern Australia. He suggested that dispersal distances of *Avicennia* seedlings ranged between 1 and 10 km according to spatial and temporal hydrographic patterns and tidal regime. The mean numbers of seedlings washed ashore did not vary markedly between years as reported in Queensland, Australia, where the density of seedlings arriving per 10 meters of shoreline ranged between 3 and 18 (Clarke, 1993). Probably this can be attributed to the constrained geographical location of Nabq, by comparison with the Queensland coast, where depending on hydrographic conditions, seeds may easily be carried out of site of land. In the enclosed position of the southern Gulf of Aqaba region, this is scarcely possible to occur.

3.4.5. Seedling Survival

Following dispersal, considerable seedling mortality occurred where seeds had been deposited on unfavourable substrates, so that they were physically injured or could not become firmly rooted. Also, as reported by Clarke and Myerscough (1993) in south-eastern Australia, the presence of macroalgal mats covering the substrate appeared to reduce the chances of seedlings establishing themselves successfully.

3.4.6. Sapling survival and growth

During the winter period (October to April, 1997) mean sapling mortality within study quadrats was 14% +/- 1.1 (S.E). Over the following period (April 1997 to May 1998) mean mortality was notably lower at 8.3% +/- 0.97 (S.E). For comparison, in Australia, Clarke and Allaway (1993) found that seedling mortality during the first year ranged between 22-38%. These authors also recorded an annual growth rate of saplings equivalent to 19% of original height. This compares with growth indices of 13 - 43% recorded during the present study in Nabq. As described in the results section spatial and temporal variation in seedling and sapling survival and growth at Nabq appeared to be related to variation in freshwater run-off, both above and below ground. In line with this observation both waterlogging (Naidoo, 1987) and increased salinity (Ball, 1988) have been reported to affect the relative size of *A. marina* saplings.

3.4.7. Fresh water drainage

As described above, seepage of underground fresh water into the soil along the inner margin of the Nabq mangrove stands was detected through a reduction in measured below-ground soil salinity at some locations, and by monitoring water within shallow wells dug at two locations. It was not practicable to attempt to obtain a detailed record of temporal variation of the amount of fresh water input to the area. Even with regular records of soil salinity, the input of ground-water can be estimated by modelling the amounts required to reduce soil salinity to observed levels given prevailing ambient conditions. Nevertheless it is the resulting soil salinity which is most significant, and the present results support the conclusion that the pattern of fresh water input from inland to coastal sediments is a critical factor determining the distribution of mangroves in hypersaline environments (Por, 1977; Semeniuk, 1983). *A. marina* stands grow in the present locations because these are the places where there is normally some flow of ground-water which is able to compensate to a greater or lesser extent for the hypersaline conditions that otherwise develop in upper intertidal soft substrates within the Gulf of Aqaba. And growth and production of mangroves may be much greater in years when there is heavy rain in the inland catchment area of the Sinai mountains, especially if fresh water floods down the normally dry wadi beds to reach the coast. Also freshwater input may be important in influencing seedling germination and sapling growth and survival. In addition fresh water input, especially of surface water, carrying with it soil and mineral particles from the adjacent mountain and coastal plain, might also be significant in topping up the supply of key inorganic nutrients, which are known to be critical factors limiting shoot growth and tree development (Boto, 1983).

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CHAPTER 4

Abundance and Distribution of Commercial Reef Fish in Nabq, South Sinai, Influenced by a Bedouin Artisanal Fishery

4.1. ABSTRACT

Underwater Visual Census of exploited reef fish species was undertaken at 4 depths at 21 sites within, and adjacent to, the Nabq Protected Area, South Sinai. Egypt. A pattern of changing abundance with reef zone (depth) was significant for many species. *S. sordidus, S frenatus, S. psittacus, S. luridus, A. nigrofuscus, S. ghobban, S. rivulatus, C. striatus* and *A. sohal* were most abundant over the reef flat and along the reef edge. *S. sordidus, L. ehrenbergi, M. grandoculis* and *P. gaterinus* were most abundant on the shallow reef slope; and *C. miniata, E. fasciatus*, and *L. mahsena* were most abundant on the deeper reef slope. All species of serranid increased in abundance with increasing depth save for *C. hemistiktos,* which was more abundant on the shallower reef face. A particular assemblage dominated by acanthurids and siganids moved onto the reef flat over the high tide to exploit the algal turf growing there, and returned to the reef face as the ebb tide. Comparisons of abundance between more fished and less fished sites revealed that serranids were significantly less abundant at heavily fished sites ($P < 0.005$). The difference was greatest on the reef slope, and for the most commercially targeted species, i.e. *C. miniata* ($P < 0.05$) and *V. louti* ($P < 0.05$). Lethrinids were also more abundant at less fished sites, but not significantly so. Acanthurids and siganids by contrast were significantly more abundant at heavily fished sites than at lightly fished ones.

4.2. INTRODUCTION

Coral reefs and associated habitats, such as seagrass beds and mangrove stands, typically have a high primary productivity compared to the surrounding oligotrophic tropical ocean (Lewis, 1977; Mann 1982). In consequence they support productive stocks of fish, many of which, in developing countries, are extensively exploited by commercial or artisanal fishermen.

Despite the vital importance of these fish stocks there is increasing evidence that in many, if not the majority, of coral reef areas reef fish are being seriously overexploited (Koslow *et al.* 1988; Sadovy, 1989). Such overfishing in part reflects the pressures of human population and economic necessity, and the ease of access to reef areas, which are essentially marine "commons". It also reflects the frequently emphasised difficulty of managing fisheries of a complex multi-species multi-gear nature (Bohnsack, 1990; Russ, 1991). There is an almost bewildering variety of commercial or otherwise edible fish species present on reefs, and it is not possible with the fishing methods available to target some species so as to avoid overfishing others, even assuming that the necessary studies could be completed and the sustainable yields estimated for each of the many species present. In any case enforcement of catch quotas is more or less infeasible with large numbers of artisanal fishermen operating over large areas that are difficult to access and patrol, and landing their catches at numerous coastal locations, rather than at selected ports.

By contrast with other regions most coral reefs in the Red Sea have until recently been relatively lightly exploited (Sheppard *et al.*, 1992). Local coastal populations have until the last 10 to 20 years, because of the inhospitable climate, been fairly low and sparsely distributed. In fact the total fishery production of the Red Sea is equivalent to only about 0.07% of the global marine yield. However, with the rapidly expanding populations of the region, fuelled in some countries by oil wealth and in others by a more recent unprecedented increase in coastal tourism development, demand for fish has accelerated and the pressures on reef fish stocks dramatically increased. For example, in the Egyptian Red Sea, the number of licensed fishermen has increased from 14,000 in 1987 to 19,000 in 1988, and 30,000 in 1995 (Egyptian Institute of Marine Sciences, 1995). Here in particular, there has been a huge increase in demand for fish as a result of a tenfold increase in tourist accommodation and associated urban development during the last 10 years.

In southern Sinai and the Gulf of Aqaba the Government of Egypt has established a major initiative to secure the optimal management of reef and coastal resources, by declaring all coastal waters between Ras Mohammed, at the southern tip of Sinai, and the border at Taba, near the northern end of the Gulf of Aqaba, part of the Gulf of Aqaba Protectorates, under the management of the Egyptian Environmental Affairs Agency. While the southern parts of the Park, around Ras Mohammed itself, are normally closed to fishing, and the reefs principally used for SCUBA diving and other recreational activities, the reefs of the Gulf of Aqaba, north from Ras Nasrani are essentially open to traditional artisanal fishing by local Bedouin fishermen. A fisheries management programme has been initiated directed at securing the sustainable exploitation of the fishery, both for the benefit of the local fishermen and so that the reefs remain intact. As part of this programme an investigation was undertaken of the state of fish stocks, and their extent of depletion by fishing, along one section of the southern Egyptian Gulf of Aqaba coast at Nabq. This area is managed by the Park Authority as a multiple-use management zone in which traditional fishing by local Bedouins is permitted, as well as use of the terrestrial areas for grazing of their cattle, but no development activities are allowed.

In a preliminary investigation of the effects of fishing in the southern Gulf of Aqaba, Roberts & Polunin (1992) have compared fish populations at a small number of fished sites between Ras Nasrani and Dahab, essentially with unfished sites at Ras Mohammed. However, the low number of sites examined, and also the fact that all the fished sites investigated were well separated geographically from the unfished sites, limited the certainty with which the method determined differences in fish abundance due to fishing. That is, it was not clear that significant differences were an effect of fishing activities, rather than due to either zoogeographic or habitat factors.

In the present study fish populations were estimated at 21 sites all within or close to the Nabq Protectorate, and fishing effort was monitored to distinguish between heavily fished or unfished (or only lightly fished) sites. Moreover fished and unfished sites were interspersed so that zoogeographic differences could not be the principal factor influencing fish abundance.

4.3. METHODS AND STUDY AREA

4.3.1. Study Area

The Nabq Managed Resource Protected Area is one of five terrestrial sectors within the South Sinai Protectorates network which includes the Ras Mohammed National Park, the Abu Galloum Managed Resource Protected Area, the St. Katherine Protectorate and the Taba Protected Area. It stretches along about 28 km of coast on the south-western shore of the Gulf of Aqaba, and incorporates the coastal waters as well as coastal plain and mountains extending about 10 km inland. There is a well-developed fringing reef along most of the coastline; this becomes discontinous at some locations, notably at Nakhlet El Tal, where occasional inland flooding reaches the sea. The reef edge runs parallel to the coast, with the reef flat ranging between approximately 50 and 650 metres in width. In areas where the reef is further away it encloses sandy-bottomed lagoons that can reach 200 meters in diameter and up to 10 metres depth. Elsewhere, a shallow predominantly hard-bottomed irregular reef flat, that is mostly exposed during low tides, extends between the shore and reef crest.

At four locations along the Nabq coastline, there are monospecific stands of the mangrove *Avicennia marina.* These are considered the northern-most mangroves in the Red Sea / Indian Ocean region. Also, dispersed in the lagoons, on the reef flat, and on sandy parts of the reef face terrace and outer reef slope, are extensive seagrass beds (*Thalassodendron ciliatum, Thalassia* spp. & *Halophila* spp.) which thrive down to depths of 15 metres and more. A low density of live corals is present on the reef flat. while coral heads and patches are scattered in the deeper reef lagoons. On the reef face. coral cover is typically about 20 - 40 % in shallow water, but can locally reach more than that. as at some northern sites where coral cover exceeds 80%. The coral assemblage is diverse but is notable for its dense stands of *Acropora* spp., large *Acropora* tables and large colonies of *Porites* spp.

4.3.2. Methods

Assessment of the fishery

A preliminary investigation of fishing activity in the Nabq area was undertaken between September 1994 and April 1995; this allowed tentative identification of the most widespread fishing methods and the commonly used fishing sites. Field observations of fishing methods, effort estimation and interviews with fishermen were recorded for all fishing sites during that period.

This information was used firstly to select 17 stations for underwater visual fish census by SCUBA diving, in expectation that approximately half of these stations were heavily fished, while the remainder of the sites were only lightly fished. Secondly, this knowledge facilitated regular checking of fishing sites as part of a quantitative assessment of fishing catch and effort which is described in detail in chapter 6.

Underwater visual census of fishes

Underwater visual census (UVC) of fishes were undertaken in August / September 1995 at all 17 stations at Nabq, and also at two sites about 4 km south of Nabq (near Ras Nasrani), and at two sites on offshore patch reefs in the Straits of Tiran (Jackson Reef and Gordon Reef), also a similar distance from Nabq. These four sites all within the unfished zone of the National Park but all within 5-6 km of Nabq, were selected as control sites at which no fishing takes place. However, in practice, a small amount of illegal line fishing does take place at these sites, in part at night.

The method of UVC employed conformed with the Reefwatch II method promoted by the TMRU, University of York (Ormond, 1997). At each site, four transects each 200m long running parallel to the shore were established, one at each of the following reef zones (figure 1); mid lagoon or reef flat, the reef edge (nominally 3m deep), 10m and 17m deep. The lengths of these transects was measured accurately by tape, and the start and end points were permanently marked for continued annual monitoring.

Fish of the following families were then counted within a band of 10m wide along each transect (i.e. within a total area of $2000m^2$): Serranidae (Groupers), Lethrinidae (Emperors), Lutjanidae (Snappers), Haemulidae (Grunts), Scaridae (Parrotfishes), Siganidae (Rabbitfishes), and Acanthuridae (Surgeonfishes). To do this observers swam at a standard speed of 10m per minute along the appropriate depth contour, searching carefully for and recording the relevant fish. Four observers were typically present, each one specialising in only a single or two closely-related families; such focusing on fish of a particular general form and behaviour has been found to increase the ease and reliability of the count (see also Watson & Ormond, 1994). The commercially important species that were censused are shown in table 1 (piscivorous species) and table 2 (herbivorous species).

Since it was apparent that diel migrations of various herbivore species from the upper reef slope to the reef flat occurred at high tide, counts of these species could have been affected by the state of the tide. Consequently, all counts of the 3m and reef flat transects were undertaken at high tide.

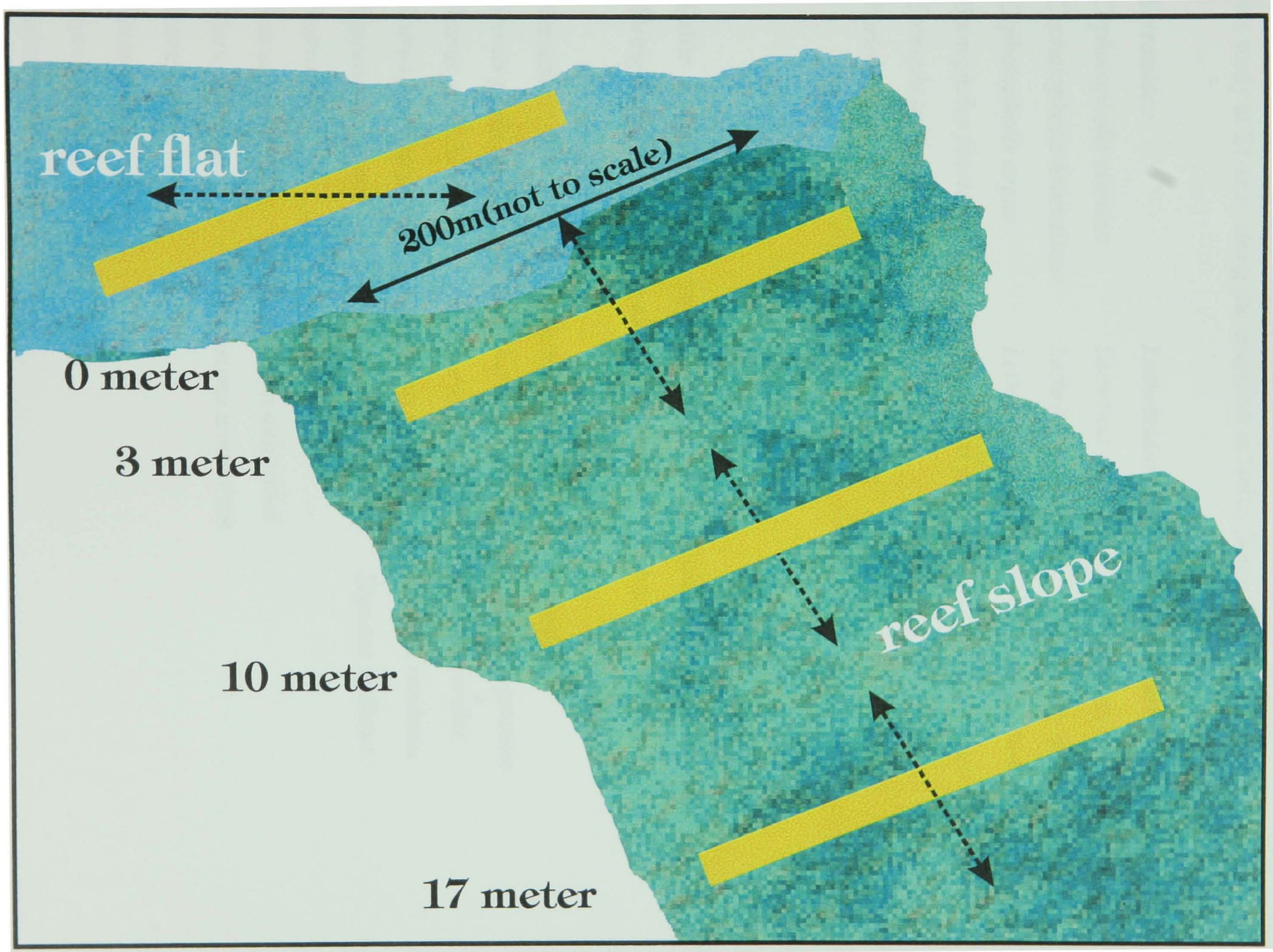

Figure 1. The location of UVC transects across different zones of the fringing reef in Nabq.

Table 1. Commercially targeted piscivorous species that were counted by UVC during this study at 21 sites along the coastline at Nabq, South Sinai.

Serranidae	*Lethrinidae*	*Lutjanidae*
Cephalopholis miniata	*Lethrinus mahsena*	*Lutjanus monostigma*
Cephalopholis hemistiktos	*Lethrinus nebulosus*	*Lutjanus ehrenbergi*
Cephalopholis argus	*Lethrinus obsoletus*	*Lutjanus bohar*
Epinephelus fasciatus	*Monotaxis grandoculis*	*Macolor niger*
Epinephelus tauvina		
Variola louti	***Haemulidae***	
	P.gaterinus	

Table 2. Commercially targeted herbivorous species that were counted during UVC during this study at 21 sites along the coastline at Nabq, South Sinai.

Scaridae	*Acanthuridae*	*Siganidae*
Scarus ghobban	*Acanthurus gahhm*	*Siganus argenteus*
Scarus sordidus	*Acanthurus nigrofuscus*	*Siganus luridus*
Scarus fuscopurpureus	*Acanthurus sohal*	*Siganus rivulatus*
Hipposcarus harid	*Ctenochaetus striatus*	*Siganus stellatus*
Scarus niger	*Naso lituratus*	
Scarus gibbus	*Zebrasoma desjardini*	
Scarus frenatus	*Zebrasoma xanthurum*	
Scarus ferrugineus		
Cetoscarus bicolor		
Scarus collana		
Calotomus viridescens		
Scarus psittacus		

Fish observed were recorded on sheets of translucent waterproof paper mounted over pre-prepared laminated fish identification cards, one for each observer, as developed for the Reefwatch II project (Ormond, 1997). All fish were recorded as belonging to one of four size classes (juvenile, half-grown, three-quarters-grown, and full size), except for acanthurids and siganids, which due to their high mobility and high numbers could only be estimated to total number. The overall length of serranids was estimated to the nearest 5cm; if less than 50cm long, or to the nearest 10cm if more then 50cm long. Length estimations were regularly checked against objects close to the fish, using the side of the dive slate as a measure, and sometimes individual fish could be approached close enough (30cm) to be measured directly by a pre-trained observer. The two shallow (reef flat and 3m) transects were counted by snorkelling, while SCUBA diving gear was used for the counts on the two deeper transects (10m and 17m).

Estimation of biomass

Conversion of length data to biomass was undertaken using length - weight relationships of each species through the following equation:

$$\mathbf{W = a\,(L)^{b}}$$

where a and b for each species were estimated from published L-W relationship data developed in Fishbase by ICLARM (Pauly and Froese, 1991) for the Red Sea, Gulf of Aden and the Arabian Sea (see chapter 5).

4.4. RESULTS

4.4.1. Overall abundance

The overall abundances of each species in each of the four reef zones across all twenty one censused sites are shown for each family surveyed in figures 2 to 8. It can be seen that within each family the most abundant species are as follows:

Serranidae:	*C. miniata* and *E. fasciatus*
Lethrinidae:	*L. mahsena* and *M. grandoculis*
Lutjanidae:	*L. ehrenbergi* and *L. bohar*
Haemulidae:	*P. gaterinus*
Scaridae:	*S. sordidus, H. harid, S. frenatus* and *S. niger*
Siganidae:	*S. luridus*
Acanthuridae:	*A. nigrofuscus, C. striatus*

The abundance patterns of species across the Nabq reef sites were tested for variation at both the species level and family level. A pattern of changing abundance with reef zone (depth) was significant for a large number of species (see table 3). Species that are principally most abundant over the reef flat and along the reef edge rather than at other zones of the fringing reef include *S. sordidus, S. frenatus, S. psittacus, S. luridus, A. nigrofuscus,* S. *ghobban, S. rivulatus, C. striatus* and *A.sohal.* On the shallow reef slope *S. sordidus, L. ehrenbrgi, M. grandoculis* and *P. gaterinus* were the most abundant. And on the deeper reef slope *C. miniata, E. fasciatus*, and *L. mahsena* were present in relatively higher numbers.

Most of the herbivorous species monitored in this study (table 2) were found to be most abundant on the shallower transects. The overall patterns of relative abundance of different families across the different reef zones are shown in figure 9, and this confirms that scarids, acanthurids and siganids are most abundant on the reef flat, but decreases in abundance moving down the reef face and across the reef slope. Results of significant variation for these families between different depths (reef zones) are shown in figure 9. It was apparent that these species dominated the fish assemblage that moved onto the reef flat over the high tide period to exploit the grazing there. This assemblage was dominated by acanthurids, that account for more than 67% of the total abundance, with scarids accounting for 27% and siganids for merely 6% of recorded herbivores. Similarly at the reef edge and on the shallow reef face acanthurids accounted for 63%, scarids for 29%, and siganids for 8% of recorded herbivore species.

In contrast to herbivores, piscivores were more abundant along the reef face or on the reef slope, particularly the deeper part (figure 10). All species of serranid increased in abundance with increasing depth save for *C. hemistktos* which was more abundant on the shallower reef face. Lethrinids in general were most abundant along the shallower reef face, but were also relatively abundant at greater depth where, for example, *L. obsoletus* was common around seagrass beds. *Monotaxis grandoculis* were mostly recorded in the reef edge zone since they tend to remain relatively inactive in the water column by day, but are believed to spread out across the seabed at night to feed. Recorded piscivores were seldom encountered on the reef flat transects except where the transect crossed a lagoon or reef flat pool (0.5 - 3m deep), and several species of *Lutjanus* and *Lethrinus* were sometimes found sheltering close to overhangs or feeding over sand. Variation in relative abundance between zones across different families was confirmed by use of the Kruskal-Wallis test (see figure 9).

Table 3. Results from the statistical analysis of UVC data by using Kruskal-Wallis test. The null-hypothesis that species abundances do not differ between different reef-zones is rejected at 95% confidence levels for the listed species except those shown in bold.

	species	Chi-Square	Asymp. Sig.
Lethrinids	*L. mahsena*	24.2	0.000
	L. nebulosus	10.5	0.015
	M. grandoculis	21.8	0.000
	L. obsoletus	9.2	0.027
Lutjanids	***L. ehrenbergi***	6.6	**0.084**
	L. monostigma	28.7	0.000
	L. bohar	19.7	0.000
	M. niger	3.6	**0.310**
Haemulids	*P. gaterinus*	14.2	0.003
Serranids	*C. miniata*	41.2	0.000
	C. hemistiktos	28.0	0.000
	E. fasciatus	3.8	**0.289**
	C. argus	25.0	0.000
	V. louti	14.5	0.002
	E. tauvina	23.2	0.000
Scarids	***S. fuscopurpureus***	1.9	**0.590**
	H. harid	1.7	**0.647**
	S. niger	14.8	0.002
	C. viridescens	7.0	**0.072**
	S. ferrogineus	6.0	**0.111**
	C. bicolor	1.2	**0.756**
	S. collana	6.4	**0.095**
	S. psittacus	21.3	0.000
	S. ghobban	6.3	**0.098**
	S. sordidus	22.1	0.000
	S. gibbus	16.7	0.001
	S. frenatus	46.9	0.000
Acanthurids	*A. gahhm*	8.3	0.040
	A. sohal	39.0	0.000
	A. nigrofuscus	29.8	0.000
	C. striatus	26.7	0.000
	N. lituratus	7.1	**0.068**
	Z. desjardini	20.4	0.000
Siganids	***S. argenteus***	2.0	**0.563**
	S. luridus	11.7	0.009
	S. rivulatus	12.7	0.005
	S. stellatus	20.0	0.000

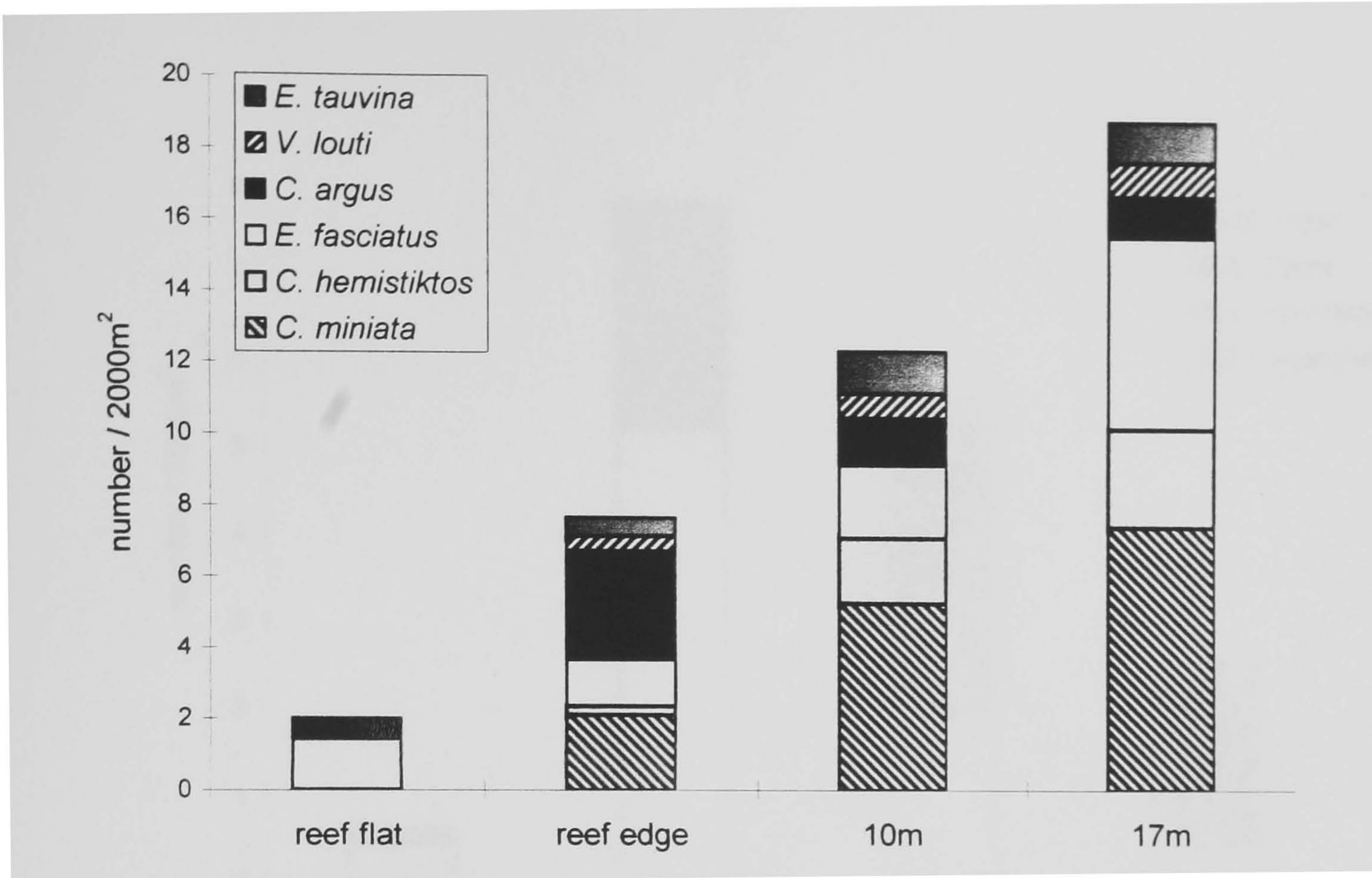

Figure 2. Abundance patterns of different species of Serranidae along four zones of the fringing reef in Nabq.

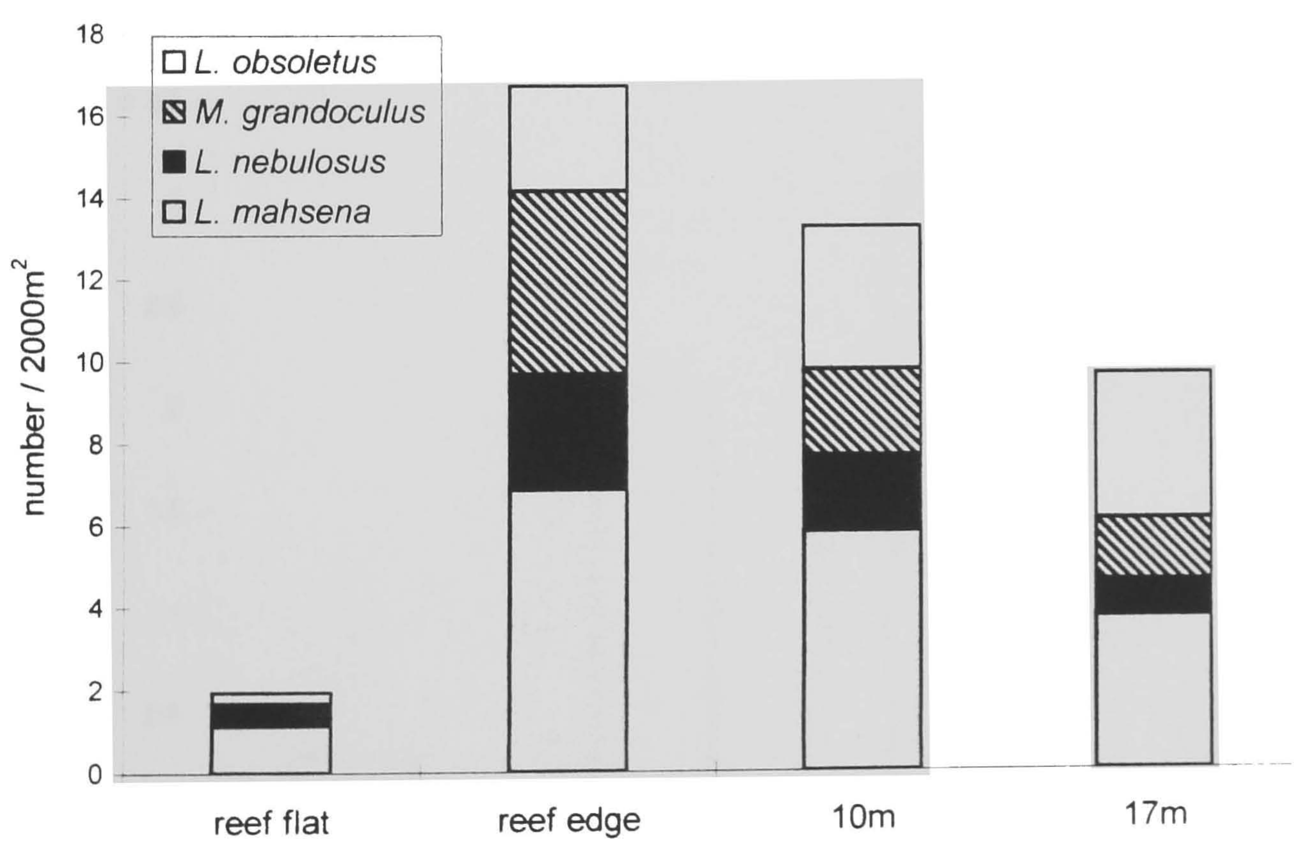

Figure 3. Abundance patterns of different species of Lethrinidae along four zones of the fringing reef in Nabq.

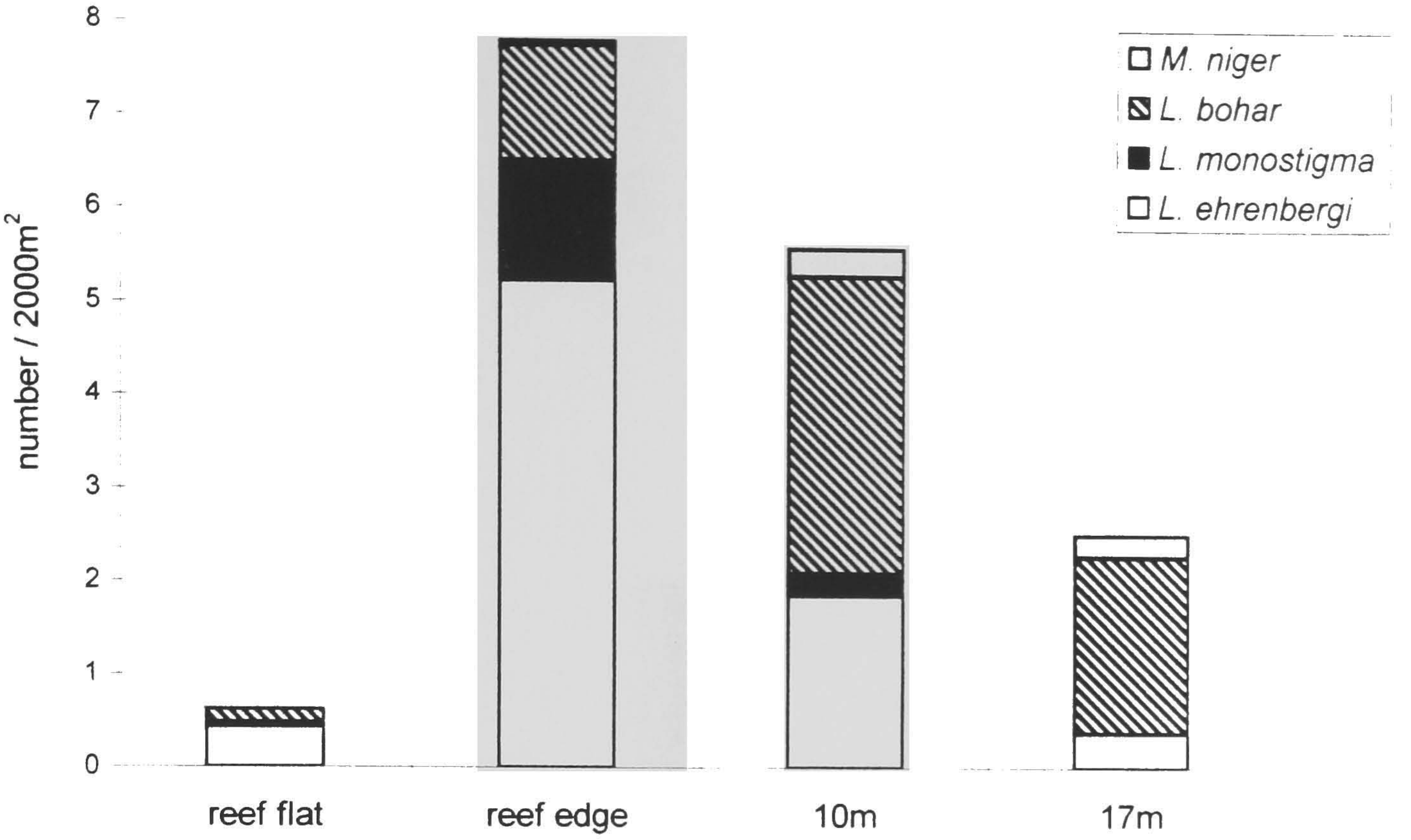

Figure 4. Abundance patterns of different species of Lutjanidae along four zones of the fringing reef in Nabq.

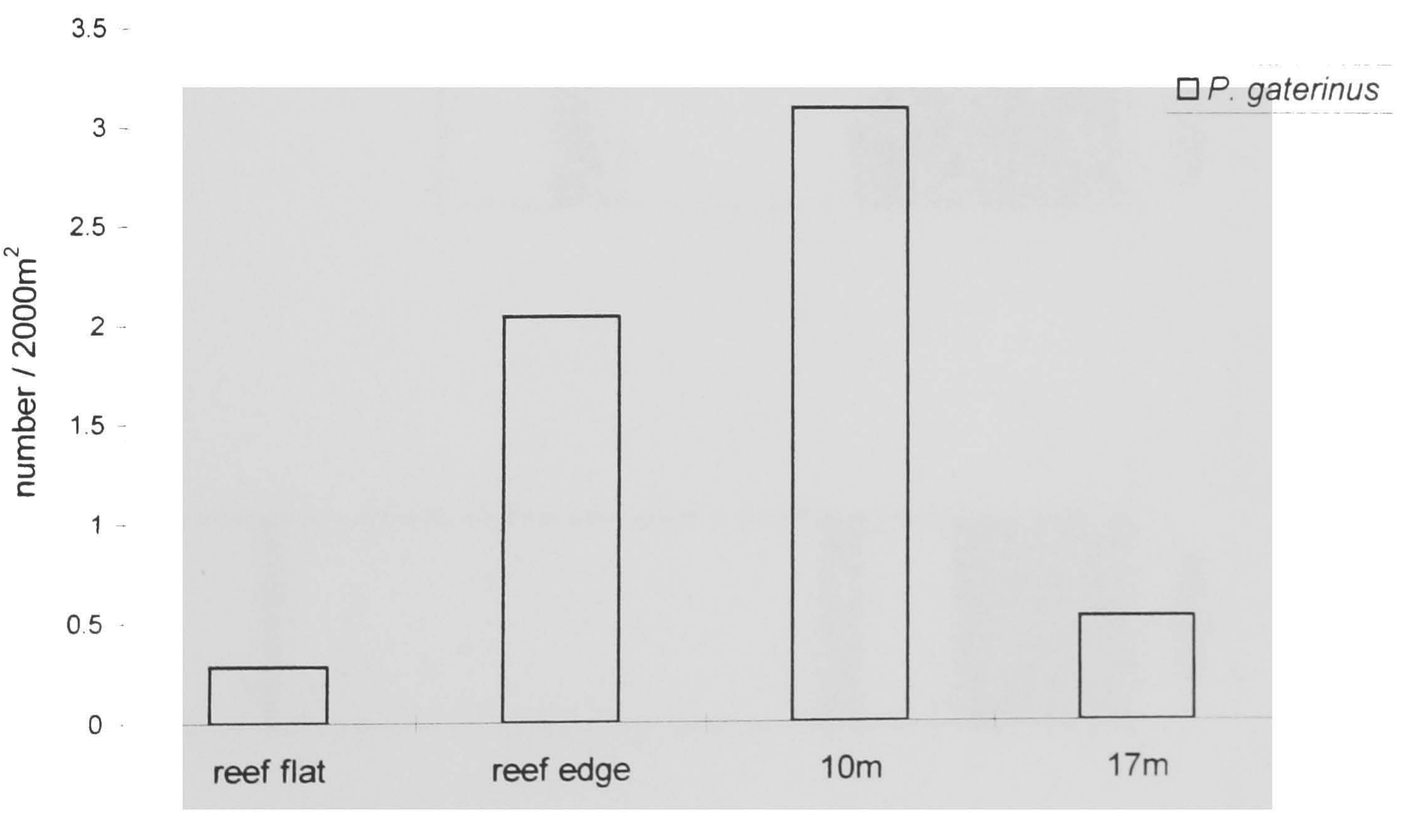

Figure 5. Abundance patterns of Haemulidae species (*P. gaterinus*) along four zones of the fringing reef in Nabq.

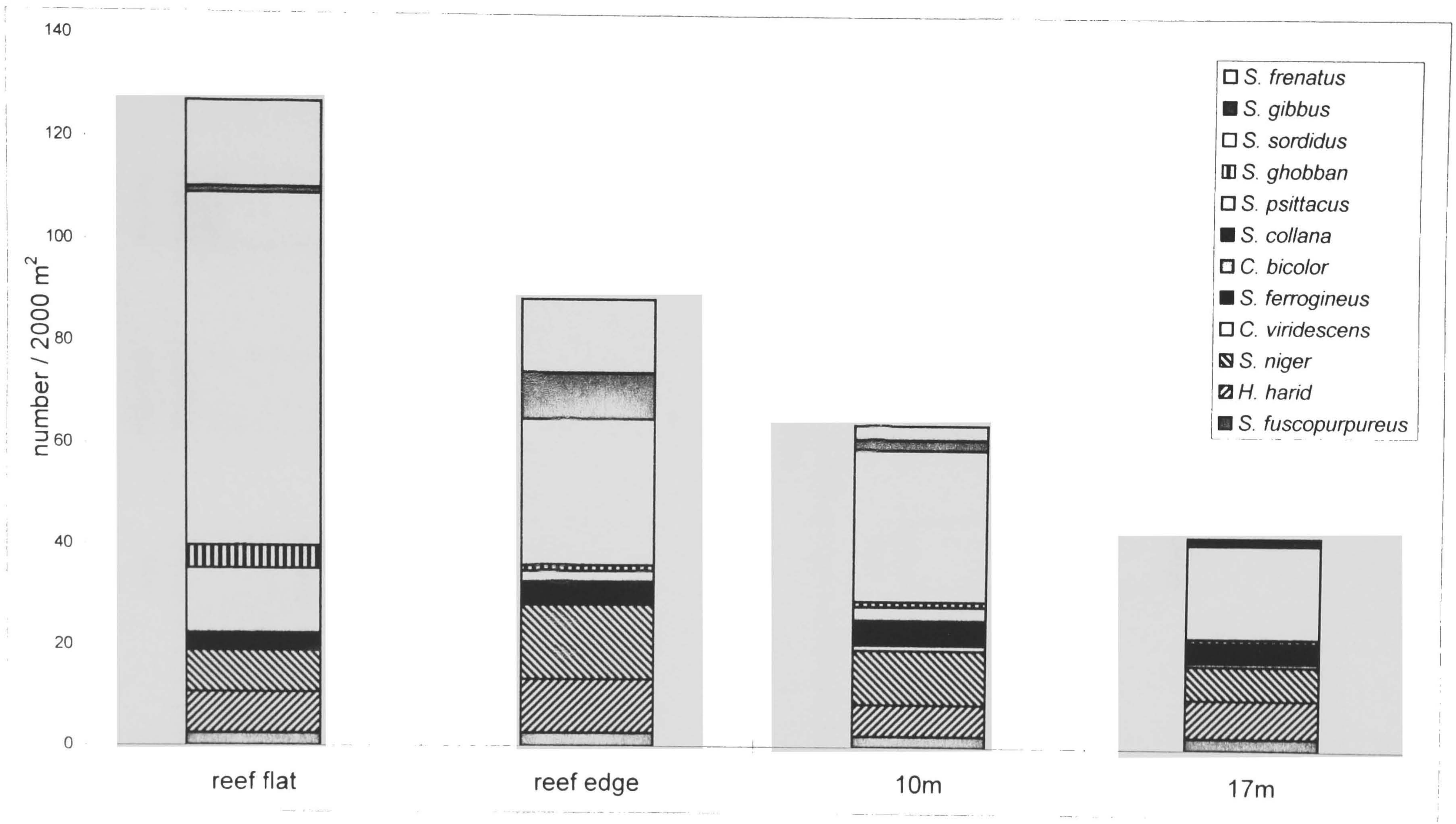

Figure 6. Abundance patterns of different species of Scaridae along four zones of the fringing reef in Nabq.

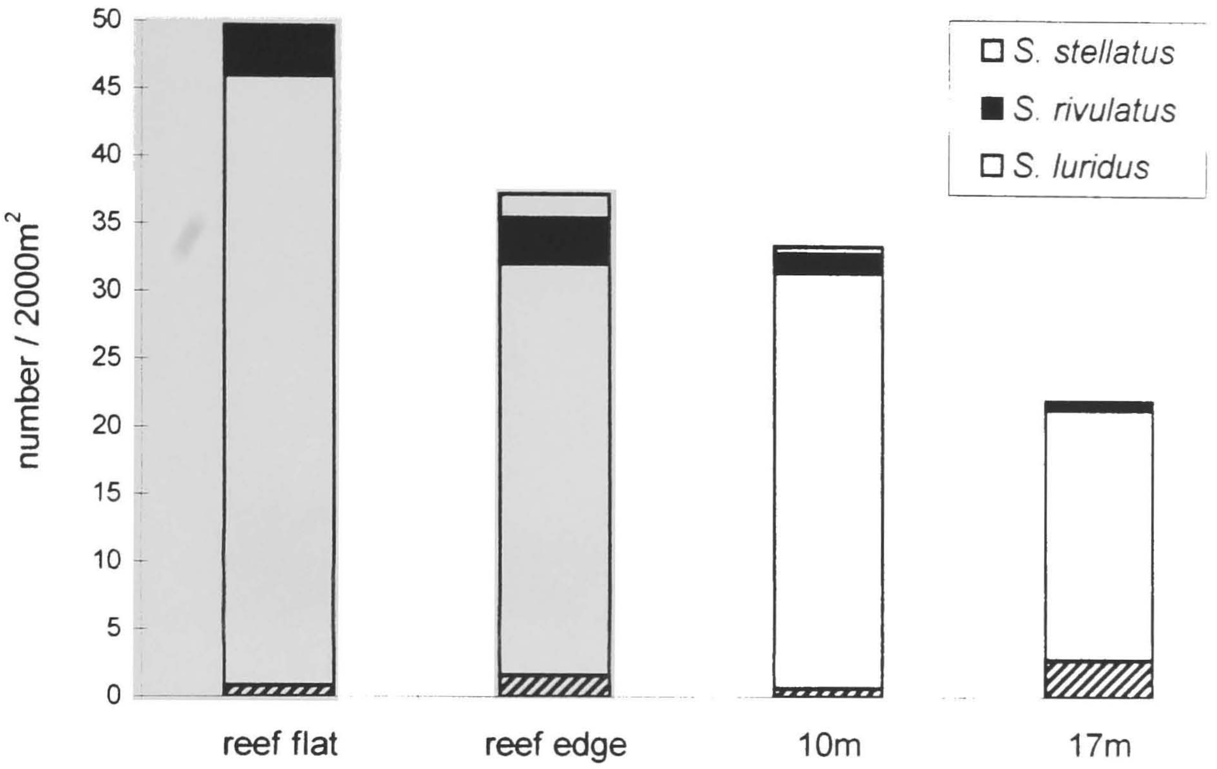

Figure 7. Abundance patterns of different species of Siganidae along four zones of the fringing reef in Nabq.

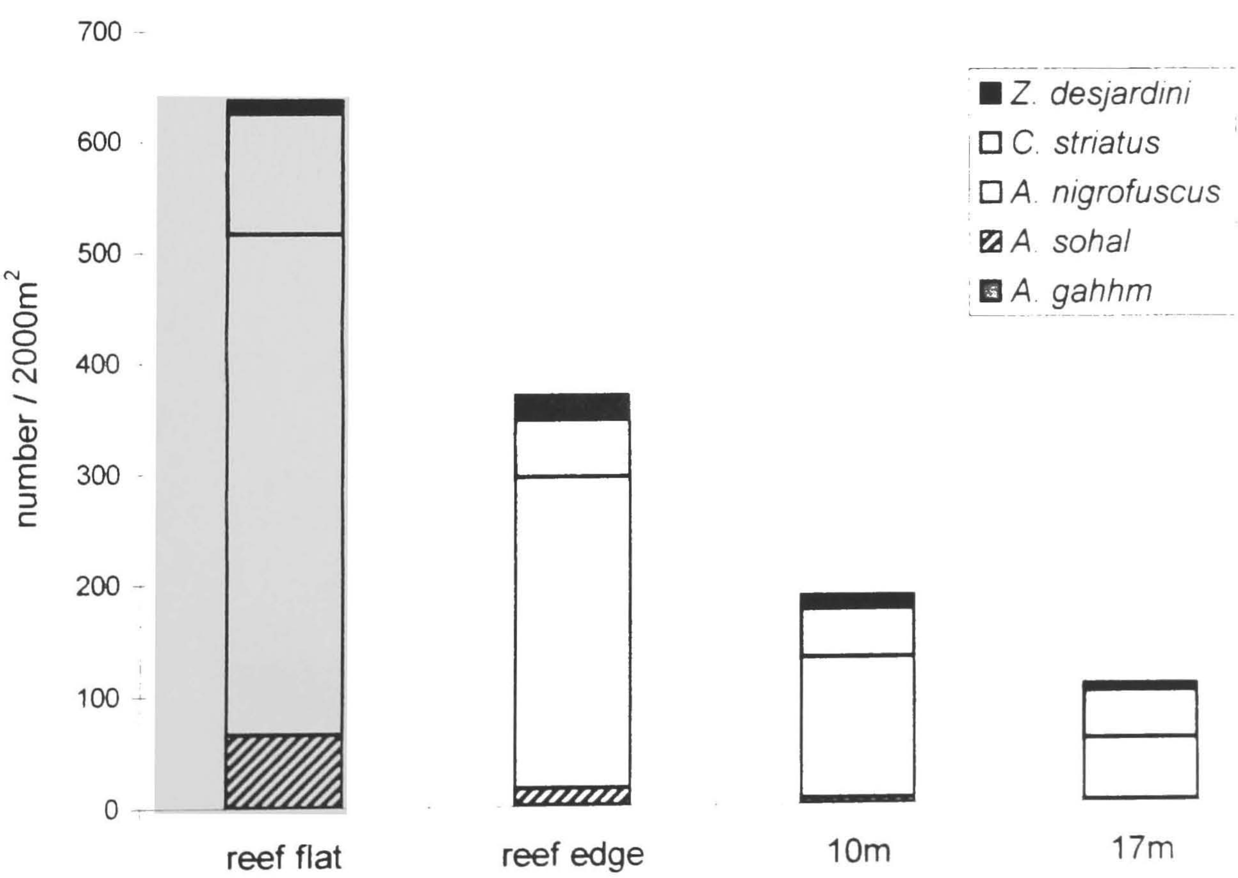

Figure 8. Abundance patterns of different species of Acanthuridae along four zones of the fringing reef in Nabq.

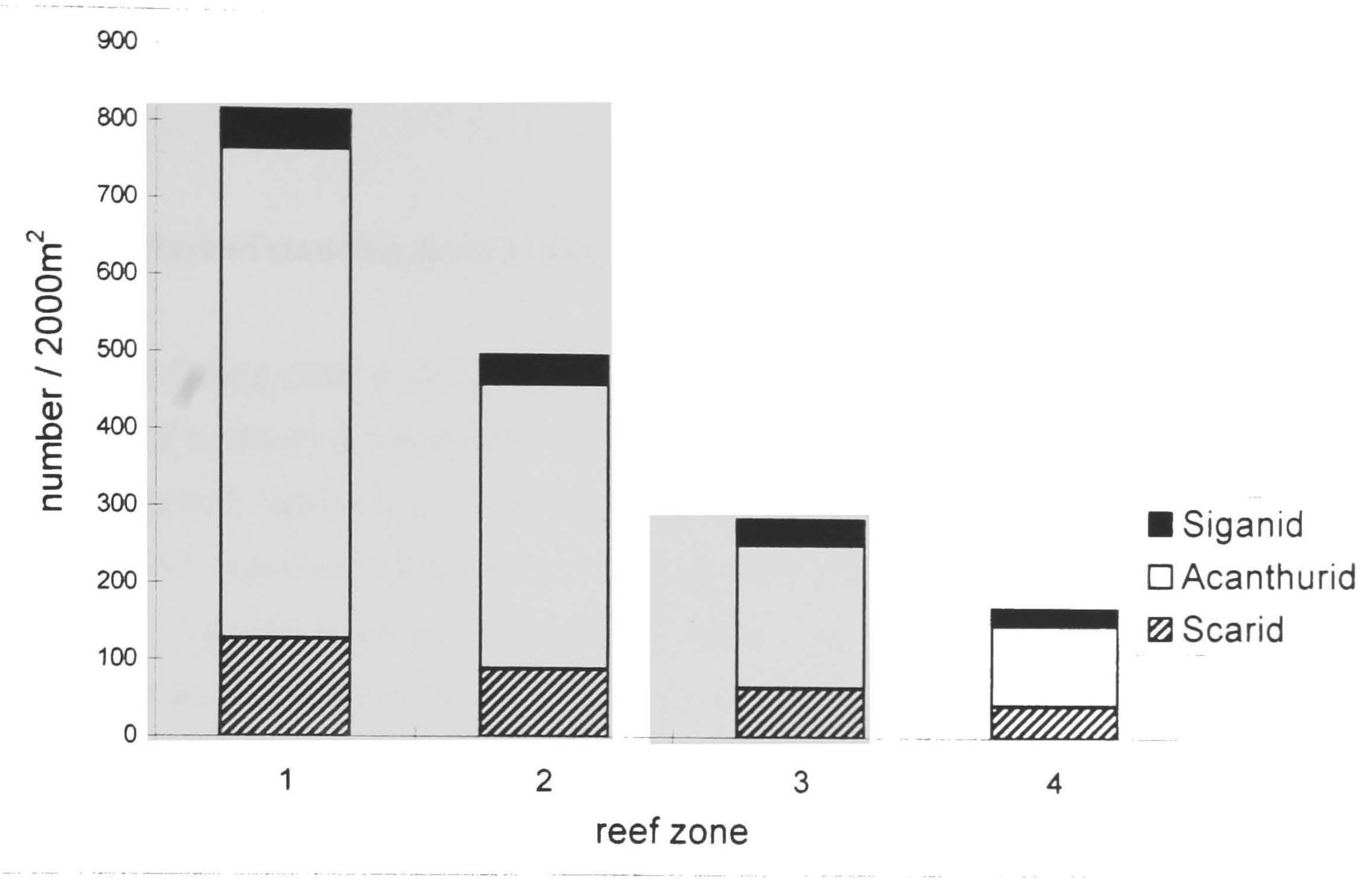

Figure 9. Relative abundance of herbivore families at different zones of the fringing reef in Nabq. Reef zones that were surveyed by UVC are as follows: (1) reef flat, (2) reef edge, (3) shallow reef slope and (4) deep reef slope.

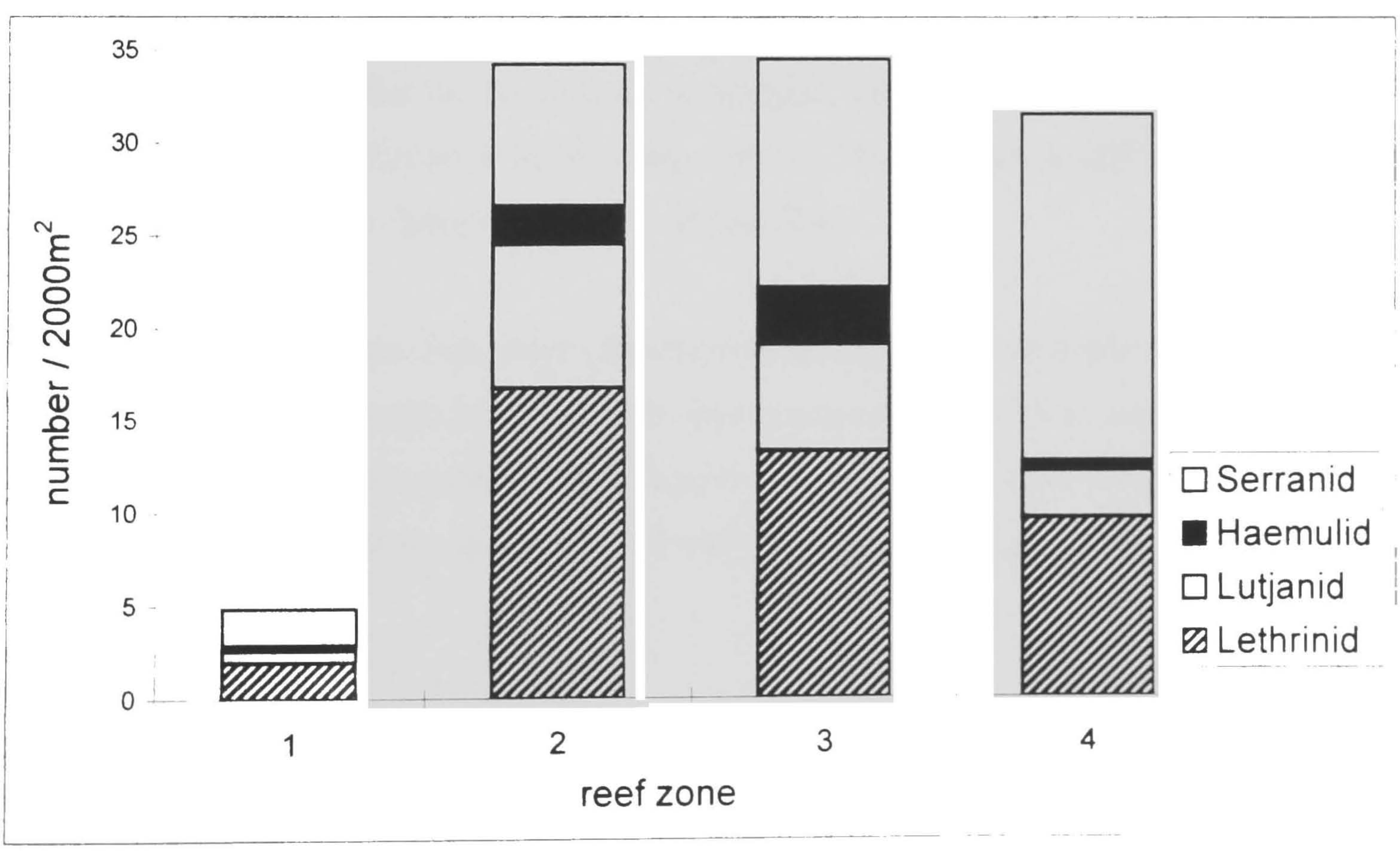

Figure 10. Relative abundance of piscivore families at different zones of the fringing reef in Nabq. Reef zones that were surveyed by UVC are as follows: (1) reef flat, (2) reef edge, (3) shallow reef slope and (4) deep reef slope.

4.4.2. Comparison of standing stock at heavily fished and lightly fished sites.

Data on fishing effort at different sites (see chapter 5), indicated that a fairly clear distinction could be drawn between those that were fished more heavily, and those that were fished relatively lightly, if at all. Abundance and size data for each species that were estimated by UVC, allowed the calculation of biomass through published L-W relationships. Comparisons between more heavily fished sites (fished) and lightly fished sites (unfished) are shown for serranids in figure 11, for lethrinids in figure 12, for lutjanids and haemulids in figure 13, for scarids in figure 14, for acanthurids in figure 15, and for siganids in figure 16. It can be seen that there are some major differences in biomass. Statistical comparisons were made using the Mann-Whitney U-test. Serranids were found to be significantly less abundant at heavily fished sites ($P < 0.005$). The difference was greatest on the reef slope, and for the most commercially targeted species, i.e. *C. miniata* *($P < 0.05$)* and *V. louti* ($P < 0.05$). Lethrinids were found to be more abundant at lightly fished sites than at heavily fished ones, but this difference was not statistically significant. Acanthurids and siganids by contrast were significantly more abundant at heavily fished sites than at lightly fished ones. For scarids no significant difference was found between lightly and heavily fished sites.

In general for most species these differences appear consistent across most depths, but it is noticeable that for some families the differences were more marked at some depths than at others. For example for serranids the differences are most marked on the deeper reef slope (where these species are mostly fished) while for lethrinids the difference is greatest at the reef edge.

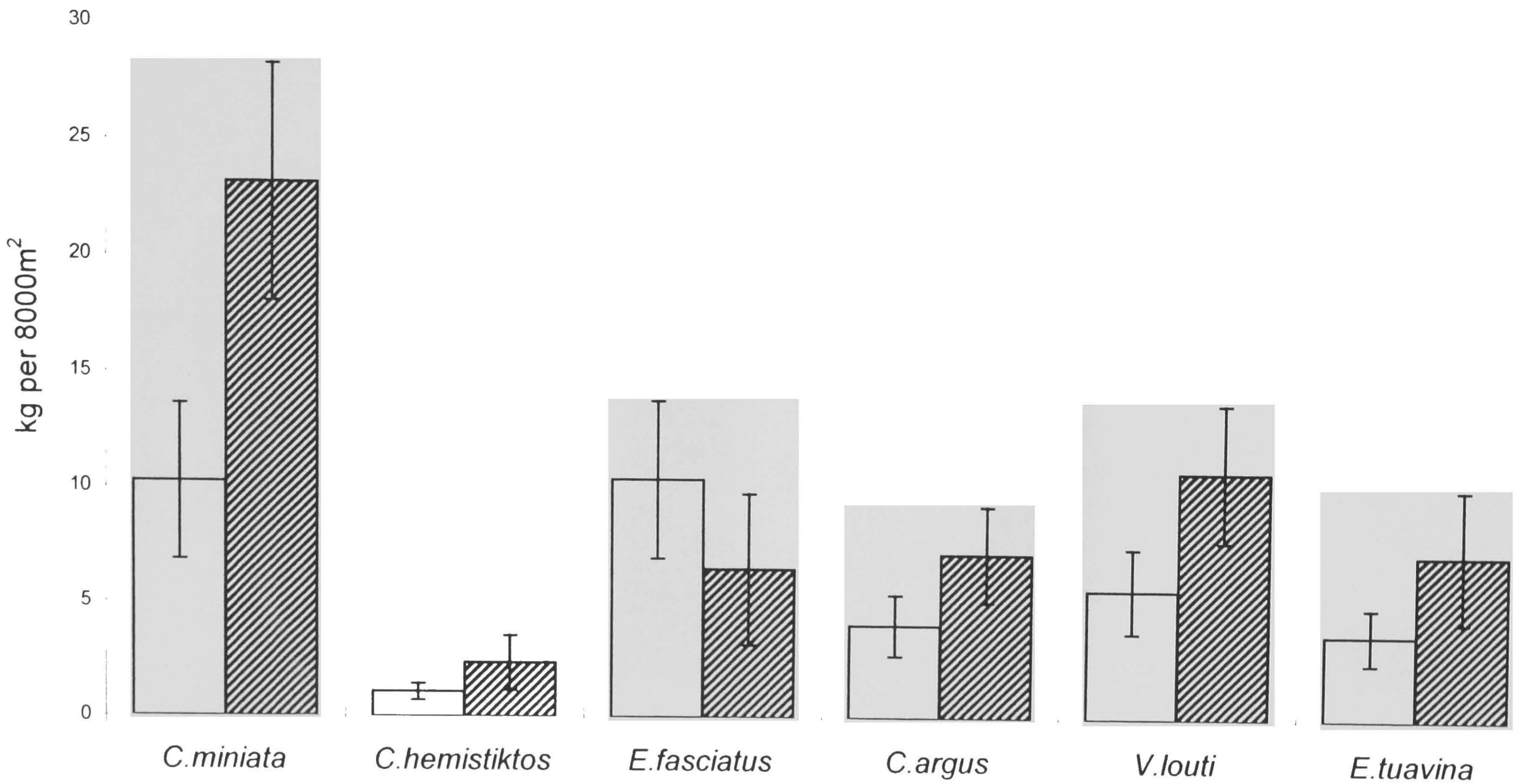

Figure 11. mean biomass of serranid species at lightly fished sites, represented by the unfished dark bars, and heavily fished sites expressed as fished. Error bars represent standard error of the mean.

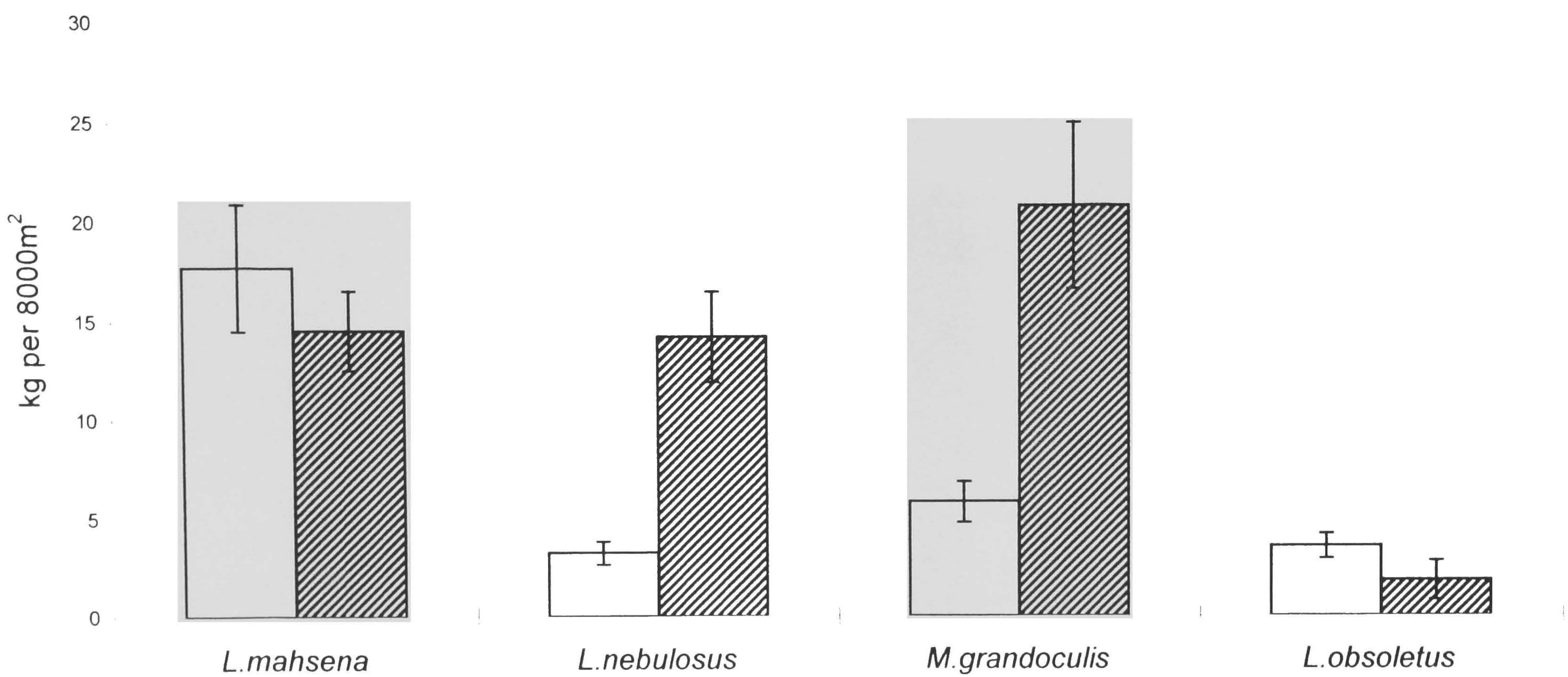

Figure 12. mean biomass of lethrinid species at lightly fished sites, represented by the unfished dark bars, and heavily fished sites expressed as fished. Error bars represent standard error of the mean.

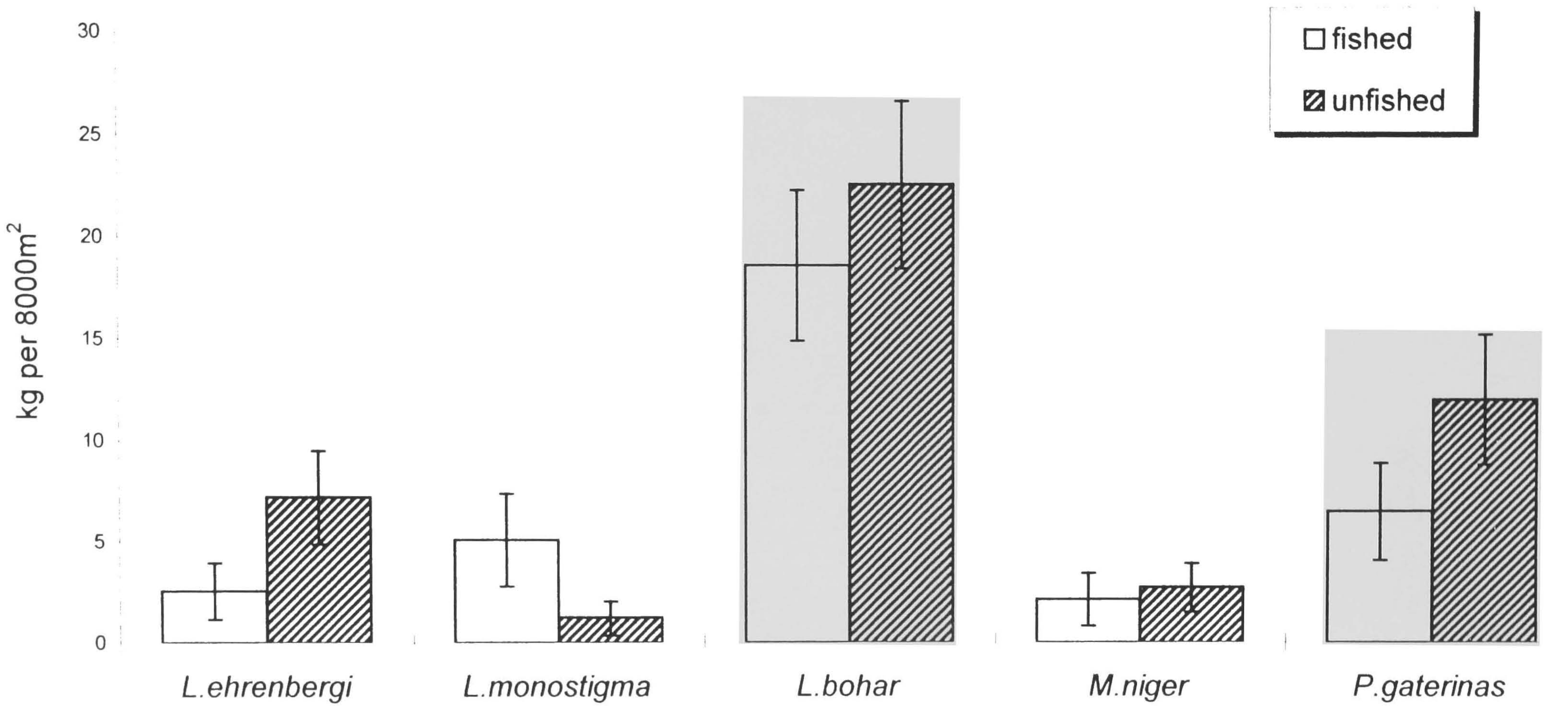

Figure 13. mean biomass of lutjanid and haemulid species at lightly fished sites, represented by the unfished dark bars, and heavily fished sites expressed as fished. Error bars represent standard error of the mean.

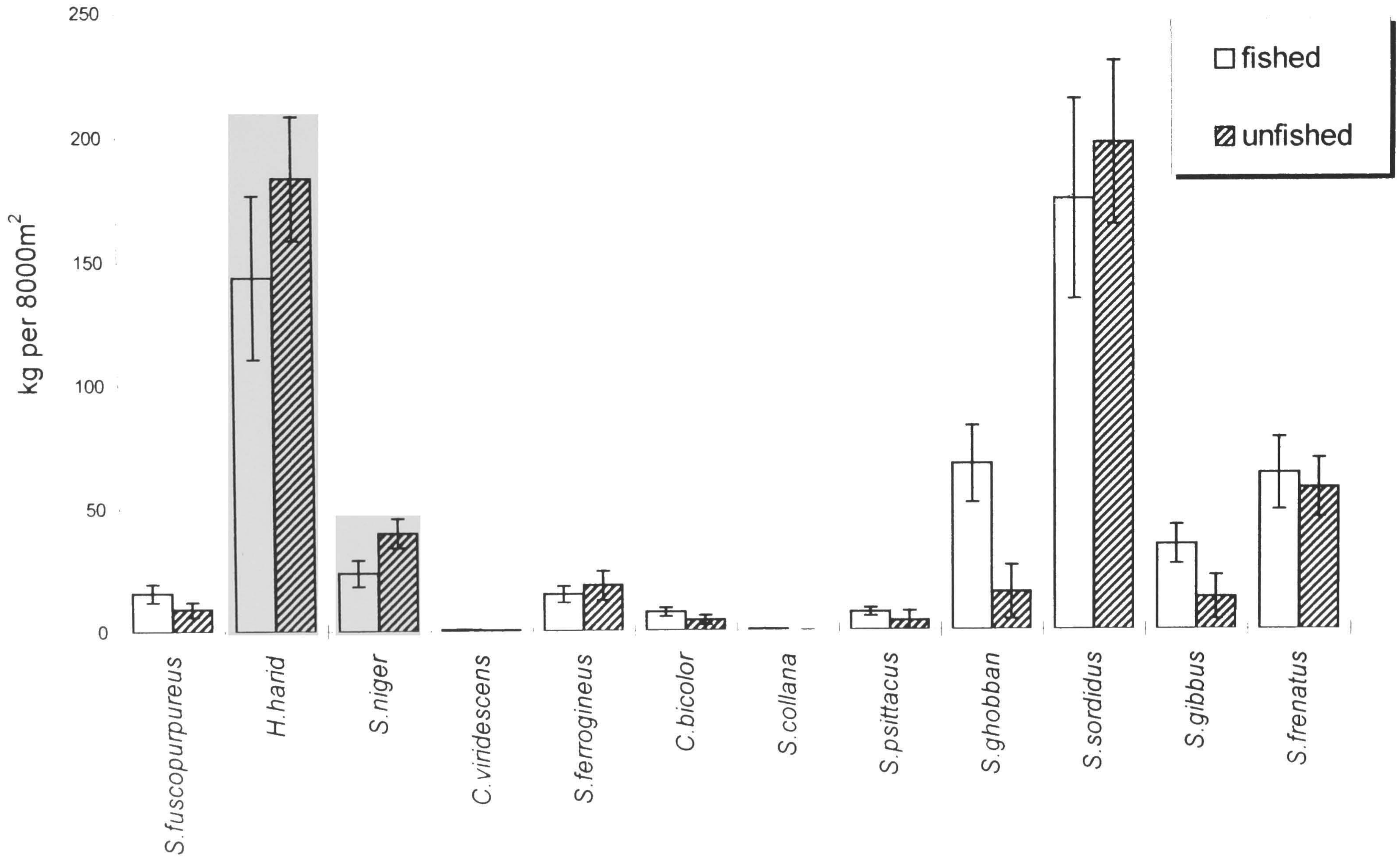

Figure 14. mean biomass of scarid species at lightly fished and heavily fished sites. Error bars represent standard error of the mean.

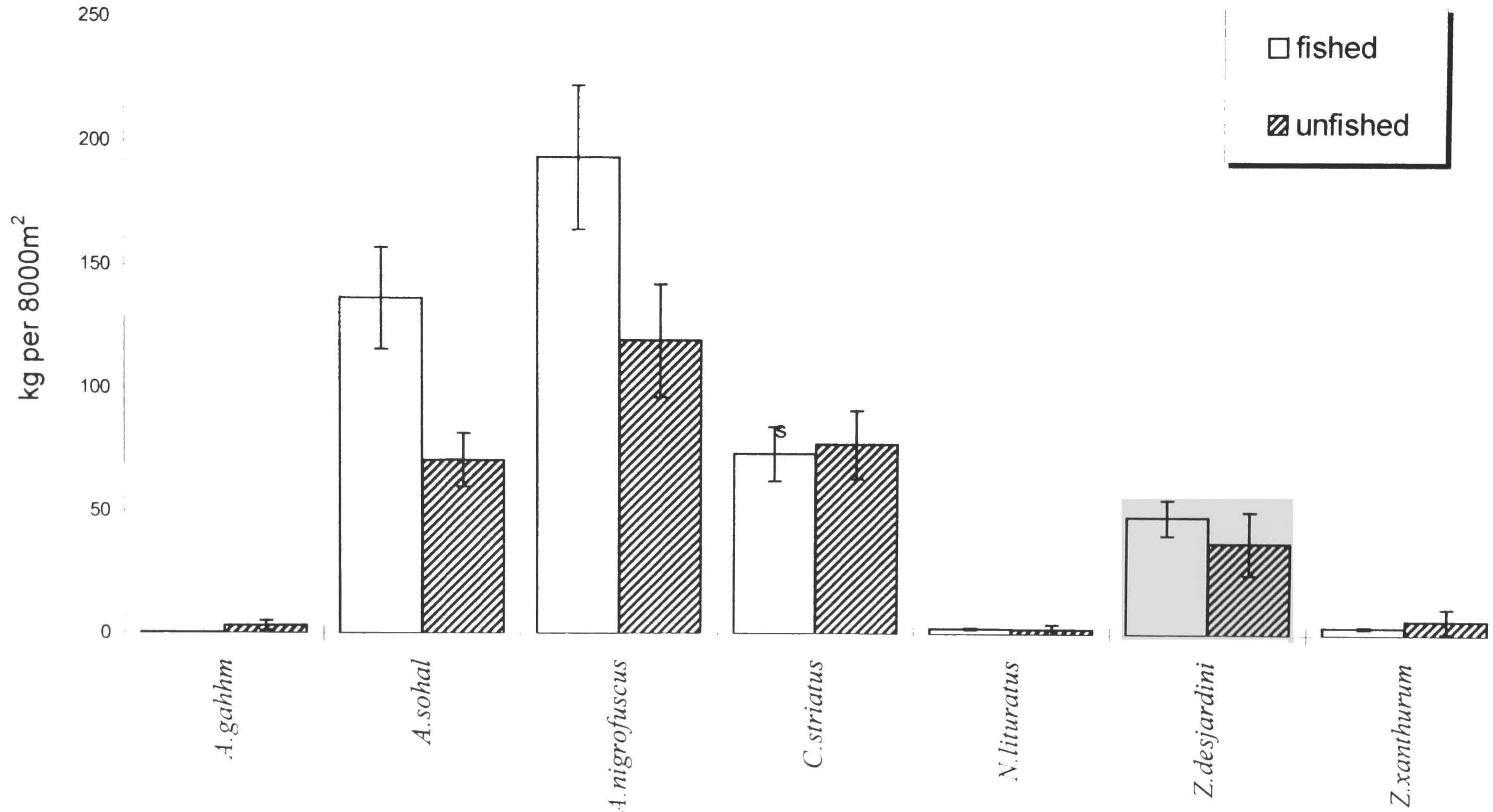

Figure 15. mean biomass of acanthurid species at lightly fished and heavily fished sites. Error bars represent standard error of the mean.

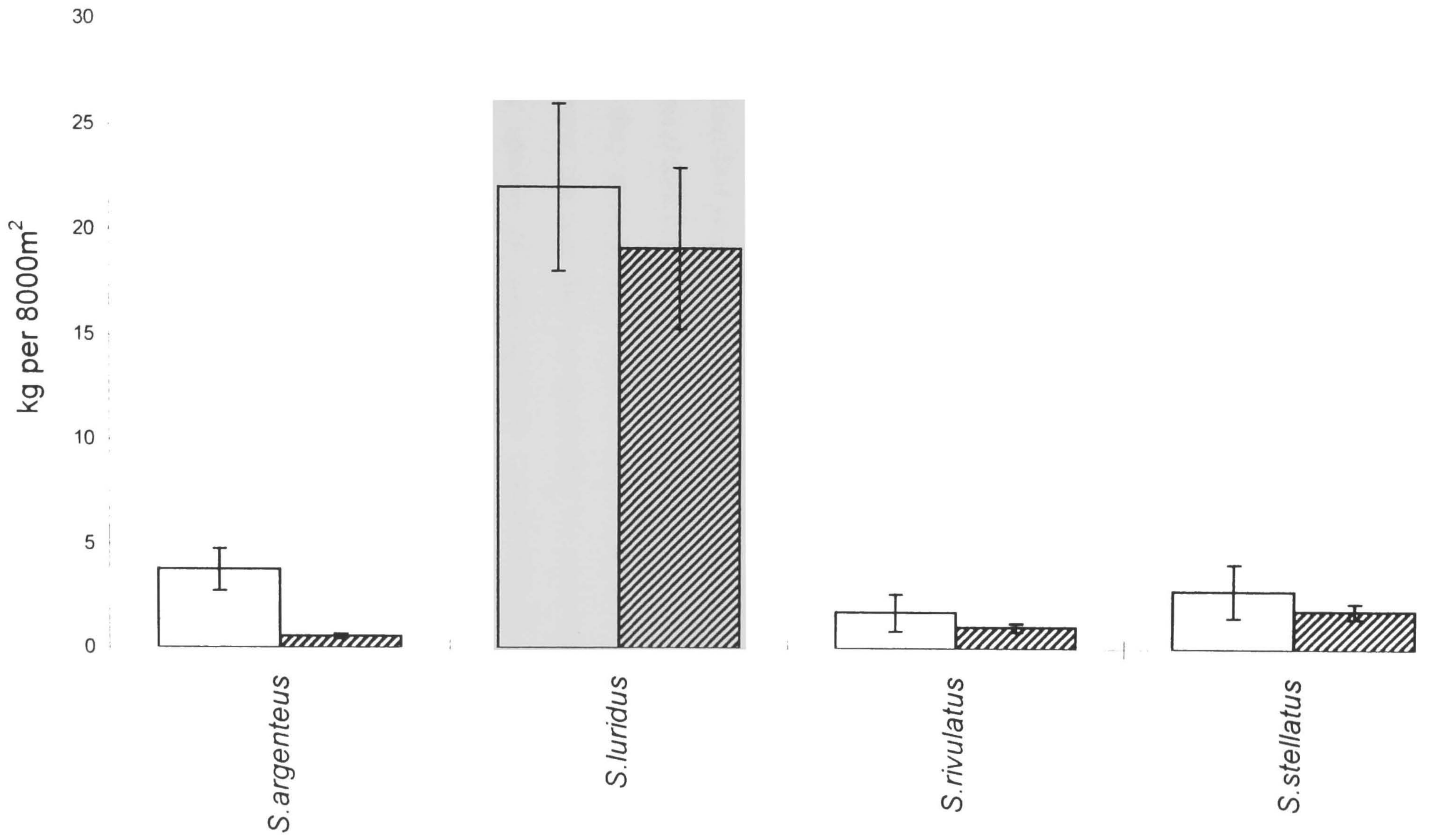

Figure 16. mean biomass of siganid species at lightly fished sites, represented by the unfished dark bars, and heavily fished sites expressed as fished. Error bars represent standard error of the mean.

4.5. DISCUSSION

The species within the families concerned, and their overall densities observed during visual census, are not greatly different from those recorded using comparable methods elsewhere in the northern Red Sea (Navaro and Vivien, 1981; Roberts and Polunin, 1992). The transect width used was set at ten metres (i.e. five metres at each side of the two hundred metre transect). In general this width provided a satisfactory sample size (2000 m^2), but for the species being censused did not seem so wide that detection of fish further away from the observer was reduced, as described by Sale and Sharp (1983) for band transect surveys of smaller reef fish families.

The tendency of reef fish species to occur within preferred physiographic zones has been frequently described (e.g. Smith, 1978; Sale, 1983; Sheppard *et al.* 1992). In the present study the typical distribution was clearly modified by the presence of pools and lagoons, since where they were present more serranids and lethrinids were observed, and where they were absent the reef flat was dominated by acanthurids and siganids, as well as by characteristic species of non-exploited (smaller-sized) families such as damselfishes (Pomacentridae) and wrasse (Labridae).

Species preferences for different zones of the reef conforms with other studies of zonation of coral reef fishes in the Gulf of Aqaba as those previously reported by Bouchon-Navaro and Hermlein-Vivien (1981) for herbivorous species. Such zonation for the reef flat and shallow zones can be related to feeding requirements, in that herbivory by fishes is highest on reef flats and shallow reef slopes where growth rates of the algal turfs on which they browse, is greatest.

The difference in abundance of fish on lightly fished as compared with heavily fished sites is in line with the other recent studies undertaken in the Indo-Pacific (e.g. Alcala, (1988) in the Philippines; Watson & Ormond (1994) in Kenya; Koslow *et al.* (1988) in the Caribbean as well as the study by Roberts and Polunin (1992) in the Sinai region). Such differences contrast with earlier reports that differences in at least some fish, particularly serranids of the genus *Plectropomus*, were hard to detect between fished and unfished reefs on the Great Barrier Reef (Ayling & Ayling 1986). The differences observed here are, in general, supporting those recorded by Roberts & Polunin (1992) with respect to the higher abundance and average length of groupers, emperors and snappers at the lightly fished sites, and the lower abundance of siganids and acanthurids at sites heavily fished by Bedouin fishermen. However, in Roberts and Polunin's study in 1992, because of the limited number of sites, the differences in abundance were not fully significant. In the present study, because of the much larger number of sites, most of the dissimilarities in species abundance and average length were statistically significant. Moreover whereas the previous study was potentially flawed by the geographical separation of fished and unfished sites, in the present study lightly and heavily fished sites were spatially interspersed within a relatively homogeneous area.

Nevertheless, the differences in fish abundance between more-fished and less-fished sites at Nabq, could still, to a point, reflect differences in habitat and reef characteristics. Even with sites which are in close proximity to one another, a high proportion of the differences in fish abundance and diversity may be attributed to site characteristics (McClanahan, 1994; Ormond *et al.* 1996). For example, the higher abundance of piscivores in the control stations at Ras Nasrani and the Straits of Tiran may be attributed to the proximity of deep water and the location of these reefs adjacent to strong currents (Roberts and Polunin, 1992). Also, whereas most of the reefs at Nabq have broad reef flats, with a well-formed reef edge and slope descending to 20-25 metres, at some locations exposed to occasional fresh water run-off (for example Nakhlet Al Tal, Checkpoint, and north Ghargana), the fringing reef becomes discontinuous with gaps opening into reef flat pools and lagoons. These are the sites that, because of their morphology, are most suitable for use of trammel and drive gill nets.

Suprisingly the abundance of acanthurids was significantly greater at more-fished rather than less-fished sites. The most obvious explanation for such a finding would be that fishermen favour those sites with higher populations of target species, and that fishing intensity across the more-fished sites as a whole is not great enough to reduce the abundance of these species to, or below, those at the less-fished sites. However the morphological features which make some sites more convenient for fishing also result in differences in extent of different types of substrate, providing for larger amounts of shallow sandy bottom habitat and less expanse of dense coral. Mazeroll and Montgomery (1995) have described how the abundance of *Acanthurus nigrofuscus* is influenced by the availability of food resources, in particular the extent of algal growth, which, since it occurs on open reef substrate, is favoured by lower levels of coral cover. These preferred fishing sites also tend to be the ones that have lagoonal sea-grass beds or are close to mangroves stands; input of inorganic nutrients from these habitats into the reef ecosystem might also promote algal growth, and input of leaf litter favour detritivores, such as the acanthurid, *Ctenochaetus striatus*.

An alternative and more interesting explanation could be that abundances of acanthurids are higher at these sites because of a lower predation pressure, the result of the populations of larger piscivores being reduced at these sites by the greater fishing pressure. *Acanthurus nigrofuscus*, for example, has been reported to be a common prey species of groupers on reefs in the Gulf of Aqaba (Shpigel and Fishelson, 1989). Elsewhere it has been reported that fish community structure can change as a result of fishing pressure, and both McClanahan (1994) and Polovina (1984) have suggested this could result in changes in predator-prey dynamics, and produced models indicating that removal of predators can cause an increase in the abundance of herbivores.

The apparent difference in zonation pattern of some herbivorous species between heavily and lightly fished sites could reflect a change in behaviour in response to fishing, as well as, or instead of, a reduction in numbers in the most heavily exploited reefs zones. For example the abundance of *C. bicolor* and *S. ghobban* at heavily fished sites was lower over the reef flat and reef edge but higher over the reef slope, than in less-fished sites. These are both large mobile species of parrotfish, which may be observed moving along hundreds of metres of reef face, or across the reef between reef slope and reef flat. It is not impossible that some individuals may have learnt to avoid the reef flat area following close encounters with fishing nets.

A trend of decreasing individual fish size with increasing fishing intensity was apparent for some of the families concerned in this study, most notably for serranids. These changes match those reported by, for example, Bohnsack (1982) and Munro (1985) following similar comparisons of mean size and population size structure of species on reefs subject to different fishing pressures where such marked changes can result in growth overfishing.

The fishery described here may be characterised as a low-intensity traditional artisanal fishery. In most cases fishing is used to supplement the diet of Bedouin families or to supplement their income. Only a small number of fishermen were found to be entirely dependent on the fishery as a means of livelihood. However, as on the one hand, the availability of consumer goods increases, and on the other hand the demand for fish by the hotel / tourism industry increases, so also the amount of fishing effort and the pressure placed on local fish stocks, in areas where fishing is allowed, may be expected to increase.

In fact it is perhaps surprising that the methods used by fishermen are relatively limited. Even hand-lining off the reef (i.e. over the reef slope) is relatively little used. This is in part because most local Bedouin fishermen are too poor to own a motorised boat, and in part because the alignment of the coast in the Nabq area exposes the reef face to waves generated by the prevailing north-east winds, so that for much of the year anchoring and fishing above the reef slope presents access difficulties.

It is also perhaps surprising that some other methods of fishing are not used, for example hook-and-line fishing from long poles as in Sri Lanka, or basket traps (garghour) or fence traps (hadra), which are widely used in the Arabian Gulf. It is probably because of the restricted range of gear used that despite the large variety of species available on the reef, a relatively small number of species make up the bulk of the catch.

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CHAPTER 5

Effects of Fishing Effort on Underwater Visual Census (UVC) Estimations of Biomass and Length of Coral Reef Fish Stocks at Nabq, South Sinai

5.2. INTRODUCTION

On tropical coasts reef fisheries are typically important both in providing local populations with their major source of food protein and in generating incomes for fishermen and their families (McManus, 1988; Dalzell & Wright, 1990; Salvat, 1992). The sustainable yield of reef fisheries was initially estimated to be about 4-5 t. k^{-2}. yr^{-1} (Stevenson and Marshall, 1974). However, more recent estimations by Munro (1977), Marten and Polovina (1982), Alcala and Gomez (1985) and Russ (1991) suggest that sustainable yields significantly greater than 5 t. k^{-2}. yr^{-1} may be possible. The highest yield recorded has been estimated at 44 t. k^{-2}. yr^{-1} in American Samoa by Wass, 1982.

However coral reefs are now being over-exploited on a global basis, and in many areas it is becoming difficult to make a living from fishing, as first the large commercially valuable species such as groupers disappear, and then smaller ones. Further throughout the tropics urbanisation is changing the nature of reef fishing from a subsistence fishery into a major source of income (Ruddle, 1996), as for example in Western Samoa (Helm, 1992). Consequently as over the last 3 decades increasing human populations have placed increasing pressure on such fish stocks, their sustainable exploitation has become a matter of considerable concern.

Heavy fishing pressure on reefs has been found to impact sustainability through a wide range of direct and indirect mechanisms. The most widely reported direct effects on targeted stocks are reductions in yield and catch per unit effort (Gulland, 1979; Koslow *et al*, 1988; Alcala and Russ, 1990). In addition, the fact that it is predominantly the larger fish which are removed has effects upon both population structure and population dynamics, as reviewed by Munro and Williams (1985) and Russ (1991). Effects have also been reported upon recruitment (Munro, 1983; Doherty & Williams, 1988a), mortality rate (Ralston, 1987; Russ and St. John, 1988) and reproductive behaviour. In particular a marked reduction in mean individual size of exploited reef species has been described by

Bell (1983), Russ (1985), Ayling and Ayling (1986a), McClanahan and Muthiga (1988), Samoilys (1988), Polunin and Roberts (1993) and Watson and Ormond (1994). This in turn has a profound influence on the reproductive output of the stock (Bohnsack, 1990)

However fishing on reefs does not simply involve the removal of targeted species from targeted stocks. There are a wide range of direct and indirect mechanisms by which reef productivity may be more generally undermined; these have been described in reviews by Munro and Williams (1985), Russ (1991) and Dalzell (1996). Heavy fishing frequently causes extensive physical damage to reef habitats (Carpenter & Alcala, 1977; Gomez *et al.*, 1987) and fishing may also have marked effects upon community structure (Russ, 1985; Koslow *et al*, 1988). Changes in relative abundance of different species have been described by Bohnsack (1982), Russ (1984c), Ayling and Ayling (1986a), Polovina (1986), Alcala (1988), Samoilys (1988), Russ and Alcala (1989), Roberts and Polunin (1992), McClanahan (1994) and Watson and Ormond (1994).

The present study has investigated the effects of artisanal fishing by Bedouin upon the biomass and size structure of fish on reefs within the Nabq Protected Area. These reefs running north along the coast from Ras Nasrani to Ras Atantur (see figure 1) are managed by the Park Authority as a multiple-use management area in which traditional fishing by local Bedouins is permitted. A fisheries management programme has been initiated by the park managers and directed towards securing the sustainable exploitation of the fishery. The state of exploitation of commercially targeted species in the area was not previously known apart from a short descriptive report of the fishery (Fabian, 1993). Quantitative surveys were required to determine the effects of fishing upon fish biomass and population structure so that the sustainable level of exploitation could be assessed, and the decision making capacity of the park managers in relation to fisheries management issues enhanced.

Until the last 10 to 20 years, coastal populations have been low and sparsely distributed, and the absence of infrastructure made exploitation of coastal fish stocks on a commercial basis impracticable. However, with the rapidly expanding populations of the region, fuelled in some countries by oil wealth, and in others by a more recent unprecedented increase in coastal tourism, demand for fish has accelerated dramatically, greatly increasing the pressures on coral reef fish stocks. In the Egyptian Gulf of Aqaba in particular there has been a huge increase in demand for fish as a result of a tenfold increase in tourist accommodation and associated urban development during the last 10 years (Roberts and Polunin, 1992; Pearson, 1998). Associated with this the number of licensed fishermen in the Egyptian Red Sea has increased from 14,000 in 1987 to 30,000 in 1995 (Egyptian Institute of Marine Sciences, 1995).

In the marine sector of the Nabq Protected Area local Bedouin fishermen conduct an artisanal, small-scale coral reef fishery. Access to the reef is most usually undertaken by foot, as fishermen walk from the shore across the fringing reef. However small dories (hassaka) are sometimes used to reach the offshore reefs (e.g. the large reefs of the Tiran Straits and nearer shore patch reefs at Nabq), although this is only possible when weather permits. The local fishermen use almost exclusively gill nets and hook and line fishing gear. This type of multi-gear artisanal fishery is typical of many coral reef regions (Munro and Williams, 1985), including other parts of the Red Sea (Kedidi, 1994b), south-east Asia (McManus, 1988; Sawyer, 1992) and the Caribbean (Koslow *et al.*, 1988).

Underwater Visual Census (UVC) was used to estimate species biomass and mean length, both because it was a practicable approach under the clear, warm-water conditions of the Gulf of Aqaba, and because unlike methods dependent on catch statistics, it is not subject to gear selectivity or fish species catchability.

5.3. METHODS

5.3.1. Study area

In the Gulf of Aqaba, as in the Red Sea proper, the predominant reefs are fringing reefs. Those of the south-western Gulf of Aqaba have been described by Gvirtzman and Buchbinder (1977). They are mostly continuous with a well-developed reef flat ranging between 30 - 650m in width. Beyond this the reef slope drops steeply to a depth of 5 - 12m to reach a gently inclined sandy bottom, which extends offshore for up to 1km before reaching a depth of 100m. and more. In the shallower parts of these sandy areas numerous coral knolls and coral heads are interspersed with extensive seagrass beds. Dominant corals include various species of *Porites*, *Acropora* and *Stylophora*. while the seagrass areas are dominated by *Halophila stipulacea*, and also *Halophila ovalis*, *Halodule uninervis* and *Cymodocea rotundata*.

In some places however the reef structure is more irregular and interrupted by small sharms (embayments) and reef top pools and lagoons ranging from 10 - 100m in diameter and 0.5 to 10m in depth. These sharms and pools are mostly located opposite or near Wadi (usually dry stream bed) outlets on the alluvial fans of Wadi Kid and Wadi Addawy, presumably since the very occasional flood water discharge tends to inhibit coral and reef growth. The fishing effort tends to be focused on these sharms and pools across which gill and other nets can be set. These areas are also the ones in which thickets of mangrove *A. marina* tend to fringe the shoreline.

Habitat Characterisation

Reef morphology as well as different habitat parameters (e.g. coral and other substrate cover) were recorded for all studied sites using a standardised approach on pre-printed site characterisation form. Analysis of this data allowed the sites to be clustered into three major groups representing different sub-types of fringing, or fringing like, reefs. These were:

Reef type I *(Fringing reefs with broad flats and intermixed habitats)*

Most of the study sites (>75%) at Nabq are characterised by a fringing reef with a broad reef flat on which scattered small lagoons, reef pools and sea-grass beds occur. The dissimilarities of species abundance due to site characteristics were thus minimised by separating these sites into one group that is separately treated for statistical analysis.

Reef type II *(Fringing reefs with drop-off)*

These are sites characterised by a narrow reef flat leading to a continuous reef edge that gives onto a steep reef slope (or drop-off) falling away to some depth; these sites are thus close to deep water and also exposed to strong tidal currents.

Reef type III *(Flood drainage embayments)*

These are sites (for example Nakhlet Al Tal, and the Nabq Checkpoint) characterised by a broken discontinuous fringing reef formation often composed of coral knolls and gullies aligned north-east, into the direction of the prevailing wind. The intervening areas of sandy reef slope are typically covered with extensive seagrass beds and areas of dense coral patches.

5.3.2. Methods

(i) Records of fishing effort:

Data on fishing activity and effort were collected between January 1995 and May 1997 by systematically patrolling along the shore on a number of days in each week. Fishing activities was normally indicated by the presence of a typical pick-up vehicle containing fishing equipment and parked on the shore next to a likely access point to the reef, usually opposite an inlet or lagoonal pool where conditions are suitable for setting nets. Where possible fishermen were approached and interviewed about their prospective fishing effort, and in addition or alternatively fishing activity was determined by direct observation. In addition, on a randomly selected proportion of occasions, fishermen were accompanied (and if appropriate assisted) while they are actually fishing. Data that were recorded included the number (and, when possible, names) of fishermen, for nets: number of nets used, the size of each net, and the actual soak time; and for hand-lining: the number of lines and the time spent fishing. Collection of data was aided by the use of pre-printed forms specifying the information required (figure 1).

Two months into monitoring survey, a young local Bedouin fisherman was trained to assist by regular collection of effort data. Thus it was possible to record effort on 15 or more days per month throughout the year. The data recording forms were also distributed to several other local fishermen who expressed willingness to record their own fishing effort. Of these three returned completed forms regularly. While this data could not be used to assess total fishing effort, it was nevertheless helpful in confirming records and in illustrating the pattern of fishing of at least some individuals. The accuracy of the records collected by this assistant was from time to time confirmed by later interview with the fishermen concerned. The reasonableness of the effort data and other information was also checked by extensive discussion with some of the fishermen. In general, the close working relationship with the fishing community that was established has been found invaluable for the success of this study.

Several forms of fishing were observed as follows:

1. Drive gill netting

Gill nets were set within pools or across the entrance to sharms, typically when numbers of fish were observed, and the fish encouraged towards the net by the fishermen walking through the pool, or enclosing the location with additional nets.

2. Overnight trammel net sets

Trammel nets (a special type of gill net) were set overnight, typically across the entrance to lagoons and reef pools, and the catch collected the following morning. When this type of gear was used, the soak time was adjusted to reflect the effective fishing time of the net, which occurs on the ebb tide when fish on the reef top try to return to the reef slope.

3. Hook and line fishing

Hook and line fishing was observed to occur at a larger number and wider range of locations. In fact hand-lining could be used anywhere along the fringing reef edge or in the deeper reef top lagoons, as well as off the reef front from small dories in calm weather.

Fishing effort form Nabq fishery survey TMRU							Nabq Protected Area Gulf of Aqaba Protectorates EEAA
Observer name:							
Date:							
fihsermen number	**site name**	**gear type**				**soak time**	
		gill	**trammel**	**line**	**other**	**From**	**to**

Figure 1. Pre-printed form used for the recording of fishing effort data by community Rangers and the author in the Nabq Protected Area. Gear type and sites were marked as numbers representing the number of nets, fishing lines and the code of fishing site respectively. (Original in arabic)

(ii) Underwater visual census (UVC)

1. Field surveys

The sites that were surveyed in August 1995 (see chapter 4) using UVC were re-censused during August 1996 to test for possible changes in species abundance, biomass and mean fish length in relation to changes in fishing effort. The UVC method employed and the species censused are described in chapter 4. Identification of species was checked by reference to quality identification texts (Lieske & Myers, 1994; Randall, 1986)

2. UVC accuracy and bias

Data on predator fish species were collected in both 1995 and 1996 by the author. Data on herbivorous species were collected by trained volunteers who differed between the two years. The overall lengths of each individual predator fish were estimated to the nearest 5 or 10cm depending on size of species. However, it was not practicable to do this for the herbivorous species, because a) the volunteer observers were insufficiently experienced, b) individuals of most species (apart from small juveniles) did not differ obviously in length, and c) many of the herbivorous species (e.g. *A. nigrofuscus, A. sohal, S. sordidus*) were so abundant that it was not possible for any observer to do more than record their abundance.

Training to improve accuracy of underwater estimation of fish length was undertaken during August 1995 and again during July 1996 prior to the start of each survey using the method described by Bell *et al.* (1983). Different length PVC pipes were placed underwater and their lengths estimated by eye, and the results checked for error and bias. In addition, length estimates of less mobile live fish (e.g. *C. miniata, M. grandoculis* and *P. gaterinus*) was made underwater at distances of 2, 4 and 6 m, and then checked directly by approaching the fish to as near as 0.5m and holding a pre-scaled plastic slate next to the fish to check the actual size.

By comparing data obtained by different observers at the same time over the same transects differences in observer catchability could be determined. The catchability coefficient as applied to observers detecting fish is effectively the probability that the observer will record any fish of a given species encountered during the UVC of a specific transect. The catchability coefficient for each diver was calculated in relation to the abundance estimates made by the most experienced observer (the author). Subsequently different species were counted exclusively by each observer (diver), and their counts subsequently adjusted in the light of the previously determined catchability coefficient.

3. Estimation of standing stock biomass

The total biomass for each species was estimated by conversion from length estimates using L - W relationship equations for the same geographical region published in the literature or obtained from locally collected fisheries statistics (Table 1). The L-W relationship constants for most species were obtained by reference to the Fishbase database (available on CD-ROM) developed by ICLARM (The International Center for Living Aquatic Resources Management) (Pauly & Froese, 1991). The obtained weights of each species were pooled to estimate specific stock biomass at each transect.

5.4. RESULTS

5.4.1. Fishing Gear and Practice

Three artisanal fishing methods were observed to be employed by the local Bedouin fishermen:

1. Gill netting

Gill nets were set during the day on the back reef. Typically fishermen would then herd fish towards the net, following which the prospective catch was entrapped by bringing in the ends of the net in a semicircular fashion. This method principally targeted herbivorous species (see chapter 6 for species list) that enter the reef flat zone with the rising tides in order to feed on macroalgae and algal turf. The use of gill nets in this way is essentially similar to the use of "drive nets" on the reef platform as described by Ruddle (1996). Approximately 46% of the fishing trips at Nabq used this method. Typical net size was recorded to range between 18 - 25m in length and 1.4 - 1.8m depth.

2. Trammel netting

Trammel nets, which are effectively a special type of gill net, consist of smaller mesh panels hanging loosely from larger mesh panels. Typical net size was 18 - 25m length and 1.4 - 1.8m depth. They were widely used, being set at high tide across entrances to reef flat passages and lagoons to catch fish returning to deeper water for periods of low tide. The nets are anchored to the bottom and left overnight, the catch being collected the following morning. Such overnight use of nets is usually however dependent on lunar phase so that the right tidal conditions occur at the right time of day. Trammel nets accounted for 32% of all fishing trips recorded during the study.

Species	increment scale	number of size classes	a	b
C. miniata	10	5	0.0655	2.76
C. hemistiktos	10	4	0.0455	2.76
C. argus	10	5	0.0155	3.02
E. fasciatus	10	4	0.0322	2.87
E. tauvina	20	4	0.0228	3.02
V. louti	20	4	0.0134	3.04
L. mahsena	20	4	0.0161	2.97
L. nebulosus	20	4	0.0161	2.97
L. obsoletus	10	4	0.0429	2.84
M. grandoculis	10	5	0.0259	2.99
L. monostigma	10	4	0.0275	2.94
L. ehrenbergi	10	4	0.0275	2.94
L. bohar	20	5	0.0175	3.02
M. niger	10	5	0.0175	3.02
P. gaterinus	10	5	0.0259	3.01
C. viridescens	-	-	0.0233	2.98
C. bicolor	-	-	0.0333	2.98
H. harid	-	-	0.0233	2.98
S. ghobban	-	-	0.0141	3.06
S. sordidus	-	-	0.0127	3.14
S. fuscopurpureus	-	-	0.0435	2.87
S. niger	-	-	0.0122	3.17
S. gibbus	-	-	0.0388	2.90
S. frenatus	-	-	0.0233	2.98
S. ferrugineus	-	-	0.0233	2.98
S. collana	-	-	0.0122	3.17
S. psittacus	-	-	0.0114	3.16
A. gahhm	-	-	0.0199	3.05
A. nigrofuscus	-	-	0.0440	2.81
A. sohal	-	-	0.0192	3.07
C. striatus	-	-	0.0210	3.04
N. lituratus	-	-	0.0497	2.84
Z. desjardini	-	-	0.0471	2.86
Z. xanthurum	-	-	0.0129	3.29
S. argenteus	-	-	0.0250	2.88
S. luridus	-	-	0.0158	3.01
S. rivulatus	-	-	0.0120	3.01
S. stellatus	-	-	0.0286	2.95

Table 1. Length - weight relationship equation constants for different species obtained from published studies (see text). Also shown is the length increment scale (cm) used during UVC between different size classes for piscivore species.

3. Hook and hand-line

Hand-line fishing is used much less (22%) than the other two methods. Hand-lining was usually employed in deeper lagoons and reef-pools on the back reef, off the reef edge or from small wooden canoes known as hassakas. Typically these are pulled over the reef at high tide and then anchored in place for fishing off the reef slope at lower tides. A single baited hook is attached to a short line, which is usually held by hand. It was observed that this method is highly selective for larger, predatory fish species (see species list in chapter 6).

Fishing trips typically involved a group of 2-3 fishermen, although sometimes a single fisherman might fish on his own or with the assistance of young boys. Most groups of fishermen use two or three types of gear during the same season, and even during the same diel period. The gear used depends on atmospheric and oceanographic conditions, tidal patterns, and the relative needs of the fishermen to meet the subsistence requirements of their families or to generate income. The number of nets used on a fishing trip ranged between 1 and 5 with a mean of 1.7 +/- 0.23 (S.E) over all recorded fishing. Local fishermen resident at Nabq accounted for 56% of total fishing effort, while fishermen from neighbouring towns and areas (Dahab, Abu Galloum, Sharm El Sheikh) visiting the area on short fishing trips (2-3 days) accounted for the remaining 44% of fishing effort.

5.4.2. Temporal patterns of fishing effort

The mean daily effort for each season over 1995 / 1996 is shown in figure 2. Significant variation was detected between different months of the year (Kruskal -Wallis test, $\chi^2 = 23.8$, $P < 0.005$). Also when the records for each season were pooled, it was evident (figure 2) that there is considerable variation in effort between seasons. This variation principally reflects seasonal differences in the frequency of favourable weather conditions, socio-economic factors and occurrence of local fish aggregations. The lowest levels of effort were found to occur during the winter months of November and December when the prevailing north wind is strongest generating rough waves and surf. Also interviews with the fishermen showed that in addition to weather conditions, social responsibilities (e.g. proximity of schools and tourism related occupations) during this period contributes to the reduction in mean daily fishing effort. During the spring season the fishing effort was recorded to significantly increase and onwards until the end of the summer season (figure 2).

When the temporal pattern of variation in mean daily fishing effort was compared to the following year, the same pattern was obtained and there seemed to be a regular preference of the fishermen to undertake the fishing activity within spring and summer months rather than autumn and winter.

5.4.3. Spatial variation of mean daily effort

Different species were commonly targeted by fishing using either gill netting or hook and lining (see chapter 6). Further, each of these gear types is used to exploit different zones of the reef. Thus, the mean effort for each gear type was treated separately for the investigation of the effects of increase in fishing pressure upon stock biomass and population size.

Although the local fishing community prefer to exploit fishing sites simultaneously, ease of access and other favourable habitat characteristics led to a marked variation in the fishing effort at different sites during the study period. This variation in the extent of fishing effort between different sites could be attributed to proximity to permanent fishermen villages and camps as in Ghargana, Manquatta and Nabq Checkpoint. This eliminates the need for transport that is required to fish more distant sites along the coast. Also, sites that are characterised by wide reef flats reaching 500m which have large reef pools and lagoons with passages to the reef face (e.g. Lighthouse, Al Kottayeb, north Nabq Checkpoint and south Ghargana) attracted higher levels of fishing effort. To a lesser extent, fishermen use hook and line-fishing gear, typically at sites, which are characterised by narrow reef flats, which notably attracted more fishing activity. This is preferable by fishermen for ease of access to reach the reef edge (e.g. Al Goz, N. Manquatta, Ras Atantour, and Wadi Kabila) and exploit the reef slope and reef face zones. Further, deeper reef lagoons (>5m) are also exploited by hook and line targeting predatory species that enter the lagoon area at high tides and could stay within the lagoons and reef pools at times of low tide for feeding upon the benthic fauna of crustaceans and invertebrates (Salem, 1997, pers. comm.).

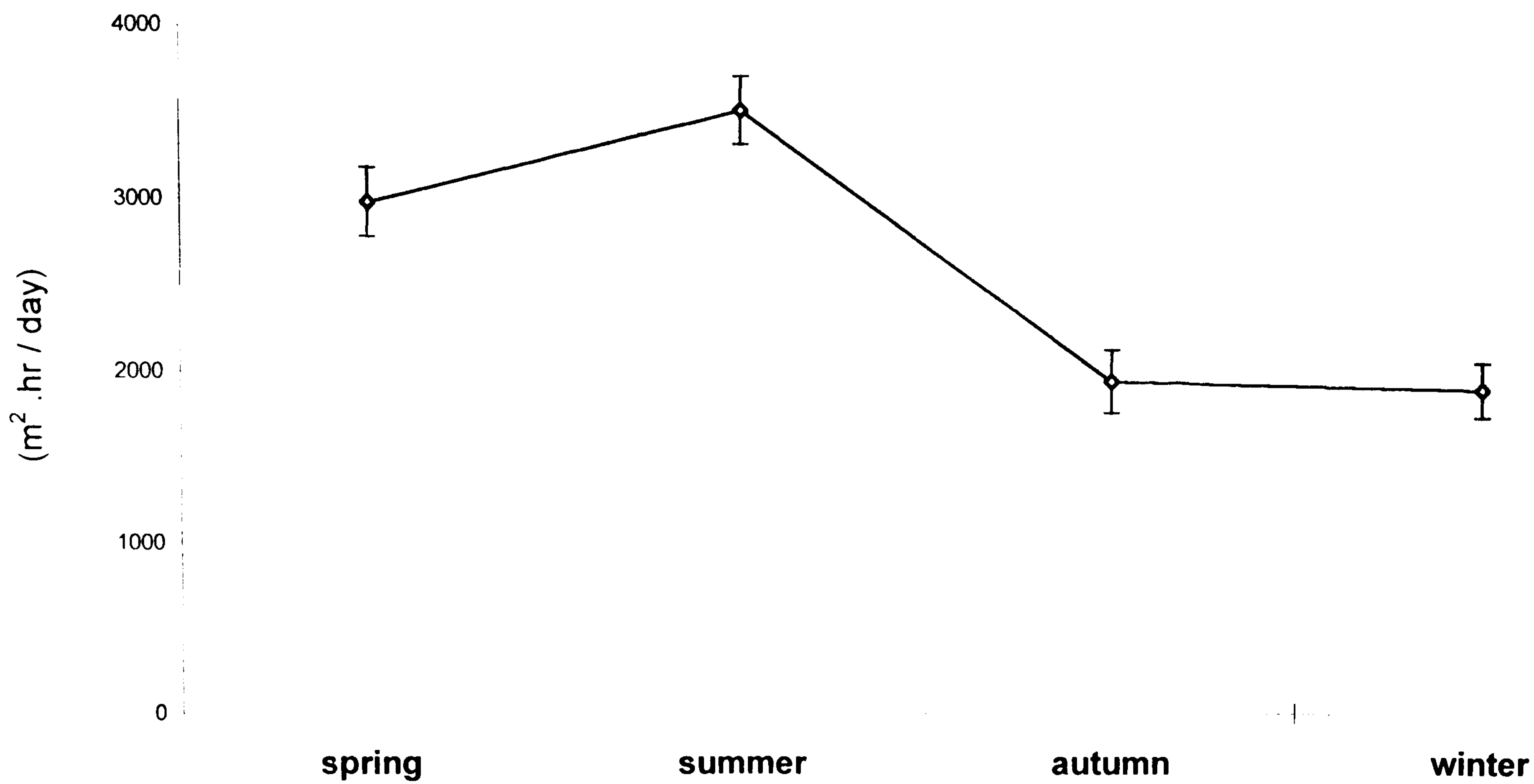

Figure 2. Mean daily effort is expressed as the mean net area in m^2 x the soak time in hours. Variation of effort within groups (seasons) was not statistically significant. Error bars represent the standard error of the mean.
Spring represents the months March, April and May; summer represents June, July, and August; autumn represents September

5.4.4. Effect of increasing fishing effort on biomass

Hook and line:

The total biomass at different effort levels of commercially targeted species that were the most common in the catches from the hook and line fishery are shown in figures 3, 4 and 5. Species that had a significant decrease (Willcoxons signed ranks test) in biomass with the increase in fishing effort using hook and line included *L.bohar, C. miniata and V. louti.* Further, an apparent reduction of the biomass of the species *M. grandoculus, L. ehrenbergi, P. gaterinus, C. hemistiktos, C. argus* was detected, although this was not statistically significant.

There was no significant effect for the increase of hook and line fishing activity upon the biomass of herbivorous species that were included in this study. This was to be expected as these herbivore species were not likely to be targeted using hook and line at all, although they were caught using gill nets.

Gill nets:

The resultant effects of gill net fishing upon commercially targeted herbivorous reef fishes appear to be relatively diverse at the species level. Six species had a significant increase in biomass at medium and highly used sites. These differences could be attributed to site characteristics, bias of counts between sites due to foraging and dial migration patterns as well as the direct and indirect effects of the gill net reef fishery. These species include; *Acanthurus nigrofuscus, Acanthurus sohal, Scarus frenatus, Scarus niger, Scarus psittacus and Siganus rivulatus* (Kruskal-Wallis test, significance of $P < 0.05$ for all species respectively).

Only one species showed a significant decrease in biomass with the increase in the intensity of fishing activities (figure 5b). This species, *Scarus ferrugineus*, was also found to represent a considerable percentage of the catches (see chapter 6) from the gill net fishery over the reef flat.

5.4.5. Effect of increasing fishing effort on mean size

The mean population length of all commercially targeted fish species was calculated at different levels of fishing effort. Figures (6,7 and 8) show the variation in mean length against different fishing effort levels (table 2) using each of gill nets and hook and line gear types separately. Piscivorous species that showed a reduction of mean population length at sites exposed to increasing fishing effort using hook and line is shown in figures 6,7 and 8.

Hook and line:

A significant decrease of biomass was detected for *C. miniata* and *V. louti* (Kruskal-Wallis test, $P < 0.05$ for both species) in relation to sites that are exposed to high levels of line fishing effort. *C. miniata* had a significantly higher abundance (see chapter 4) and biomass (figure 4) at the deeper zones of the reef slope where they are targeted by fishermen using hook and line. Likewise, the mean population length of the species at heavily fished sites, where effort would eventually exceed 20 fishing trips week, was significantly reduced (figure 8). Further, it was also concluded from the catch statistics (see chapter 6), that larger individuals of *C. miniata* were exploited by the hook and line fishery. Likewise, another serranid species, *V. louti*, was targeted by the fishery and had a significant reduction in mean population length at sites that are exposed to heavy fishing pressure (figure 6). *V. louti* had their highest abundances at deeper reef slope areas where they are constantly mobile during the day. Further, the sites which were exposed to heavy fishing pressure using hook and line experienced a dramatic decrease in the abundance of *V. louti* (see chapter 4). In Manquatta and Abo Negailla, for example, only one individual fish of the species was found along a 200m transect at the reef crest and down to a depth of 20m.

Moreover, a considerable reduction in mean population length was also observed for *L. mahsena*, *C. argus*, *P. gaterinus*, *C. hemistiktos* (figures 6,7 and 8) though these decreases were not statistically significant in relation to increasing fishing activity using

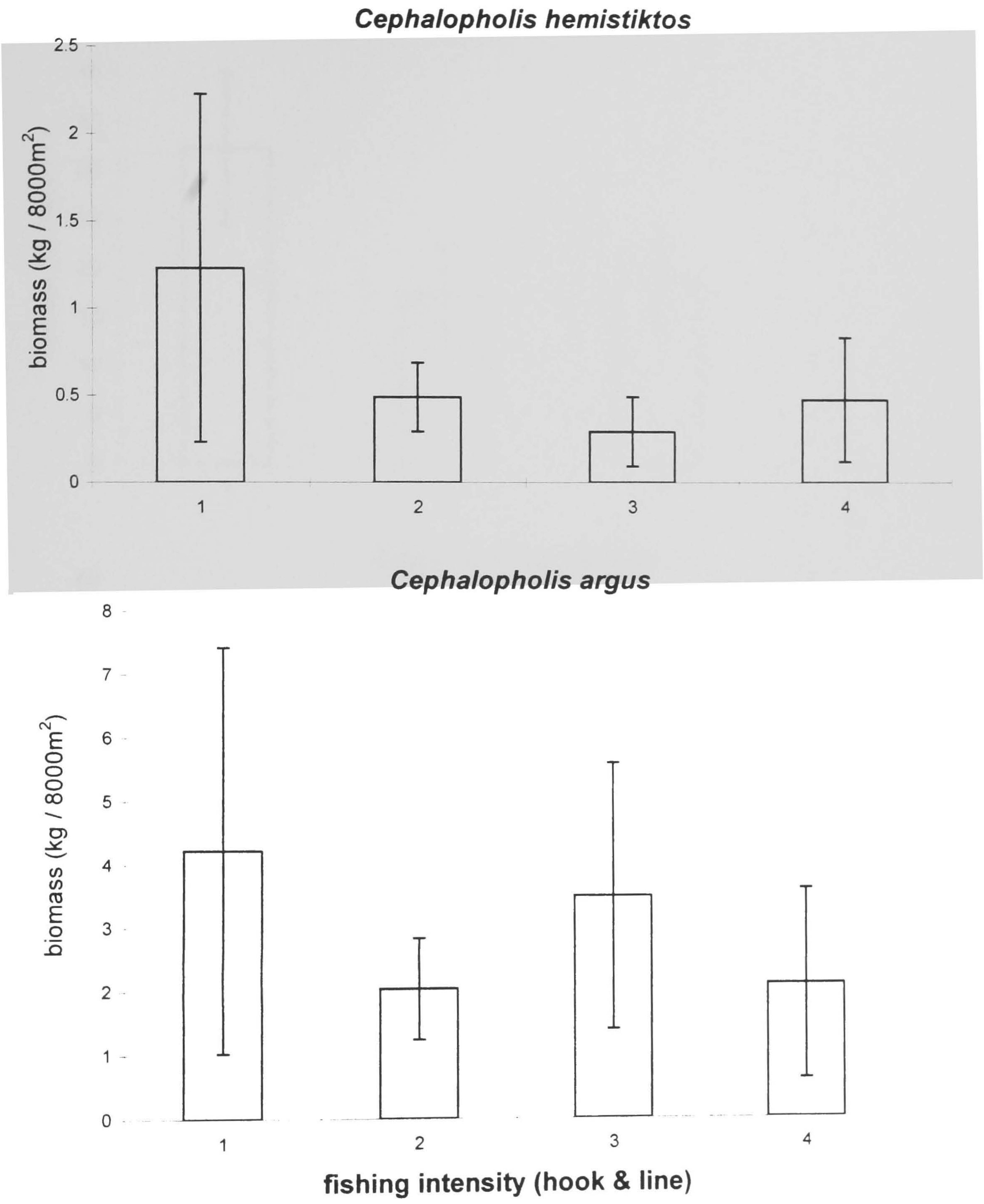

Figure 3. The variation between the biomass of two serranid species in relation to the increase of fishing effort by the use of hook and line gear type. Biomass also varied between sites that are exposed to similar fishing intensity. Error bars represent standard error of the mean.

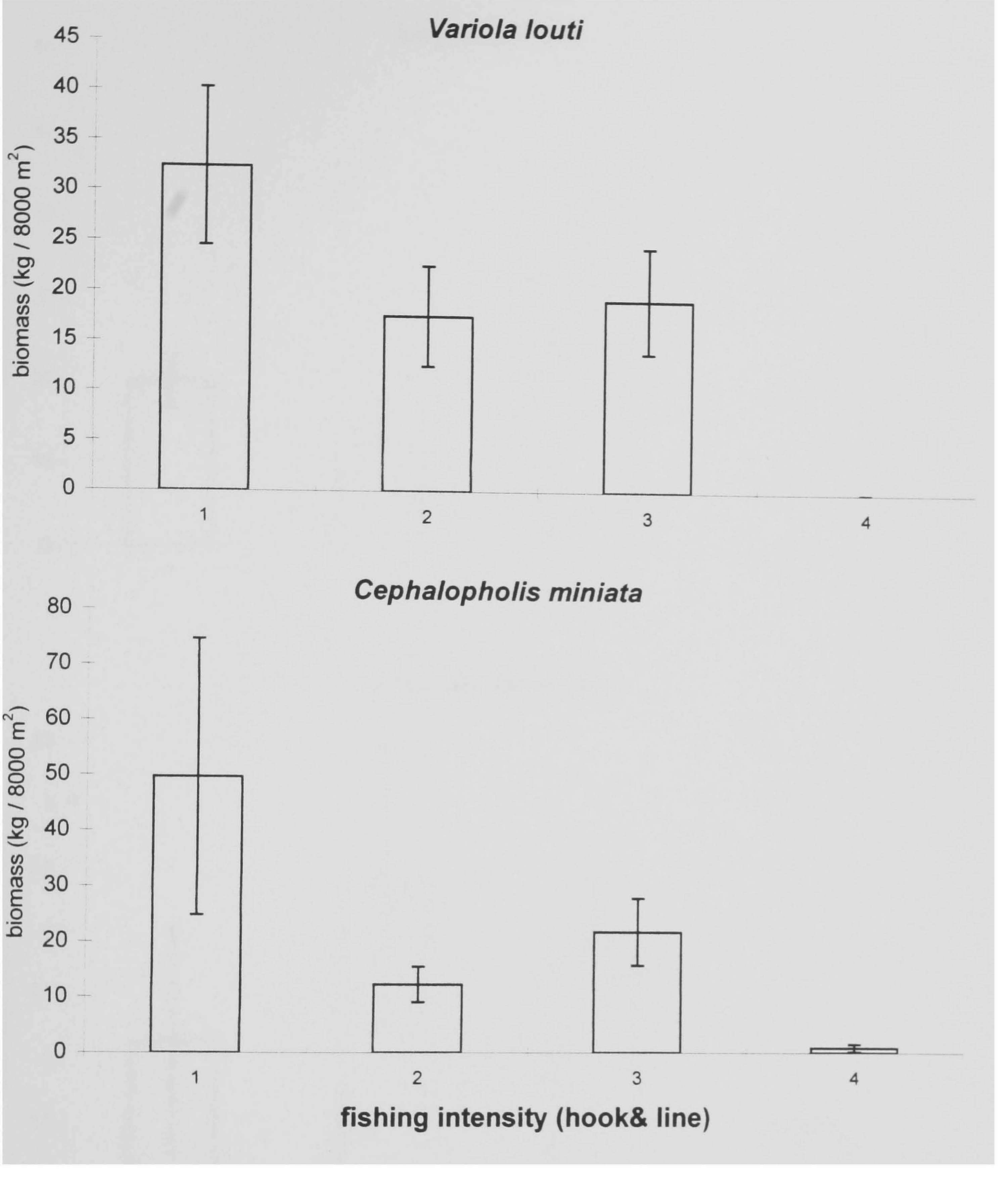

Figure 4. Variation in standing biomass of commercially targeted species in relation to the increase of fishing effort level using hook and line gear type. Error bars represent standard error of the mean.

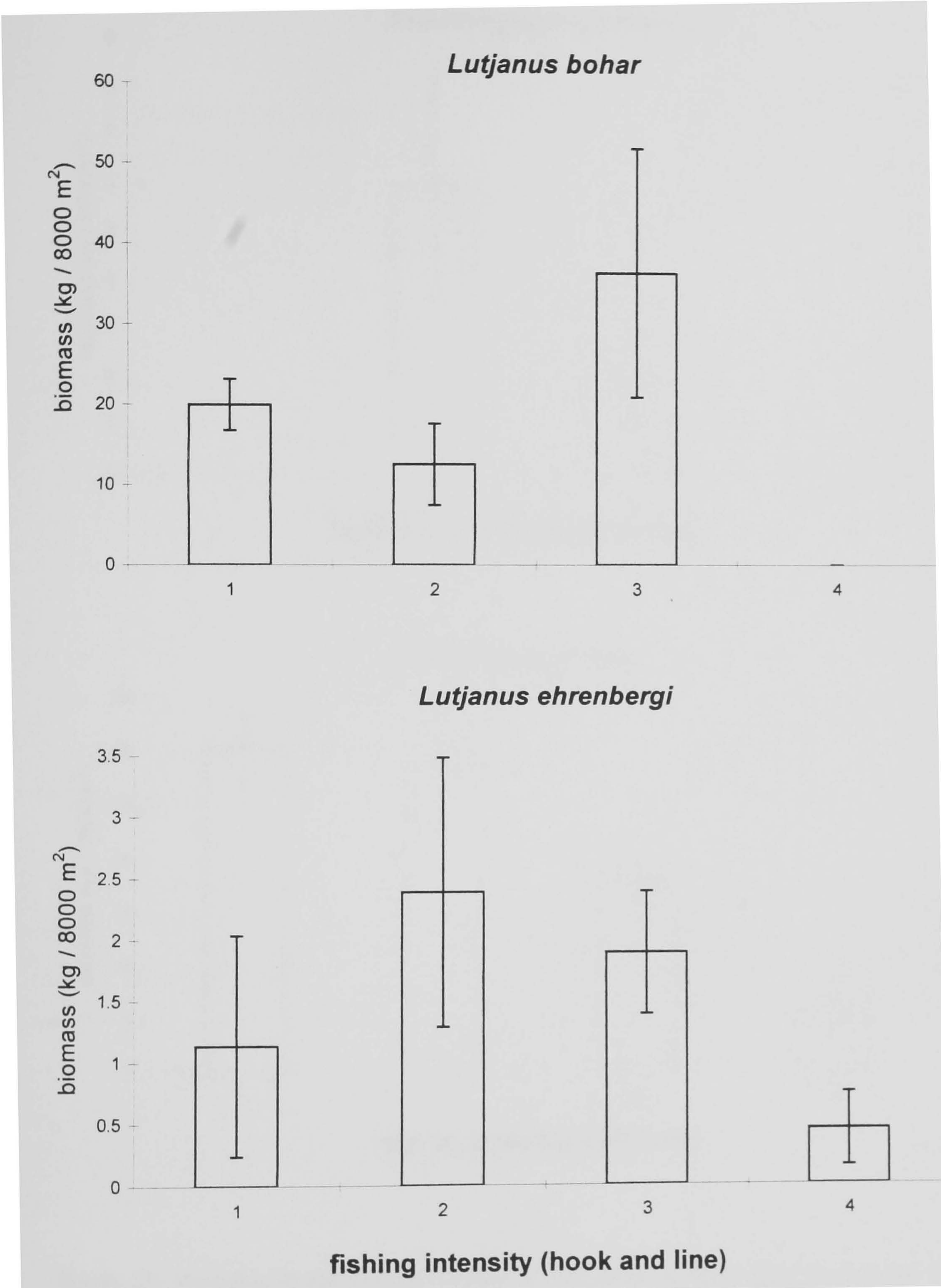

Figure 5. Variation in biomass of commercially targeted species by hook and line gear type in relation to increasing fishing effort at different sites. Error bars represent standard error of the mean.

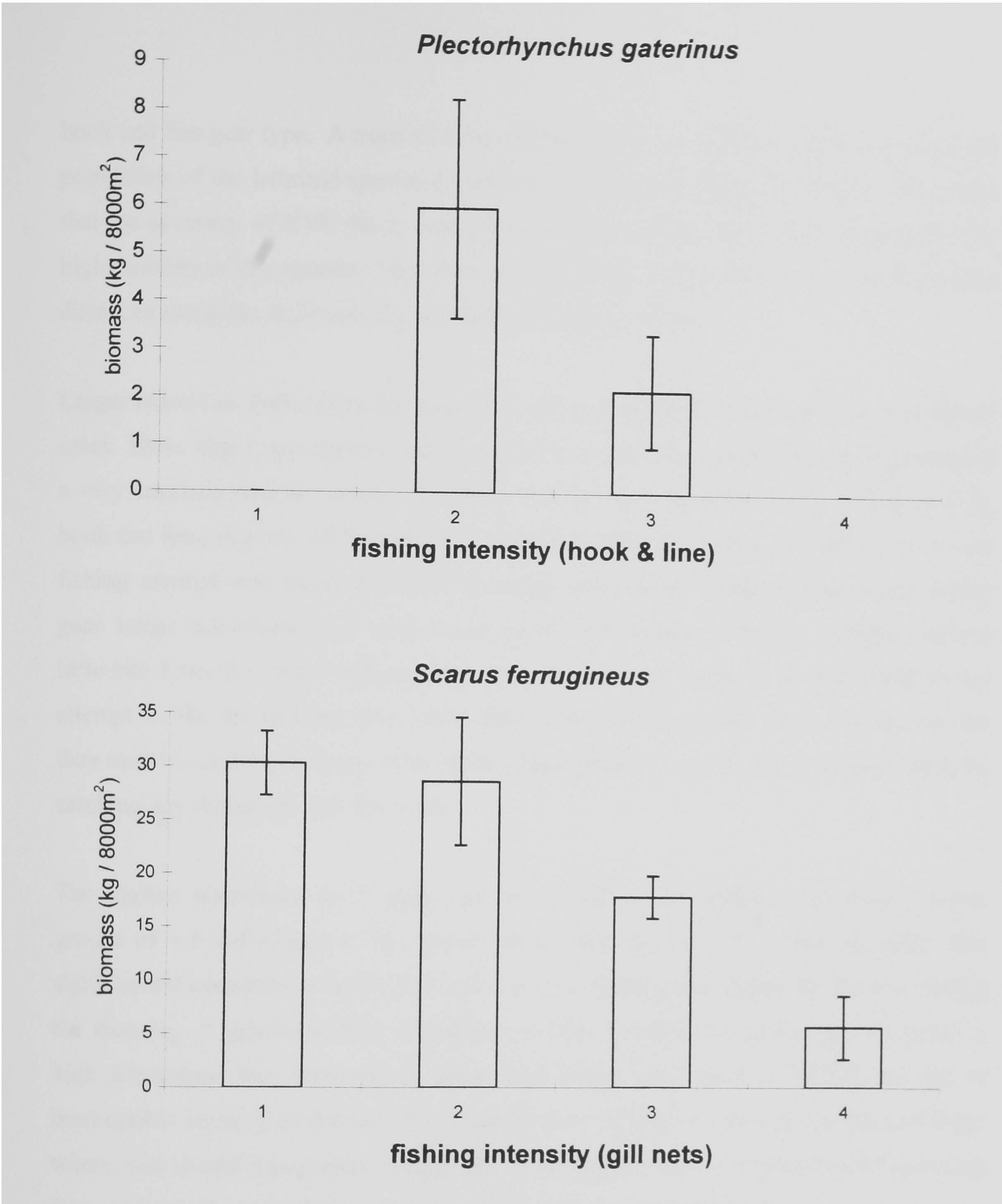

Figure 5b. Variation in standing biomass of *P. gaterinus* in relation to the increase of fishing effort level using hook and line. The effect of increasing fishing pressure upon the biomass of the herbivore *S. ferrugenius* by using gill nets is shown. Error bars represent the standard error of the mean.

hook and line gear type. A trend of a considerable removal of larger individuals from the population of the lethrinid species *L. mahsena* is apparent (figure 7). It should be noted that the accuracy of UVC for *L. mahsena* could be considerably biased based upon the high mobility of this species. They were also observed, during diving, to cover horizontal distances along the reef slope that extends well beyond 500m.

Larger individual fishes from the species, *C. argus* were rarely recorded in heavily fished areas. These larger, and typically older, individuals were also observed to have developed a very cautious attitude towards the hook and line gear type at heavily fished sites by hook and lines (e.g. the reefs confronting Ghargana village). During one survey, an actual fishing attempt was monitored from a nearby underwater location using scuba diving gear. Large individuals of *C. argus* were observed to approach the bait carefully, take a little bite from the corner and go away, then another one would do the same and do not attempt to bite the bait and then leave. Interviews with fishermen have also shown that they used to catch more larger individuals of the species *C. argus*, but none have reported catching any during the last few years.

The highest abundance of *P. gaterinus* was found at the shallow reef slopes, where groups of 4-8 individuals of the species were observed by UVC. Their numbers have significantly decreased in heavily fished sites (e.g. Manquatta) (figure 4). Inactive during the morning, *P. gaterinus* hide in shallow crevices in the upper reef slope. However, a high abundance was observed at some sites which were heavily fished although at inaccessible sections of the reef. They mainly tend to hide in crevasses in the reef slope where, due to reef topographic complexity, it is normally hard for fishermen to access on foot, which is the typical way of access to the reef edge during low tides

Although, *L. nebulosus* is frequently caught using hook and line (see chapter 6), daily sustainability of the catch could never be predicted by fishermen due to the high mobility of the species. They have been reported to have seasonal migrations over large distances for spawning during spring and summer (Salem, 1997, pers. comm.) near Ras Mohammed that is located approximately 50 km towards the south of Nabq. During

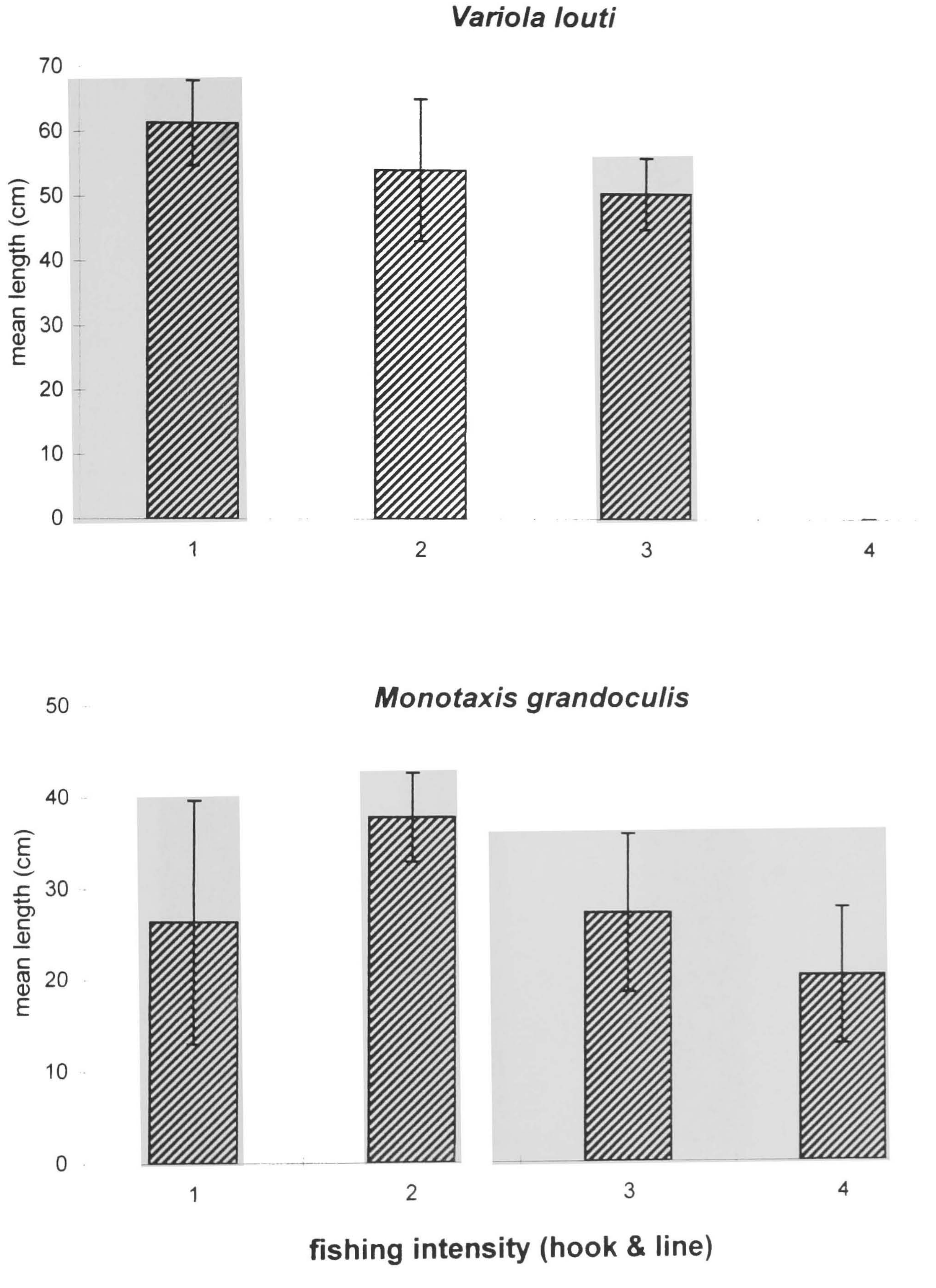

Figure 6. variation of mean population length of commercially targeted species between sites that are exposed to different fishing effort using hook and line gear type. Error bars represent standard error of the mean.

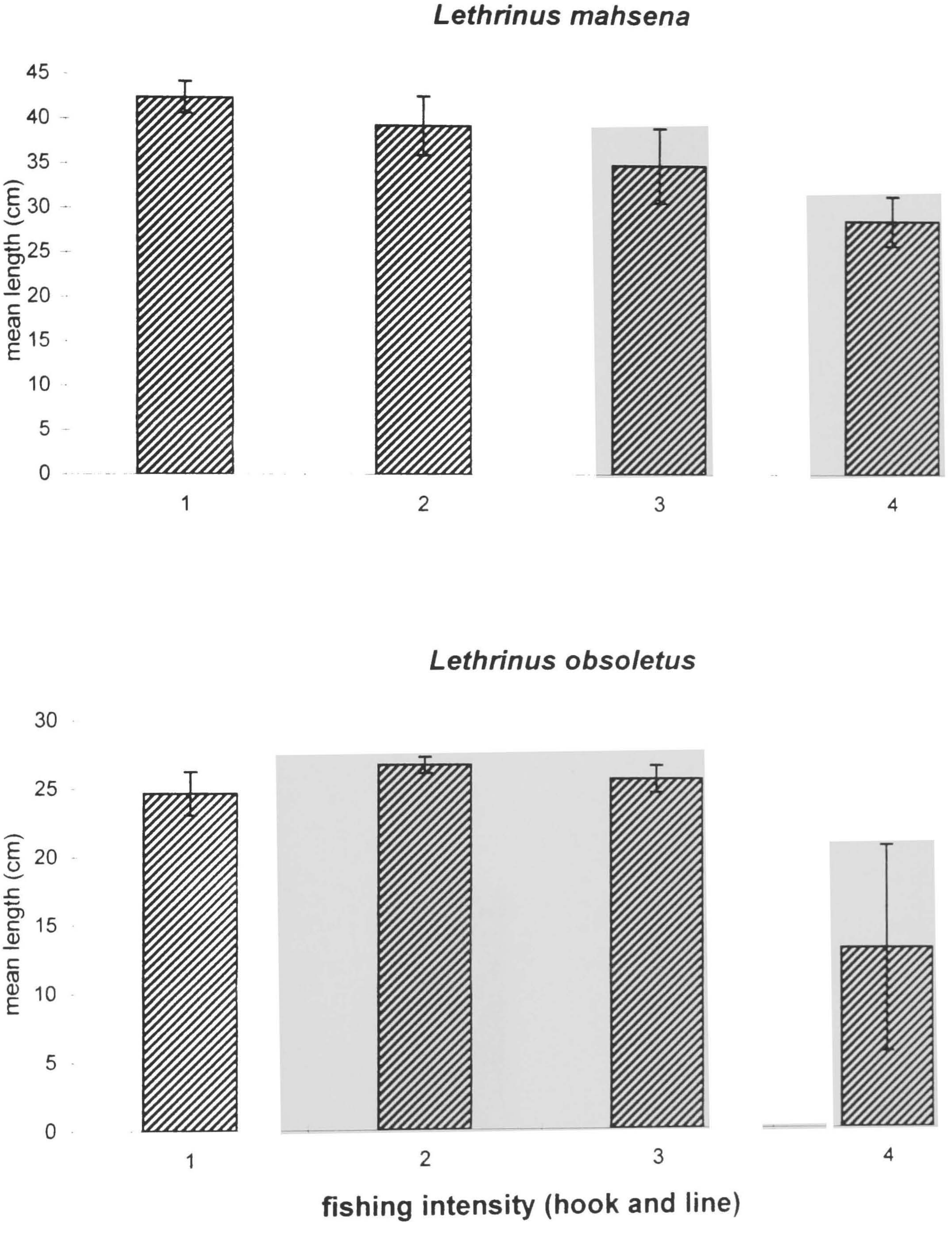

Figure 7. variation of mean population length of commercially targeted species between sites that are exposed to different fishing effort using hook and line gear type. Error bars represent standard error of the mean.

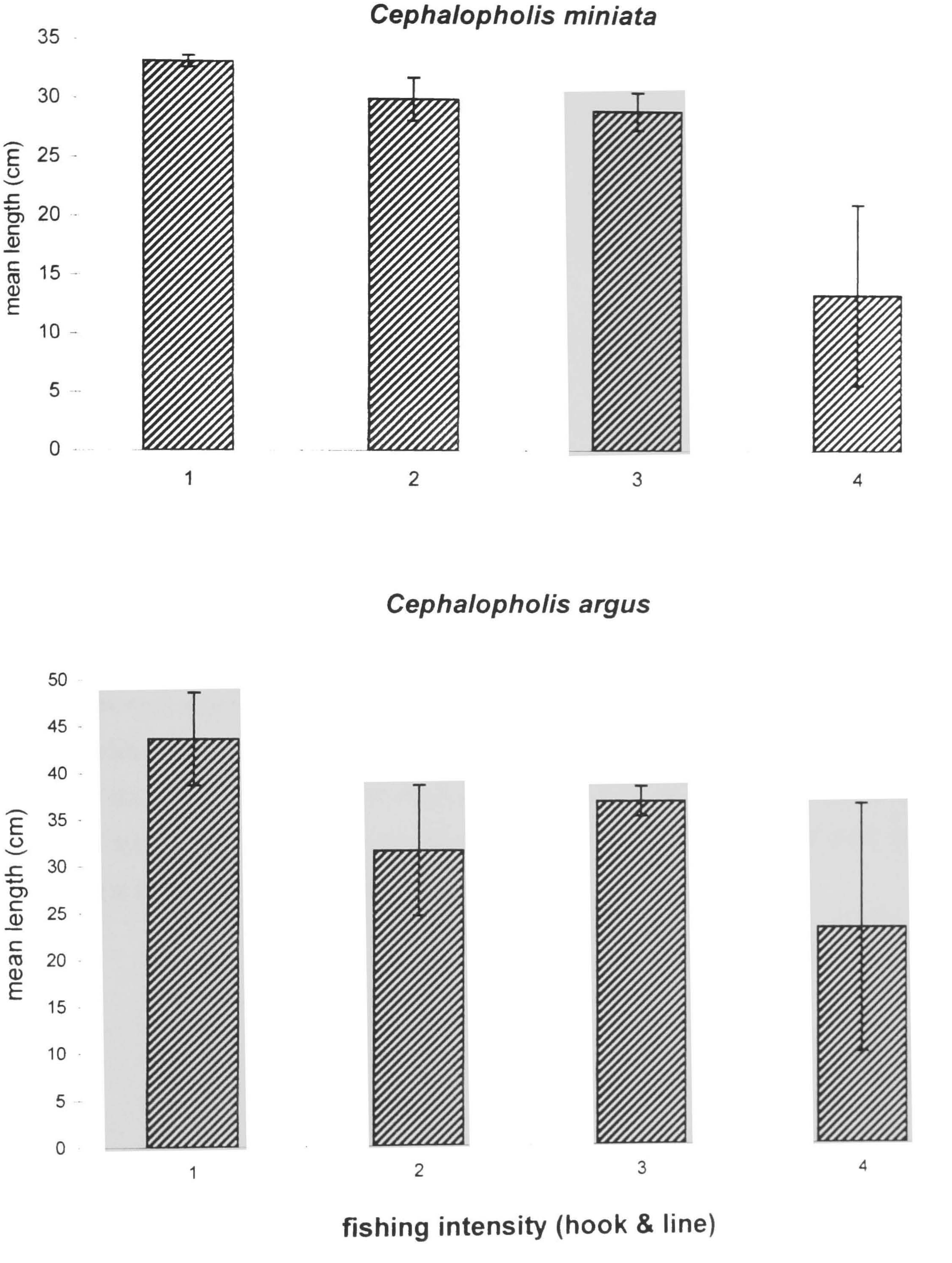

Figure 8. Variation of mean population length of commercially targeted species between sites that are exposed to different fishing effort using hook and line gear type. Error bars represent standard error of the mean.

underwater observations they were found to typically occur in shallow lagoons with sandy bottoms or also on sandy shallow expanses that could extend 500m offshore. However, they were always encountered in the vicinity of coral reefs. This mobile nature of the species together with the spawning migration makes it hard to assess the population biomass or size structure using the timed swim UVC technique. This will be discussed more specifically in the discussion to this chapter.

Length estimations for herbivorous species were not achievable accurately while swimming with a constant speed along a transect. This was due to the high mobility of almost all the herbivorous species that were included in this study as well as the very high abundance (exceeding 100 per 200 x 10m transect) for other species (e.g. *A. nigrofuscus*; *A. sohal*) especially over the reef flat when the tides are high.

Gill nets:

As observed from landings (see chapter 6) the gill net fishing gear typically targets herbivorous species that go over the reef flat and into the reef lagoons for feeding during high tides. A very small proportion of piscivorous species are caught by gill nets over the reef flat where they have been rarely observed by UVC as well. Influences of the gill net gear type upon the mean population lengths of piscivorous species were not significant in relationship to increasing fishing effort.

Fishing level	Category	Gill net effort	Hook and line effort
	Scale (1 - 4)	m^2.hr / day	Line.hr / month
Rarely fished	1	400 - 800	20 - 40
Lightly fished	2	800 - 1000	40 - 60
Moderately fished	3	1000 - 1200	60 - 80
Heavily fished	4	1200 - 1400	80 - 100

Table 2. There was no significant variation of the fishing effort within each category. Results were therefore pooled into four fishing levels for each gear type. The levels of effort using different gear types varied within sites, and were thus separated in the analysis.

5.5. DISCUSSION

At Nabq a reduction in abundance and biomass of commercially targeted species was detected at the most heavily exploited sites. The most noticeable effects appear to be on species belonging to the families Serranidae, Lethrinidae and Lutjanidae. For these families, increased fishing intensity was negatively correlated with population abundance and biomass. The changes in abundance and biomass that were apparent were comparable with those observed by Roberts & Polunin (1992) also in south Sinai, though in a study area centred slightly to the south. Such declines in abundance and biomass have also been recorded in studies in other regions by Bohnsack (1982), Russ (1984c), Ayling and Ayling (1986a), Polovina (1986), Alcala (1988), Samoilys (1988), Russ and Alcala (1989), Roberts and Polunin (1992), McClanahan (1994) and Watson and Ormond (1994). This in turn leads to a reduction in yield and catch per unit effort (see chapter 6) as discussed by Gulland (1979), Koslow *et al.* (1988), and Alcala and Russ (1990).

A significant decline in mean length of some piscivorous species, in particular *V. louti, C. miniata,* and *L. mahsena*, was also detected at sites that were heavily exploited by hook-and-line. This reflects the fact that this fishing method is highly selective for these larger predatory species which typically occur along the reef slope where this fishing method is employed. It is widely understood that increased fishing pressure tends to reduce mean individual size, both because it is the larger individuals which tend to be most easily caught, and because the removal of individuals prevents them from becoming larger. Such an effect has been reported by Bell (1983), Russ (1985), Ayling and Ayling (1986a), Alcala, (1988); Koslow *et al.* (1988), McClanahan and Muthiga (1988), Samoilys (1988), Polunin and Roberts (1993), Watson and Ormond (1994). The larger individuals also tend to be targeted by fishermen because of their greater market value. Their carnivorous feeding habits and aggressive nature make them relatively easy to catch under calm weather conditions.

The removal of larger individual fish is believed to influence the population dynamics of targeted stocks. Effects upon recruitment (Munro, 1983; Doherty and Williams, 1988a), mortality rates (Ralston, 1987; Russ and St. John, 1988), behavior, sex reversal and reproductive output (Bohnsack, 1990) have all been identified as inherent to increasing fisheries exploitation in reef areas. These effects have been reviewed in detail by Russ (1991) and Jennings and Lock (1996). Other indirect influences on community ecology occur, including effects upon assemblage structure (Russ, 1985; Koslow *et al.*, 1988).

For herbivorous species targeted by the Nabq fishery no significant decline in biomass was detected at sites that were heavily exploited either by gill net or by hook-and-line. The lack of effect of hook-and-line fishing was to be expected since these fish are not caught by this gear type, but the fact that sites exposed to heavy fishing pressure by gill nets did not experience significant reductions in biomass of herbivores is perhaps more surprising. In fact the surgeonfishes (Acanthuridae) showed a significantly greater biomass at heavily fished sites than at unfished ones. This could be attributed to reductions in the abundance of larger potential predatory species, as also proposed by McClanahan (1988) and Polovina (1984), both of whom have produced models which suggest that the removal of predators can cause an increase in the abundance of lower trophic level herbivores. Further, *Acanthurus nigrofuscus*, for example, is a common prey of groupers on reefs in the Gulf of Aqaba (Shpigel and Fishelson, 1991). An alternative interpretation is possible however; it may be that the fishermen principally target those reef flat sites that are known to have the highest abundances of surgeonfishes by using trammel and gill netting.

Habitat characteristics

Differences in fish population parameters at heavily fished sites could in principle be due to differences in reef character and habitat type, rather than to differences in fishing pressure. This could be relevant since, as described, fishing tends to be concentrated at particular locations where drive nets can be used or trammel nets most conveniently set, or access most easily obtained to the reef edge. A number of studies have found that the community structure and abundance of coral reef associated fish species are influenced by habitat type (McClanahan, 1994), reef complexity (Roberts and Ormond, 1987), and reef morphology and zonation (Bouchon-Navaro, 1981; Shpigel and Fishelson, 1991). Food resources will also be important; for example a recent study by Mazeroll and Montgomery (1995) showed that the abundance of *Acanthurus nigrofuscus* is influenced by the availability of their food resources, which in turn is dependent on the relative percentages or coral algal cover, and the extent of different reef zones.

Unquantified ecological processes, such as oceanographic processes and larval settlement and recruitment, may also be responsible for differences between sites, and have been suggested by McClanahan (1994) to account for approximately 75% of variation in fish populations. In addition the proximity of other habitats, for example mangrove stands, or sea-grass beds, could also influence fish species and abundance in the surrounding coral reef areas. For example the presence of mangroves could result in an increased input of nutrients to the reef environment, leading to an increase in the algal growth or increased abundance of detritivore invertebrates. Alternatively seagrass beds are known to be important as nursery grounds for some fish species; numbers of juveniles, e.g. of *Lethrinus mahsena* and *L. obsoletus*, were encountered during underwater counts using this habitat as a refuge, and this could result in more individuals entering the fishery at such sites. Thus the assumption underlying the present study that fringing reef sites throughout the Nabq protectorate have comparable habitats may be violated.

To attempt to allow for such factors comparisons were made undertaken between and within sites with different reef sub-types. Abundance and species composition of commercially targeted fish stocks did not appear to vary between or within reef sub-types except for type 2 reefs. These were the offshore reefs in the straits of Tiran, and the most northerly sites around Ras Atantour, both of which are characterised by being less turbid and closer to deep water, resulting in differences in reef form and coral assemblage. Here larger predatory species appeared notably more abundant. Roberts and Polunin (1992) similarly reported that larger piscivores seemed more abundant at these locations and attributed this to the proximity of deep water, and the location of these sites close to the convergence of currents flowing between the Gulf of Aqaba and the Red Sea proper. Because of this evident difference these sites were excluded from the statistical analysis.

In addition an effect of fishing effort upon biomass and population size of commercially targeted species was tested for using only type 1 reef sites (the commonest type of site) and following selection of replicate sites that represented different levels of fishing effort. This gave a significant result. A previous study to assess the effects of fishing effort on South Sinai reefs (Roberts and Polunin, 1992) was potentially flawed by the geographical separation of fished and unfished sites into largely separate regions (a form of pseudo-replication). In the present study this difficulty was avoided by selecting sites subject to contrasting fishing effort while they were spatially interspersed among each other along relatively homogenous fringing reefs at Nabq.

Other findings

The high mobility of some herbivorous surgeonfishes (especially *Acanthurus nigrofuscus* and *Ctenochaetus striatus*) that were observed to forage over broad areas of the reef certainly influenced the reliability of UVC on these species. The reef flat transects occupy less than 20% of the home range available to these species which appeared to migrate daily in groups between the reef face and foraging areas on the reef flat. Some scarids were also observed to join these movements. As a result, UVC data for these species were highly variable and could reflect bias related to reef flat form and extent. Elsewhere acanthurid species have been reported to show regular movements for foraging and perhaps spawning over distances of up to several km (Rakitin and Kramer, 1996; Russ and Alcala, 1989).

The commercially important species *L. nebulosus* may also be included among species, which can not be reliably assessed with the timed swim UVC technique. It appears that they may show daily foraging migrations of up to 3 km from roosting sites near reef slopes to offshore sandy seabed areas as well as reef -flat pools and lagoons. *L. nebulosus* also show annual spring migrations, possibly over large distances, to spawn at deep water sites such as Ras Mohammed and Tiran which are located approximately 50 and 25 km. to the south of Nabq. Thus overall abundances may be either over- or under-estimated, depending on whether populations are present in the area of the transect at the time when UVC is completed. The patterns of these daily and annual movements deserve further investigation in the future, perhaps by tagging experiments and capture-recapture methods.

The effects of these movements on the accuracy of stock estimates is supported by a recent study of Connell *et al.* (1998) who in a multispecies fishery compared estimates of relative species abundance obtained from CPUE data to those obtained by UVC. Multivariate analyses showed large differences between CPUE and UVC estimates, for which, when the data were further analysed, species of Acanthuridae and Scaridae were found to be principally responsible for this variation. This result highlights the point that the choice and use of particular methods for fish stock assessment requires careful consideration in relation to the nature of the habitat and the behaviour of the species being investigated. Many problems of sampling are specific to particular locations and species, and often fisheries investigations may benefit from adoption of a more pluralistic approach.

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CHAPTER 6

Determination of Optimal Fishing Effort in a Bedouin Coral Reef Fishery, at Nabq, South Sinai

PAGE

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6.1. ABSTRACT

The catch composition was recorded at each of the most commonly exploited sites within the Nabq Protected Area, Egyptian Red Sea. Mean catch composition was found not to vary significantly between principal landing sites. The principal families of fish caught (in term of weight) were parrotfishes (Scaridae), surgeonfishes (Acanthuridae), and rabbitfishes (Siganidae). Overall the highest proportion both by weight and by numbers were parrotfishes, which accounted for slightly more than 50% of total landings. There was significant variation in the mean catch per trip using different gear types, trammel nets (set overnight and collected the following morning) producing the highest catches per trip. By contrast, the highest mean CPUE was obtained using gill nets (1.48 kg / unit gear. hr.), markedly higher than that obtained using trammel nets (1.26 kg / unit gear. hr.). The relationship between CPUE and fishing intensity at different fishing sites showed that the mean catch per unit effort declined sharply from 1.3 - 2.7 kg / net.ha at lightly to moderately fished sites, to 0.6 - 1.8 kg / net.ha at those sites which were most heavily exploited. The total yield from each fishing site was found to range between 1.9 and 6.2 ton. kg^{-2} .yr^{-1}. The highest yields (greater than 5 ton. kg^{-2}. yr^{-1}) were obtained at three sites, Abu Negailla, Manquatta, and Ghargana, but these yields appeared to start to decline at sites exposed to annual fishing efforts exceeding 100 - 150 unit gear.kg^{-2}.yr^{-1}. A market survey showed that piscivore species were more highly valued than herbivores. Retail prices of fish of different families ranged between 3.5 (for Siganidae) and 8.5 (for Serranidae) EGL per kg.

6.2. INTRODUCTION

It is now being widely acknowledged that reef fisheries provide large local populations in much of the tropics not only with a major source of protein for fishermen and their families but as economic benefit realised through the sale of part or all of their catch as well (Dalzell and Wright, 1990, McManus, 1988; Salvat, 1992). Although the typical yield from coral reef fisheries under sustainable exploitation was initially estimated at 4 - 5 $t.km^{-2}.yr^{-1}$ (Stevenson and Marshall, 1974), more recently a wider range of figures have been suggested (Munro, 1977; Marten and Polovina, 1982; Alcala and Gomez, 1985). In some areas the range of yields obtained from some sites has been reported to reach much higher levels. In the islands of the western Pacific estimated yields range from 0.3 - 44 t. km^{-2} (Dalzell and Daboa, 1994; Wass, 1982) and in the Philippines from 5.2 - 36.9 t. km^{-2} (Alcala and Russ, 1990; Lopez, 1986). By contrast published yield estimates for the Red Sea have been low (Kedidi, 1984), not exceeding 1 t. km^{-2}, probably reflecting the intensity of fishing which until very recently has been fairly low through most of the region.

Currently however coral reef fisheries through most of the tropics are, it is widely acknowledged, being severely overexploited, despite the fact that most are artisanal and small scale. However, a wide range of fishing gear is used (nets, traps, hand-lining, etc.), including in many areas methods that are extremely destructive, not only of the fish stocks, but of the reef habitat that supports them. Also a large variety of species is principally available for exploitation, although the difficulty of managing these multi-gear multi-species fisheries, in which activity and landing sites are widely dispersed and hence difficult to monitor, is not well-known (Russ, 1991).

At Nabq, in the south-western Gulf of Aqaba, an artisanal, small-scale, reef fishery is conducted by Bedouins. The fishing grounds are directly accessed by foot or by the occasional use of small boats to reach the few offshore reefs including reefs in the Straits of Tiran and offshore patch reefs at Abu Negailla, Ghargana and Abo Zabad. The gear used are principally trammel nets and gill nets, although hand-lining from the reef edge or small boats is done occasionally. These gear types are widely used in small-scale artisanal fisheries in the tropics (Munro and Williams, 1985). However the reef areas used are now included within the boundaries of the Nabq Protectorate Area which is managed by the EEAA as a multiple-use management zone in which the traditional fishing by local Bedouins is permitted to a sustainable level. Thus, since the magnitude of the Nabq artisanal fishery had not previously been assessed, research directed at determining the sustainable levels of exploitation was initiated.

At Nabq fishing intensity is thought to have increased in the last few years due to the demand for larger fish from the rapidly increasing number of hotels and restaurants associated with the rapid development of international tourism to the area (Pearson, 1998). Some fishing sites were observed to be subject to higher levels of exploitation (see chapter 4), due either to their proximity to fishermen's villages and encampments, or to the morphology of the reef at those points which facilitated both access and setting of nets. Also the sizes and population structures of exploited fish stocks were found to vary between more exploited and less exploited sites (Chapter 5). The final stage of research was therefore to compare yields and catch per unit effort between sites, with a view to estimating optimal fishing effort and probable maximum sustainable yield. The results of this work are described here.

6.3. METHODS

Catch records from landing sites

Landing sites in the Nabq fishery were identified, during a preliminary survey in 1994, to be dispersed along 30 km of the Gulf of Aqaba coastline, from Ras Nasrani in the south to Ras Tantour in the north (figure 1). Some sections of the coast experienced minimal fishing activity (less than 3 days per month), usually because of factors such as hard accessibility or sever wave action. Because of their infrequent use these sites could not be effectively sampled. By contrast nine sites (figure 1) were regularly exploited by local fishermen, and many landings were recorded at these sites.

Overall, landings were sampled on a multiple stratified-random design, such that equal numbers of catches were sampled during different fishing seasons and at sites exposed to different levels of exploitation by fishermen. At the same time the frequency with which catches were landed during monitoring within different sub-areas (figure 1) was assumed to reflect the distribution of total catch between sub-areas.

In a minority of cases catches were recorded immediately after they were by the fishermen. But this was not always possible because of the occurrence of multiple landing sites, so that frequently simultaneous landings occurred at different sites. Thus more frequently fish were measured and weighed a little later (1-5 hours) by inspecting the catches that fishermen had stored inside iceboxes or domestic-size freezers.

For each catch that was monitored, the following were measured and recorded:

- Fork length of all fish in the catch.
- Total weight of catch, and, when possible, the weight of each species.
- The identity (i.e. species) of all fish, or where this was not practical, the genus.

Figure 1. The most commonly used access points to fishing grounds at the Nabq artisanal reef fishery. These are also the sites for landing of catches. The shown boundaries of Nabq Protected area extend further towards the northern and western directions.

- The fishing method used.
- Total number of nets, size of each net, and soak time.

Although most local fishermen supported this study and were helpful in providing information about soak or fishing time, many objected to the removal of fish from their iceboxes / freezers for individual weighing, once they had been chilled or frozen. This was because the frequent opening and closing of the icebox / freezer over an extended period of time resulted in melting of the ice and deterioration of the catch. Where only the length of each individual could be measured, the weight of each individual was estimated subsequently by reference to published length - weight relationships (Fishbase; Pauly & Froese, 1991) from the same geographic region. The validity of these relationships was checked by comparison with the length / weight measurements of individual fishes that could be obtained.

In addition to discussion with fishermen during the monitoring of catches, more formal meetings were conducted with many of them on order to gain general information about their fishing activities and methods, and in particular to determine which sites they most frequently used. Some of these fishermen were accompanied on fishing trips to check the validity of their accounts and to insure the catch could be monitored as it was landed. In addition groups of visiting fishermen were visited regularly to obtain information about their probable fishing site on the following day, which allowed us to be present when the catch was landed. This, as indicated, was very helpful, since it was by monitoring landings before the catch was stored in the freezer that the most complete data sets could be obtained.

In modern fisheries studies it has been accepted that if the quantity of fish that is discarded before landing is significant compared to the total catch, and the majority of these are dead when discarded, then it is essential to quantify the amounts concerned in order to determine the population dynamics of the species involved. However, at Nabq, fish are rarely discarded, and on the rare occasions when a non-desirable species is caught (e.g. Lionfish, *Pterois volitans;* stonefish, *Synanceia* spp.), usually by hook and line, it is normally released immediately and probably survives. Hence it was considered impractical to devote effort to quantify this loss during the present research. However, this should be investigated in future studies.

Market Surveys

A fish market survey was undertaken in June 1998 evaluate the prices offered to fishermen by traders for fish of different families. This involved meetings with a) direct mobile traders, b) local fish retailers, c) hotels (in nearby tourist resorts) that principally purchase fish from traders, and d) specialised fish restaurants. The market value for different fish species were recorded together with rough estimates of total monthly market demand. The seasonality of the apt increase in the supply of different fish species due, primarily, to spawning aggregations was also discussed. It should be noted that these consumers do not essentially depend on catches from the Nabq area. Fish is also supplied from other major fishing centres (e.g. Al-Tor and Suez) . The accuracy of the figures obtained was verified from the meetings with the local fishermen.

6.4. RESULTS

6.4.1. Catch composition

The catch composition for each of the most commonly used gear types is shown in table 1, as well as the mean catch composition across all sites from the Nabq fishery. The most commonly caught species from different fish families are listed in table 2. These species are principally present in those for landings from overnight trammel set nets. The same species were caught using the drive gill nets during the day, except for Lutjanidae and Belonidae, which were not recorded in any of these landings.

Mean catch composition was found not to vary significantly between the principal landing sites. It can be seen that the main families of fish caught in terms of weight for all landings were, in order, parrotfishes (Scaridae), surgeonfishes (Acanthuridae), rabbitfishes (Siganidae) and emperors (Lethrinidae). Other families that represented more than 2% of the catch are shown in figures 2a & 2b.

By-catch from the gill and trammel net gear was usually dumped after the catch had been landed and sorted. However, less than 2% of the total catches are dumped for not being edible. These included species from the families Chaetodontidae, Pomacanthidae, Carcharhinidae, Ostraciidae, Tetraodontidae and Diodontidae.

By contrast the species caught by hook and line (table 2), which accounted for the least percentage of total effort in the fishery, were dominated by predatory species that belong to the families Serranidae, Lethrinidae and Lutjanidae (table 1). These highly valued species were targeted typically along the reef edge only when the weather conditions allowed. In addition fishermen reported catching species of Holocentridae, Belonidae, Carangidae, Haemulidae, and Sparidae by these methods, although they were not present in the sampled landings. By-catch caught using hook-and-line gear at Nabq was usually released while alive and included such species as lionfish (*Pterois volitans*), triggerfish (*Balistapus* spp.) and Grey moray (*Sideria grisea*).

Overall, the highest proportion both by weight and abundance of the catch consisted of species of parrotfish (Scaridae). These accounted for slightly more than 50% of the total landings. They were more abundant in catches from trammel nets (69 %) that were set overnight, than from drive gill nets used during the morning (31%). Species of surgeonfish (Acanthuridae) were also dominant in many catches obtained both by gill and trammel nets. Of these, *Acanthurus nigrofuscus* was the most common of the seven species recorded. They were mainly caught during the day by fishermen using drive gill nets wading over the reef flat for 1-3 hours. Surgeonfishes were mostly consumed by the fishermen themselves, for subsistence.

Species of emperor (Lethrinidae) were typically caught using hook and line, but a few were caught by trammel nets set overnight at the entrances to lagoons and reef pools. The most common species caught in this way were *Lethrinus obsoletus* and *L. mahsena.* These species were occasionally observed during UVC to cross over the reef flat at high tide in order to feed in large reef pools and sandy lagoons, and are typically entangled in trammel nets when attempting to return to the reef slope on the ebb tide. Similarly, a small number of piscivores of the family Serranidae (groupers) were also recorded in landings from trammel nets. These were either *Epinephelus fasciatus* or small *Cephalopholis argus*. Other serranids were only obtained by hook-and-line on the reef slope.

6.4.2. Seasonal variation in catch

There was noticeable seasonal variation in the proportion of different families within the catch. The abundance of Scaridae was noticeably higher during the winter than during other seasons (figure 2a). Numbers of Lethrinidae, Lutjanidae, Serranidae and Mullidae (table 2) were highest in the spring, while those of Labridae and Sparidae showed a peak during the autumn. By contrast, the catch of species of Acanthuridae was significantly reduced during the autumn.

The species richness of the catch was higher during spring and summer (48 and 45 species respectively) than in autumn and winter (36 and 34 species respectively).

Table 1. The proportions of fish of each family (that accounted for more than 2% of the landings) that were caught by different gear types

	Mean weight (gm)	gill nets %	trammel nets %	hook & line %
Scaridae	3036	31	69	0
Lutjanidae	64	0	34	66
Siganidae	573	37	63	0
Lethrinidae	487	9	27	54
Serranidae	118	15	12	74
Kyphosidae	230	58	42	0
Acanthuridae	530	66	34	0
Hamulidae	215	6	94	0
Mullidae	85	48	52	0
Belonidae	64	0	100	0
Labridae	132	81	19	0
Sparidae	50	64	36	0
Mugilidae	231	72	28	0

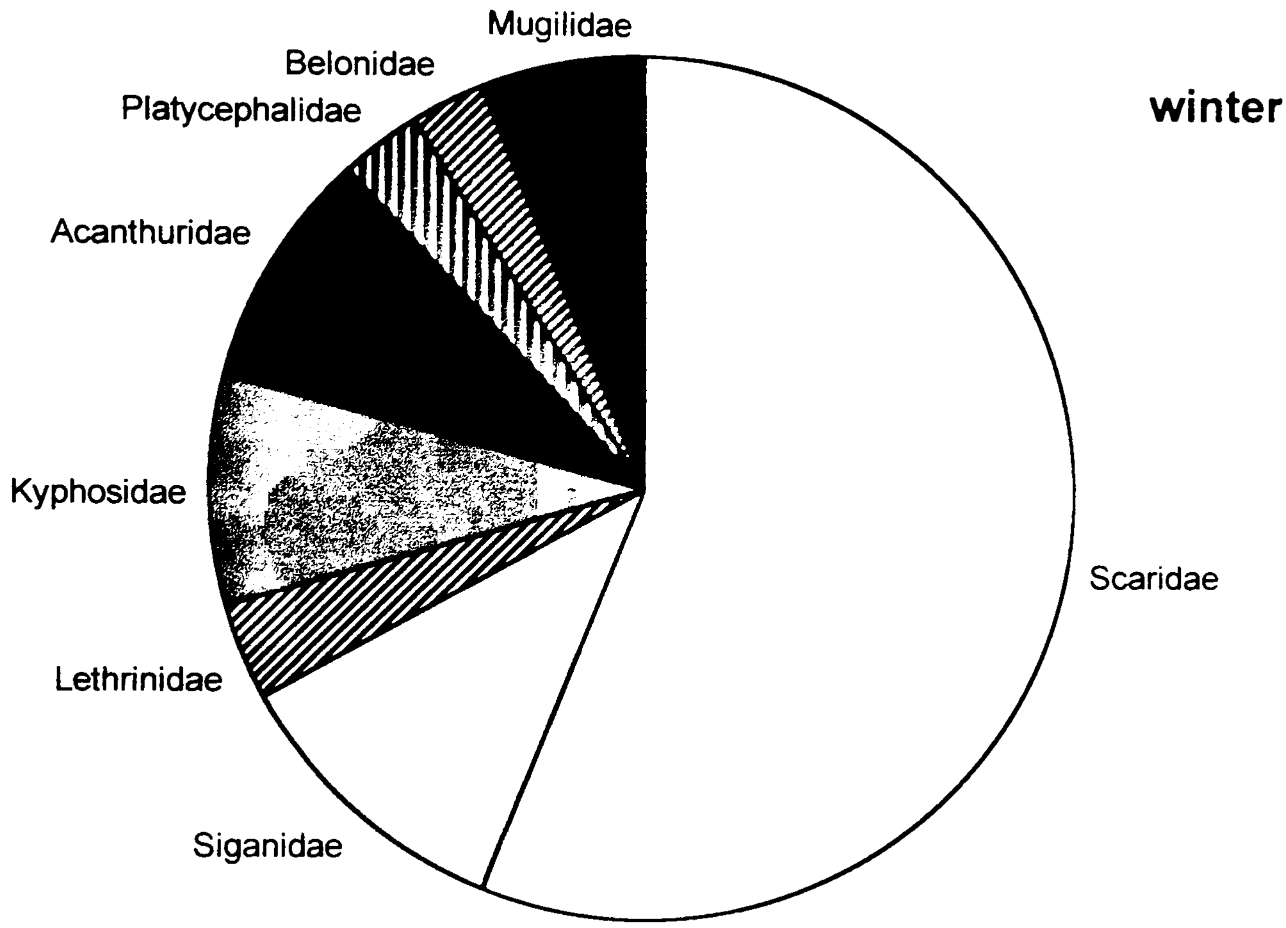

Figure 2a. Compositon of catch from the landings that were sampled during winter, 1996 / 97

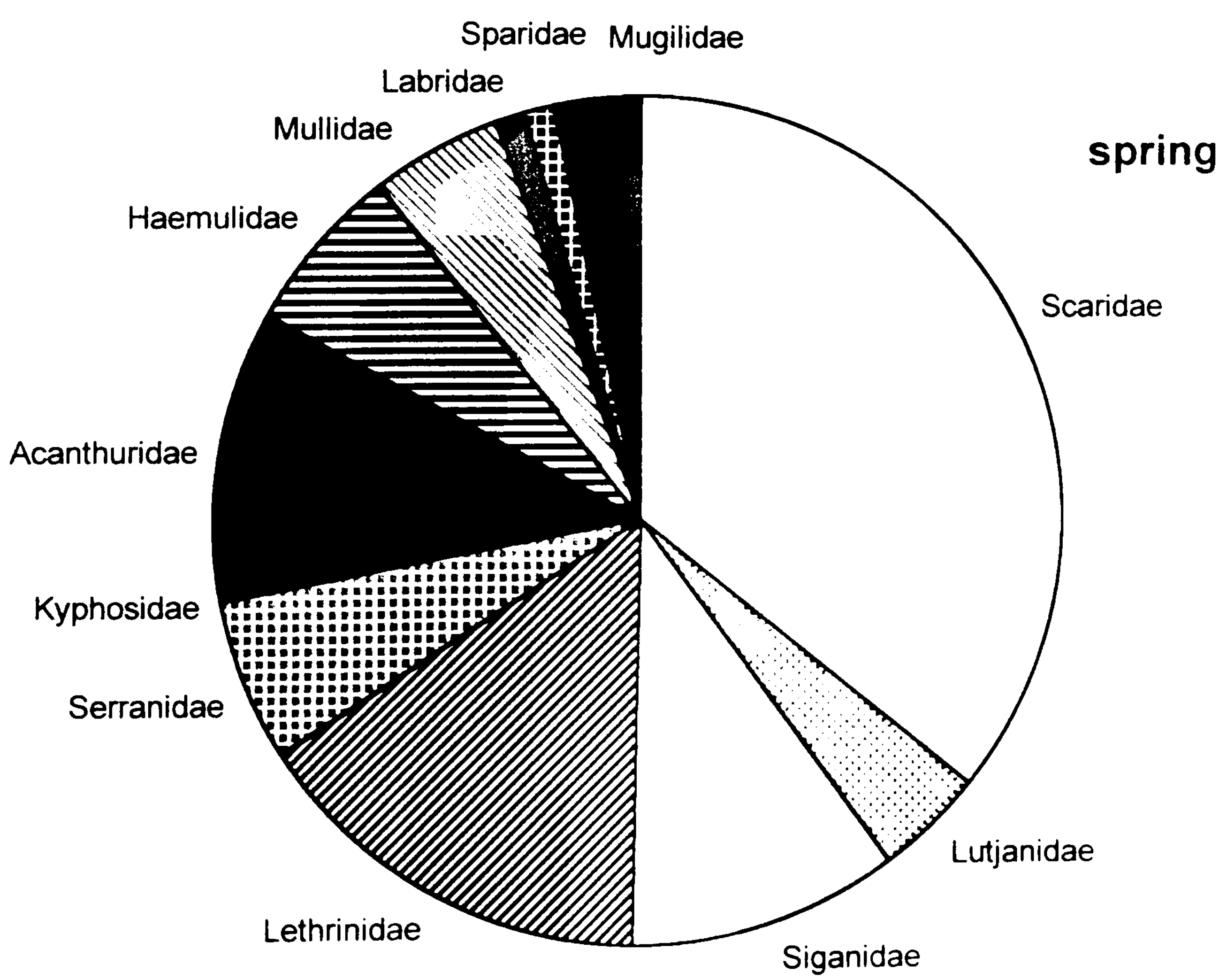

Figure 2b. Compositon of catch from the landings that were sampled during spring, 1996 / 97

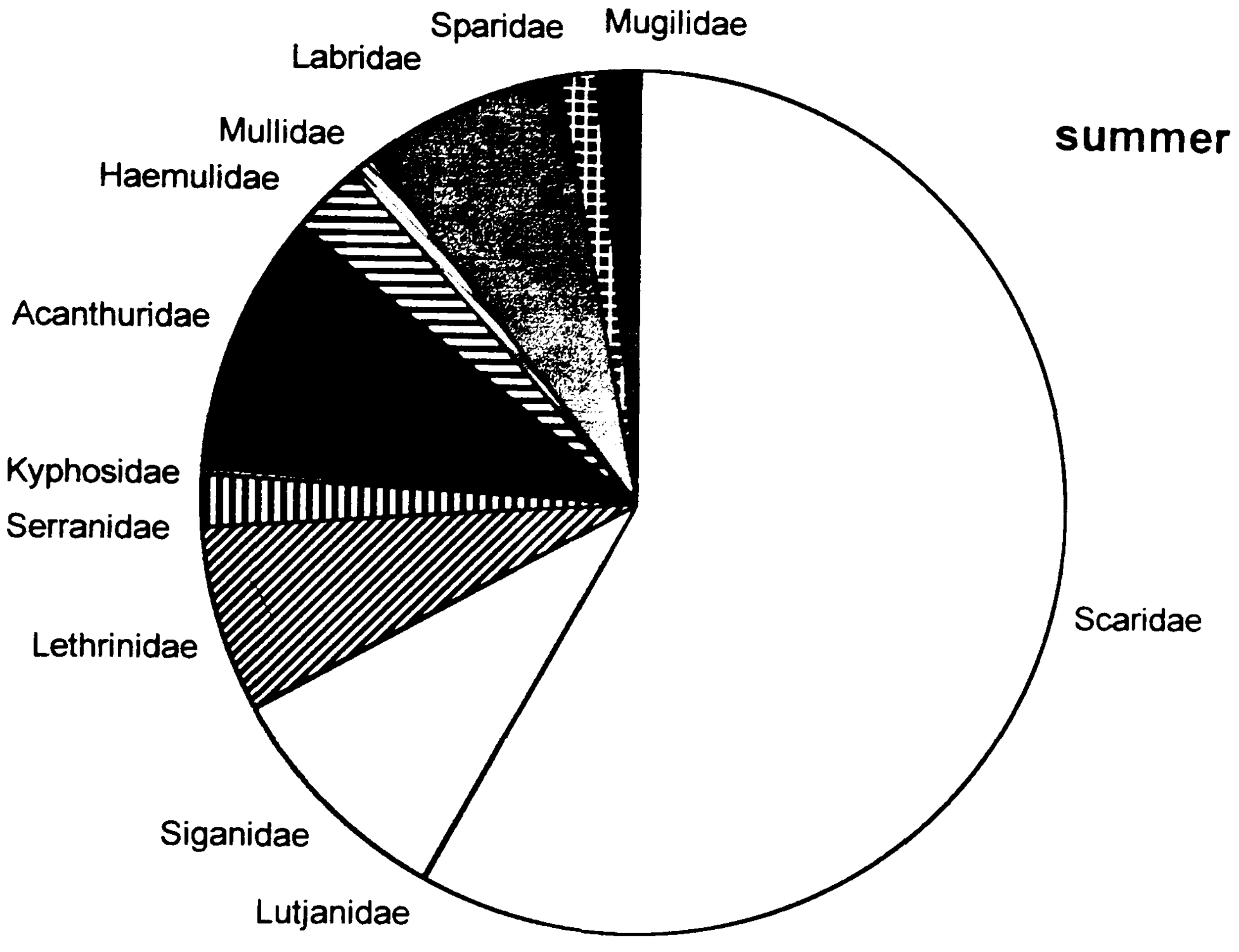

Figure 2c. Compositon of catch from the landings that were sampled during summer, 1996 / 97

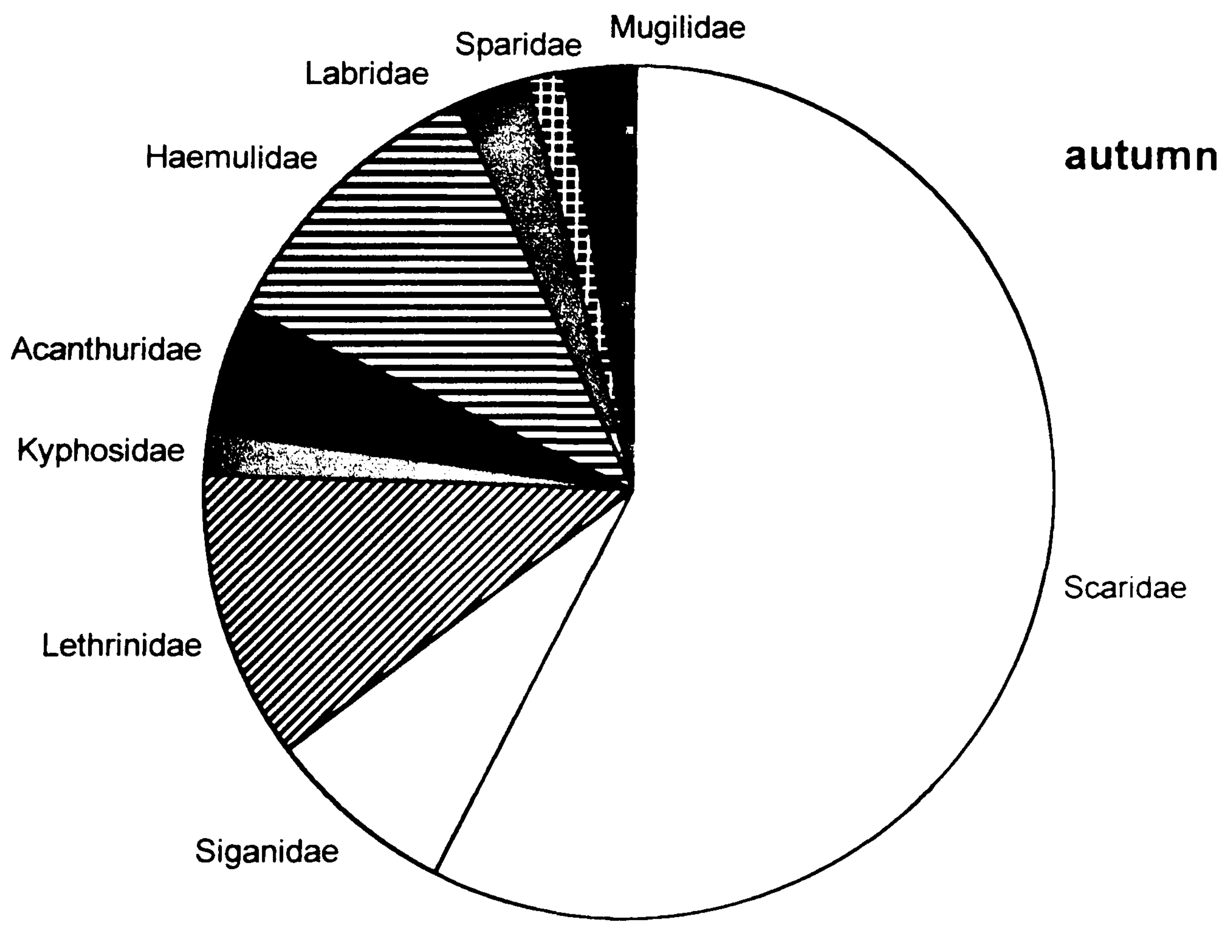

Figure 2d. Compositon of catch from the landings that were sampled during autumn, 1996 / 97

Table 2. Species list of the most commonly recorded fish in the catches sampled at Nabq during the study period (1995-1997).

Family	Species
Acanthuridae	❑ *Acanthurus sohal, A. nigrofuscus, A. nigricans*
	❑ *Zebrasoma veliferum*
	❑ *Naso unicornis, N. lituratus*
	❑ *Ctenochaetus striatus*
Belonidae	❑ *Tylosurus chorum*
Fitsulariidae	❑ *Fistularia commersonni*
Haemulidae	❑ *Plectorhynchus gaterinus, P. schotaf*
Holocentridae	❑ *Adioryx caudimaculatus*
	❑ *Myripristis xanthacrus*
Khyposidae	❑ *Khyphosus vaigiensis*
Labridae	❑ *Cheilinus lunulatus*
	❑ *Halichoeres hortulanus*
Lethrinidae	❑ *Lethrinus nebulosus, L. mahsena, L. obsoletus*
	❑ *Monotaxis grandoculis*
Lutjanidae	❑ *Lutjanus ehrenbergi, L. niger, L. bohar, L. monostigma*
Mugilidae	❑ *Crenimugil crenilabis*
Mullidae	❑ *Parupeneus forskali*
Platycephalidae	❑ *Cociella crocodila*
Scaridae	❑ *Scarus sordidus, S. ghobban, S. gibbus, S. psittacus, S. ferrugineus, S. frenatus, S. collana, S. fuscopurpureus, S. niger*
	❑ *Cetoscarus bicolor*
	❑ *Hipposcarus harid*
	❑ *Calotomus viridescens*
Serranidae	❑ *Cephalopholis miniata, C. argus*
	❑ *Aethaloperca hemistiktos*
	❑ *Variola louti*
	❑ *Plectropomus maculatus*
	❑ *Epimephelus fasciatus, E. tauvina,*
Siganidae	❑ *Siganus rivulatus, S. argenteus, S. stellatus, S. luridus*
Sparidae	❑ *Acanthopagrus bifasciatus*

6.4.3. Catch and effort

The total weight of each catch was obtained by summing the weights of all fish present. The mean weight of fish caught per fishing trip in each season of 1996/97 is shown in figure 3. Seasonal variation in mean weight of catch per fishing trip was not statistically significant. However there was significant variation in the mean catch per trip obtained using different gear types (figure 4) (Kruskal Wallis test, $\chi^2 = 6.12$, $P < 0.05$). Trammel nets (set overnight and collected the following morning) produced the highest catches per fishing trip. However, this is associated with the increase in effort represented by the longer (overnight) soak times during which the fishermen do not have to be present. Mean weight of catch was lowest for hook-and-line fishing; however, fishing effort per trip is lower for this than for other methods (see chapter 5), and the catch typically has a higher market value because of the large predatory species that are targeted.

Although some differences in mean catch per unit effort (CPUE) of different gear types was evident, this variation was not statistically significant. The highest calculated mean CPUE was obtained using gill nets (1.48 kg / unit gear.hr), the next highest using trammel nets (1.26 kg / unit gear. hr), and the lowest using hook-and-line (0.72 kg / unit gear.hr). However while gear unit for gill and trammel netting is a net with principally the same surface area, the above value of CPUE for trammel netting was that calculated using the time when the tide is high, until after it has gone down, forcing fish in to the trammel net.

The total fished area at each site was calculated as the combined surface area of the outer reef flat and reef slope. This is the zone that is actively exploited by fishermen and where commercially targeted species tend to occur the most. It is evident that the mean weight of catch per unit effort declined sharply from 1.3 - 2.7 kg / net.ha at lightly to moderately fished sites, to 0.6 - 1.8 kg / net.ha at those sites which were most heavily exploited.

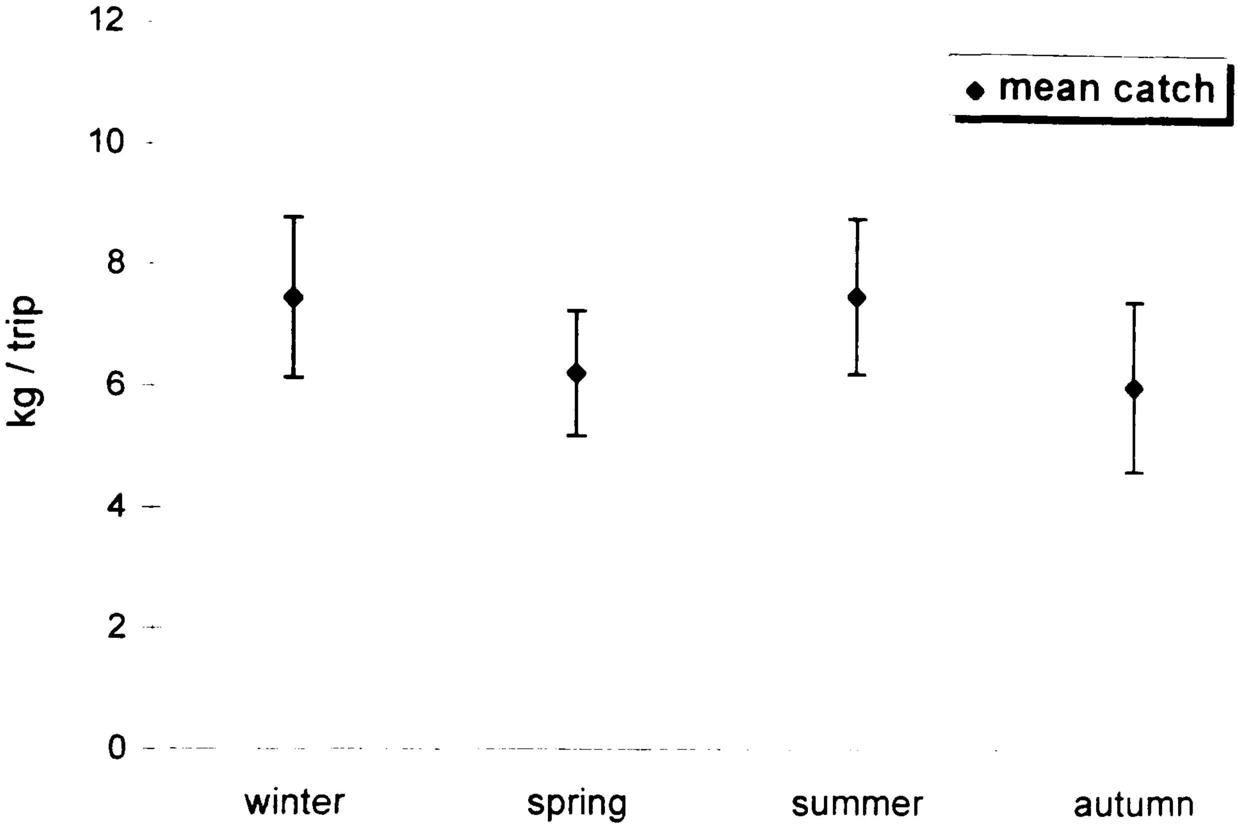

Figure 3. The mean weight of landings per fishing trip at different fishing seasons The winter season represents December to January, spring (February to May), summer (June to August), and autumn represents September to November. Error bars represent the standard error of the mean.

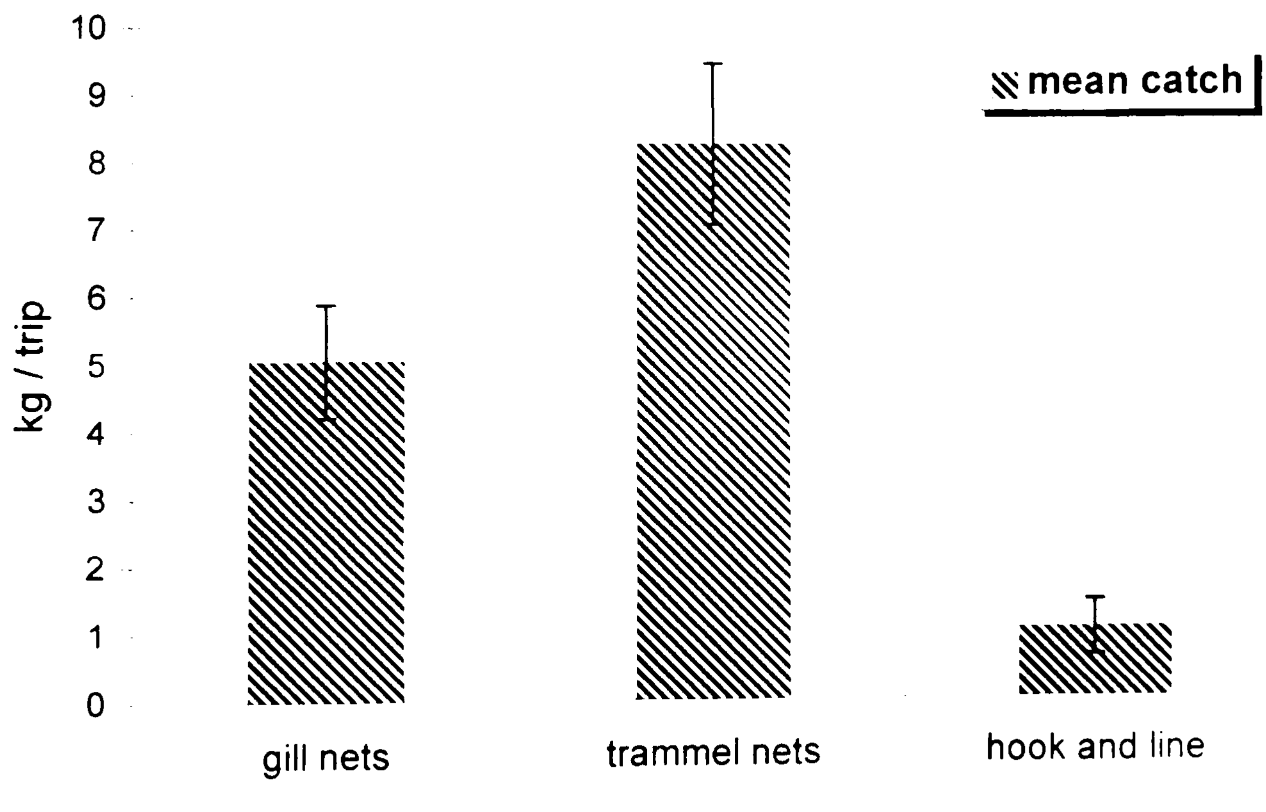

Figure 4. The mean weight for catches using different gear types are shown for each fishing activity (trip). Error bars represent the standard error of the mean.

The total yield from each fishing site was obtained from the following equation:

$$Y = \sum \{CPUE_{(i)} \ \ x \ \ F_{(i)}\} \quad \text{(equation 1)}$$

where $CPUE_{(i)}$ represents the mean catch per unit effort at each site

and $F_{(i)}$ the annual fishing effort for each site

The total yield from each fishing site in the Nabq fishery was found to range between 1.9 and 6.2 ton. km^{-2} .yr^{-1}. The highest values were obtained at three sites, Abu Negailla, Manquatta and Ghargana. Figure 5 shows the relationship between the total yield per annum (during 1996-97) from the Nabq fishery and fishing intensity across the different sites, while figure 6 shows the same relationship for yields from the gill and trammel net landings separately. The annual yield was highest at sites exposed to moderate exploitation but showed a marked decline at sites that were heavily exploited. The best fit least squares regression line shown in figure 6 shows that yields start to decrease at sites which are exposed to annual fishing effort that exceeds approximately 100 -150 unit gear. km^{-2} . yr^{-1}.

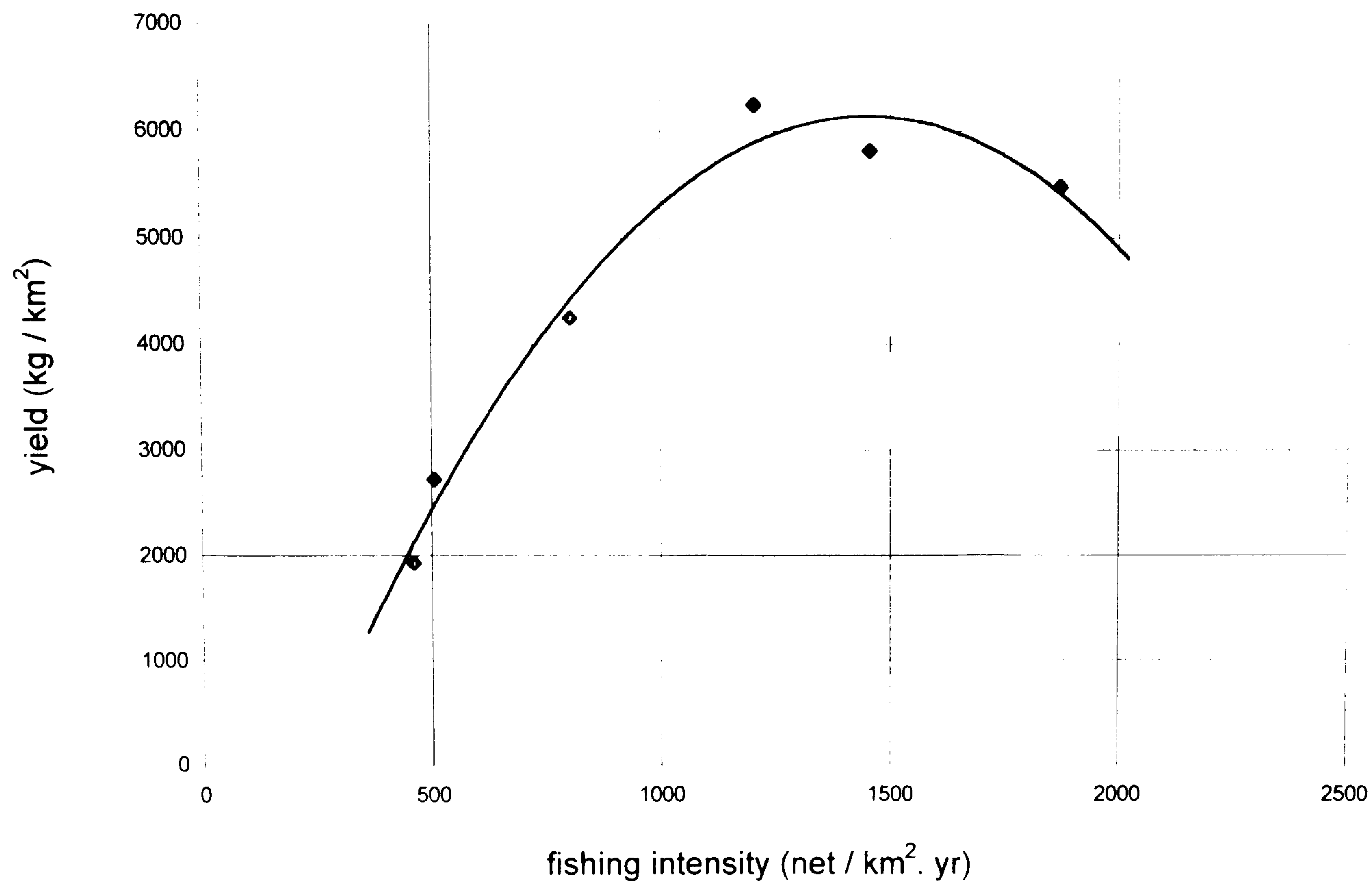

Figure 5. The total yield from the Nabq fishery is plotted for different sites that are exposed to different levels of annual fishing Total effort is normalised for each site per unit area (km^{-2}). Total yield represent landings that are pooled for all different gear

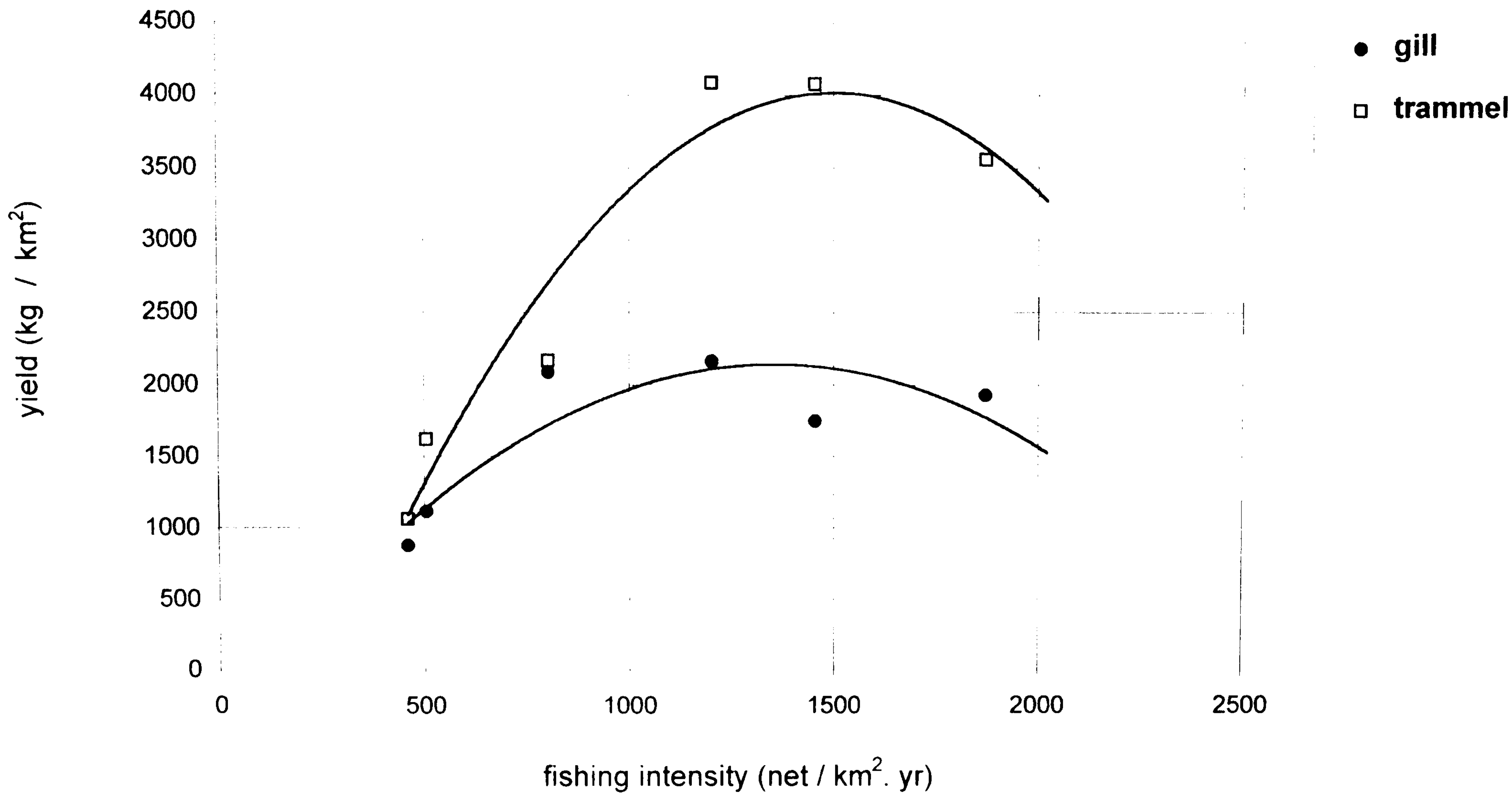

Figure 6. Yield from different fishing methods at fishing grounds that are exposed to different fishing pressure. Annual effort is normalised to unit area (km^{-2}). Estimated yields for gill and trammel nets are plotted separately.

Table 3. Market values of fish (per kg) of different families as determined by the market survey. Retail and wholesale prices are given in Egyptian Pounds. The retail price is defined as the price at which the fish is typically sold by shops or market stalls to the public. The wholesale price is the price given to fishermen by retailers, market traders or hotels.

family	retail price	index	wholesale price
Scaridae	5.5	0.39	4
Siganidae	5	0.35	3.5
Lethrinidae	10	0.71	7
Acanthuridae	6	0.42	4
Kyphosidae	6	0.42	4.5
Mugilidae	12	0.85	6
Sparidae	8	0.57	5
Haemulidae	9	0.64	5.5
Serranidae	12	0.85	8
Labridae	8	0.57	5
Mullidae	14	1	7.5
Belonidae	8	0.57	6
Platycephalidae	7	0.5	4
Balistidae	7	0.5	4

The value of individual catches was estimated by the summing of the value per weight for fish family present in the catch. The value of catch per fishing trip ranged between 8 to 55 EGL at different fishing grounds. A key finding was that the value of the catch per unit gear per hour was significantly lower at sites, which were heavily exploited by the fishery. However the total value of the catch did not significantly vary between landings from sites that are exposed to different effort levels.

6.5. DISCUSSION

The fish catches sampled at Nabq during the study period included species belonging to 17 families. However, fish of only 4 families (Scaridae, Siganidae, Lethrinidae, and Acanthuridae) constituted the bulk (79%) of the catch. Domination of the catch by these families has been suggested by McManus *et al.* (1992) to be characteristic of reefs that are exposed to moderated levels of fishing. As reef fisheries are exploited with increasing intensity it is typical that whereas initially high value piscivores such as Serranidae and Lutjanidae dominate the catch, subsequently, as these are removed and fishing intensity increases, herbivores such as Scaridae and Siganidae come to dominate. However the Nabq fishery is characterised by the predominant exploitation of the reef flat using gill and trammel nets, while the reef slope area where larger piscivores are principally found is less intensively fished. Hence domination of the catch by herbivores is not necessarily, in this case, indicative of fairly intense fishing.

Changes in catch composition associated with increasing intensity of fishing have been suggested by Russ and Alcala (1989), Koslow *et al.* (1988), Munro and Williams (1985) and Watson & Ormond (1994) as being indicative of changes in community structure consequent upon heavier exploitation of some groups rather than others. In the present study the sites that were more heavily exploited had more species in the catch. However the number of species in catches did not vary significantly between sites and in any case this trend may simply reflect the larger number of fish landed at more heavily fished sites. Reef fish assemblages may also be influenced by competition and predation (Sale, 1980), as well as by variability in recruitment (Doherty and Williams, 1988a). Ferry and Kohler (1987), Bohnsack (1982) and Russ (1985) have similarly found that with moderate levels of fishing species composition did not vary significantly between sites subjected to differing levels of exploitation. The combination of fishing methods used at

Nabq may in fact be ecologically advantageous in tending to retain a balanced fish assemblage.

Trammel set nets accounted for the highest number of species as well as for the highest mean catch. The catch was dominated by scarids, acanthurids and siganids, which were mostly consumed by the fishermen themselves or used to support their families' subsistence. These fish were also sometimes dried in which case they are consumed mainly in winter when many of the fishermen and their families move inland into the mountains to exploit the seasonal grazing for their cattle and benefit from the favourable climate. Only 8 species belonging to only three families (Lethrinidae, Serranidae and Lutjanidae) were found in sample hook-and-line catches. As explained, this gear was used over the reef slope to target these large predatory piscivores for their high market value. This was only possible when sea conditions were calm, mostly in beginning to mid summer. Nevertheless the reasonable availability of fish that could be sold to meet fishermen's cash requirements may play a role in their traditional life style. It could well have been more important to a sustainable life style to be confident that high value fish were available for catching if required than to exploit them as intensively and soon as possible. It is worth noting that two other sites that were not included in the present study nor the estimation of the total yield of the fishery were exploited by hook-and-line fishing for subsistence, though this happened only on rare social occasions due to the difficulty of accessing them. (The yield and CPUE from these sites would be worth investigating as representative of minimally exploited sites.)

Fishing intensity at different sites was calculated as the product of active soak time, area of influence and fishing power, where fishing power = gear unit x efficiency of gear. Thus, the fishing power should reflect the effectiveness of available gear in catching fish. In practice however the efficiency of gear may be influenced by the number of fishermen involved in using it and also by the experience and expertise of individuals in locating fish and setting nets. In particular it was noted that fishermen's knowledge and experience of annual spawning and aggregation grounds appeared to influence their CPUE, although this effect is less marked than it might be expected since it was apparent that most of the Bedouins at Nabq were able to acquire this knowledge from the more experienced fishermen. Thus in terms of data analysis an assumption that fishermen had similar patterns of efficiency in catching their prey is reasonable.

Yield estimates from the Nabq fishery ranged between 1.6 and 6.2 $t.km^{-2}.yr^{-1}$ with a mean of 3.1 t. $km^{-2}.yr^{-1}$. These figures are high when compared to those reported by Kedidi (1984b) for the Red Sea reefs of Saudi Arabia. However, until recently most reefs along the Saudi coast have been only lightly fished, and the yields from the Nabq fishery are on the low side of those reported for other reef areas in the Indo-Pacific region. Estimated yields have included 0.3 - 10.2 kg/km^2 in Fiji (Jennings and Polunin, 1995), 4.5 - 9.3 kg/km^2 in the Solomon islands (Dalzell and Daboa, 1994), 5.2 - 36.9 kg/km^2 in the Philippines (Alcala and Russ, 1990; Lopez, 1986) and 8.6 - 44 kg/km^2 in American Samoa (Wass, 1982). The highest values reported for the Philippines and American Samoa reflect areas that are very intensively fished. This comparison of catch rates suggests that the Nabq reefs are only lightly to moderately fished at most fishing sites. This interpretation is supported by the fact that there was no evidence that more powerful fishing techniques were being employed (e.g. motorised boats or destructive methods), or fish from smaller species or lower trophic levels being targeted, in order to maintain yields in the face of declining stocks.

The gill and trammel net fisheries at Nabq both had mean CPUEs of more than 1 kg per net (1.48 and 1.26 respectively) but decreased considerably below 1 kg per net at the most heavily exploited sites, at which estimated total yields were also reduced. This suggests that the reef top fishery using this gear type may be at or near a level of exploitation giving a maximum sustainable yield (MSY).

The mean CPUE for hook-and-line fishing at Nabq was 0.72 kg per line hr^{-1}. This figure is similar to that recorded by Amar *et al* (1996) in Malalison Island in the Philippines, although higher catch rates have been reported from some areas e.g. Pedro Bank, Jamaica by Munro (1983). This CPUE at Nabq expressed as weight caught per gear hour was the lowest for any of the gear types, but because of the high market value of the catch, the CPUE was highest if expressed in terms of value of fish caught per gear per hour.

We can compare the estimated annual yields for different reef sites at Nabq with the standing biomass of commercially targeted fish families as estimated by underwater visual surveys (UVC) (see chapter 4 and 5). These calculations indicate that between 4 and 15% of the standing biomass is caught each year. Potential yields at different sites are likely to be related to the observed standing stock. Ralston *et al.* (1986) demonstrated that the CPUE of a hook-and-line fishery was directly related to fish abundance observed by UVC. Similarly Kulbicki (1988) found total catch rates in a coral reef fishery were proportional to biomass as determined by UVC.

The data collected in the present study, extending over a relatively short period (2 years) did not allow for the assessment of cumulative time-based effects of moderate levels of fishing upon CPUE and yield. However area based surplus production models are used to examine the effect of fishing intensity upon CPUE and yield and so assess likely sustainable yield. Such models have been used by Koslow *et al.* (1994) and Munro and Thompson (1983), and in principle this approach might be applied to the data from the Nabq fishery. However there are two crucial assumptions that in practice are likely to be seriously violated so that such models should only be used with caution in reef fisheries. The first is that the habitat and community structure of different sites do not differ significantly. The second that the MSY (maximum sustainable yield) can be applied to the whole assemblage, even though in practice MSYs will differ between species and there will be unknown competitive and predator-prey interactions between species. But if these reservations are set aside, then calculations suggest that the Nabq fishery is capable of sustaining yields of up to 3.1 tons.km^{-2}.

Thus comparisons of overall yields and of CPUEs obtained by using similar gears with those obtained from other reef fisheries suggest that current exploitation rates are broadly sustainable. But further, the decline in overall yield and CPUE detected at the most heavily exploited sites, suggest that the levels of exploitation should not be increased, and indeed that management schemes should be set up for these critical sites. However caution should be exercised in assuming such yields should be expected from all reefs in the region since many of the sites are Nabq are characterised by their proximity to the most extensive combination of mangrove stands, algal mats and sea-grass beds within the Gulf of Aqaba. The interaction of these different productive habitats within a single ecosystem may well result in a higher than usual secondary productivity.

Continuing research is desirable in order to refine the present conclusion and enhance the decision-making capacity for fisheries managers. Studies over an extended period of time will allow investigation of cumulative time-based effects of moderate levels of fishing upon CPUE and yield and permit development of fisheries production models that could give more specific estimates of the levels of sustainable exploitation in different habitats. These conclusions will need to be integrated with findings resulting from the establishment of no take marine reserves which (in theory at least) cover approximately 40% of the Nabq Protectorate coastline. Within parts of these reserves and also at some other sites the reef flat and edge are hard to access or unsuitable for setting nets, which further tends to limit the overall intensity of fishing. It is anticipated that by a combination of closed areas, gear limitations and a licensing system for fishermen, the sustainability of the fishery can be ensured. However, social and economic aspects should influence levels of fishing pressure and should thus be considered more carefully. Such management aspects are discussed in more detail in chapter 7.

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CHAPTER 7

Establishment of No-Take Marine Reserves through Community Based Management and Investigation of Preliminary Effects upon Fish Stocks

7.1. ABSTRACT

Underwater Visual Census was used to compare the abundance of piscivorous fish species within the Nabq Protected Area before and after the establishment in 1995 of 5 no-take fisheries reserves. A comparison of mean abundance of groupers (Serranidae), emperors (Lethrinidae) and snappers (Lutjanidae) between 1995 and 1997 showed a significant overall increase in fish abundance in two of the no-take reserves, those at Ras Atantour and South Ghargana. There was also a statistically significant increase in mean length of the serranids, *E. fasciatus* and *C. argus*, and the lethrinids *L. nebulosus and M. grandoculis* across the no take reserves. In line with this, mean catch per unit effort within the fished area was observed to increase over the two years from 0.84 +/-0.19 S.E to 1.01 +/-0.24 S.E., though the difference was not statistically significant. Nevertheless the establishment of no-take fisheries reserves appear to date have benefited the fishery. The benefits of no-take reserves are discussed and social aspects of involving local; fishermen in the co-management of fisheries resources described.

7.2. INTRODUCTION

During the last three decades a considerable increase in the exploitation rates of coral reef fisheries in the tropics has resulted in extensive overfishing. Conventional fisheries management policies have attempted to prevent overfishing by determining maximum sustainable yields for each species, and setting and enforcing catch quotas accordingly. However this approach offers only limited management flexibility (Munro and Williams, 1985), and has proved difficult to operate and expensive to enforce (Bohnsack, 1993), to such an extent that a majority of fish stocks have declined dangerously, questioning the effectiveness of that approach.

An alternative approach that is gaining popularity is to establish no-take or marine fishing reserves so as to both regulate fisheries effort and conserve fish stocks and biological diversity (Polunin, 1990). The use of no fishing marine reserves to restore and protect fisheries has been reviewed recently by Roberts and Polunin, (1991, 1993), Dugan and Davies (1993b) and Rowley (1994). They have all agreed that marine reserves could be a valuable management tool, especially in tropical and coral reef areas. Marine fishing (no-take) reserves can not only regulate effort, but also be used to safeguard that stocks of large individuals, which contribute disproportionately to spawning effort, are protected. No-take reserves are also compatible with zoning schemes that allow different conflicting uses to co-exist, by separating them. In particular, areas that are established to protect the loss of biodiversity that occurs in most exploited reef areas can be separated from areas where reefs are impacted by human activities or exploited by fishing.

A series of studies in different parts of the world have now confirmed that reserves can be effective in protecting reef fish stocks (Roberts and Polunin, 1993; Bohnsack, 1993; and Rowley, 1994). A rapid build-up in fish numbers, and an increase in size of target species, resulting in an increase in biomass, especially of larger predatory species that were targeted by previous fishing, has been described. This was apparent in the Sumilon Island Marine Reserve in the Philippines (Russ, 1985), at Malindi and Kisite Marine National Parks in Kenya (McClanahan and Muthiga, 1988; Watson and Ormond. 1994), in the southern area of the Great Barrier Reef Marine Park in Australia (Ayling and Ayling, 1986), and in the Tsitsikama Coast National Park in South Africa (Buxton and Smale, 1989).

Moreover, marine reserves are thought to spread the benefit of protection outside reserves, resulting in an increase in fish catch in adjacent areas (Russ and Alcala. 1994; Ormond & Douglas, 1996). This is presumed to happen partly as a result of the export of pelagic larvae that could settle in other areas outside the reserve, thus replenishing these fishing grounds. In addition there is evidence that, as stocks build up, emigration of adults occurs from areas of high population density to areas where stocks are being reduced by increase of fishing mortality.

The Egyptian coastline of the Gulf of Aqaba extends for 220 km from Ras Mohammed in the south to Taba in the north. The southern section of this coastline, from Ras Mohammed to Ras Nasrani, is largely unfished, being effectively incorporated within the Ras Mohammed National Park, within which not even traditional artisanal fishing occur, except for a seasonal Shaoor (lethrinid) fishery close to Ras Mohammed. By contrast the remaining section of the coast from Ras Nasrani to Taba, including the areas of Dahab and Nuweiba, is almost all subject to an artisanal fishery conducted by local Bedouins.

The exception to this are five relatively small areas within the Nabq Protected Area which, following preliminary studies of the fishery within the protected area (chapters 4, 5, and 6), and extensive consultation with the local Bedouin community, were established as no-take reserves. It was anticipated that this might both prevent habitat degradation in these areas due to fishing activities, and, by maintaining abundance and diversity of coral reef fish within some areas, maintain or increase yields at nearby fishing grounds. The location and extent of both these no-take reserves and the exploited fishing grounds are shown in Figure 1.

Within this reserve network, five small sections of the fringing reef were set aside as marine fishing reserves, rather than one large area, in the expectation that this would be more beneficial to the fishery, since there would be a greater boundary between fished and non-fished zones across which fish could move to be available to the fishery. In addition these areas were selected to be of different sizes, with the attention that this might assist in assessing the most beneficial size for such no-take areas. Their effect was assessed by monitoring their effect on the fish stocks and yields of targeted species within and adjacent to their boundaries for two years after the establishment of these no-take areas.

7.3. Methods

7.3.1. Establishment of no-take reserves

The preliminary assessment of the fishery at Nabq included discussions and interviews with local fishermen and community leaders. This led to attendance at major social events during which it was possible to introduce discussion about fisheries issues. These informal discussions promoted understanding by the fishermen of the likely effects of increasing fishing intensities and of habitat degradation. This in turn led to more formal seminar that described the long-term effects of heavy exploitation on coral reef fisheries. Examples were described from other areas in the Indo-Pacific and the Caribbean where there had been a decline in yield and subsequently in economic output of the fishery. Other studies were also described that provided evidence for a build-up in targeted fish stocks within reserve areas, and for an enhancement of yields from nearby fishing grounds. As a result the idea of implementing a series of no take reserves became widely accepted by the fishermen. The fishermen also accepted a legal ban on the use of destructive or highly selective fishing techniques, which typically in any case were exclusively used by visiting fishermen, rather than local residents, for quick economic gain.

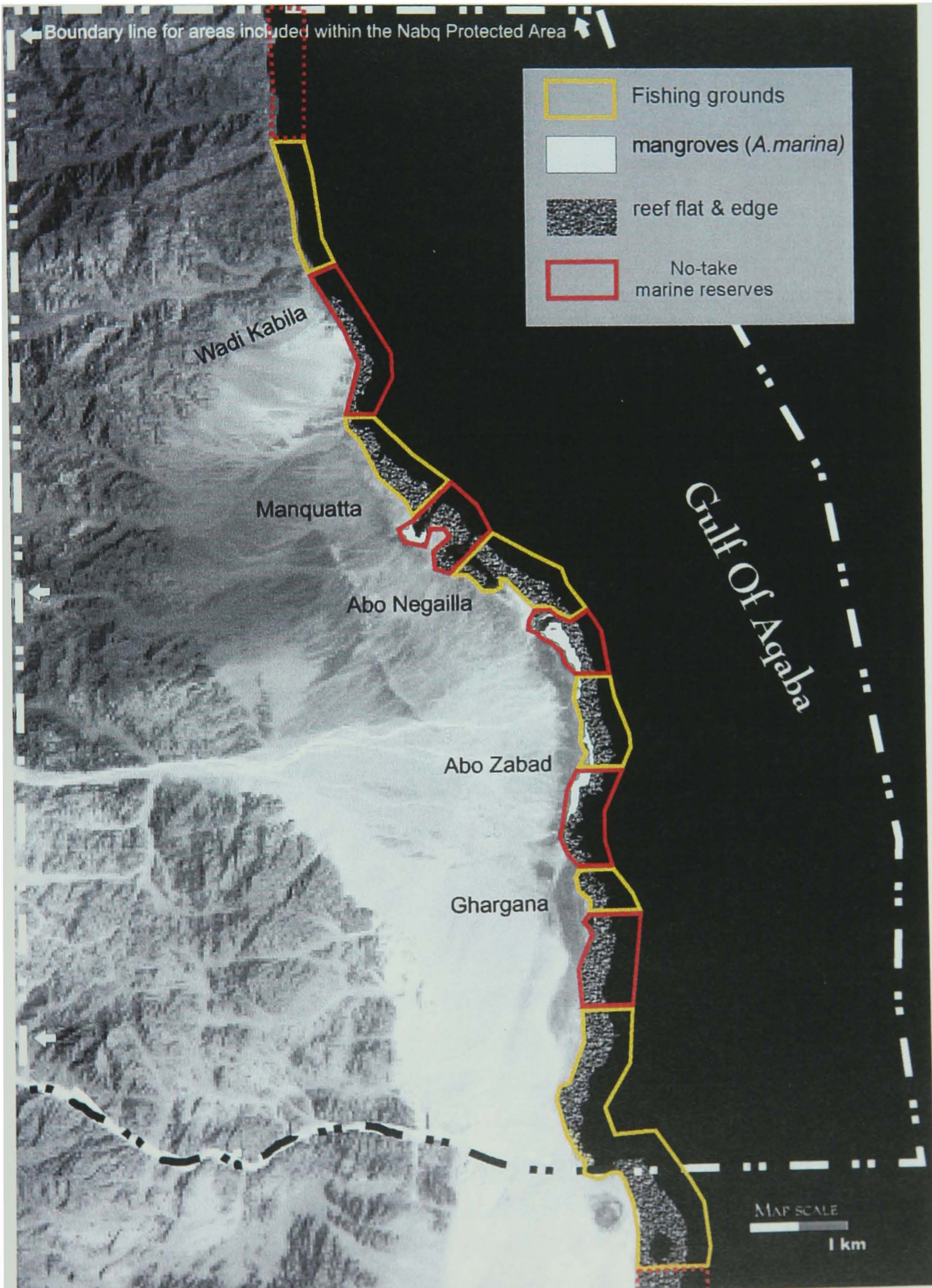
Local fishermen were further integrated into this fisheries management program by being included, together with marine scientists and Park managers, in the formal decision making processes that decided upon the size and location of the no-take reserves. The regular meetings allowed for the identification of well-respected and capable individuals who were prepared to assist with the implementation of the program. These "Community Rangers" were employed on part-time basis by the management authorities and fully integrated into the routine day-to-day management work of Nabq Protectorate. They were introduced to basic marine biological and ecological principles and to the conservation and management issues affecting the Protectorate. They were also trained to snorkel and introduced to data collection as well as involved in actively patrolling the coastline to ensure compliance with Park regulations. Experience supported the view that it was likely to be more effective if a strategy was adopted of assisting Community Rangers to acquire marine science skills rather than of training marine scientists and rangers in community management, local culture and traditional values.

In parallel with the above, the results of the preliminary assessment of the artisanal fisheries in the Nabq Protected Area and a review of the options for adopting a precautionary approach to management, while at the same time acquiring data that would facilitate estimation of sustainable yields, were presented to the EEAA. This included recommendations in support of a direct test of protective management through the establishment of a series of differently sized no-take areas, that would enhance protection of a proportion of the spawning fish stock, allowing for possible restocking of fished areas from no-take areas, and simplifying the enforcement of fisheries regulations, as well as maintaining areas of undisturbed reef habitat.

At two formal general meetings involving both local and visiting fishermen, and Park managers, rangers and scientists, the sizes and locations of the marine fishing (no-take) reserves and the details of the new fishing regulations were agreed. Then after support was acquired from other authorities that might be concerned, closure rights were granted by the EEAA through its regulatory body, the office of the Ras Mohammed National Park Sector at Sharm El Sheikh.

A final formal meeting involving most fishermen together with the Park managers and other authorities was conducted in April 1995 in order to pronounce the establishment of the no-take areas, and to liaise over the implementation of fishing gear regulations. Interpretative material was prepared and distributed to fishermen, and sign posts and marker posts installed within and at the boundaries of the no-take areas.

Figure 1. The boundaries of the no-take marine reserves that were closed for fishing since April. 1995. The major fishing grounds of the Nabq artisanal reef fishery are shown. The northern and southern most no-fishing zones extend beyond the boundaries of Nabq within the Gulf of Aqaba Protectorates.



The location and extent of the no-take reserves (figure 1) describe as follows:

(1) from Al-Zokeir to the Ghargana mangrove lagoon (Al Berka)

(2) from Nakhlet Al Tal to the southern margin of Marsa Abo Zabad

(3) from northern Abo Negailla headland to Al Dakkal

(4) from Al Hegeib to southern Wadi Kabilla

(5) From Ras Atantour to the northern Park boundary.

The regulations applying to these areas are shown in table 1.

Gear type	No-take reserves	Fishing areas	Additional specifications
Gill nets	Forbidden	Permitted	Minimum mesh size (> 5cm)
Trammel nets	Forbidden	Permitted	Minimum mesh size (> 5 cm)
Hook and line	Forbidden	Permitted	One hook per line
Spears & spear-guns	Forbidden	Forbidden	-
Reef gathering	Forbidden	Permitted	-
Dynamite fishing	Forbidden	Forbidden	-
Trawling	Forbidden	Forbidden	-
Deep (long) nets	Forbidden	Permitted	Minimum mesh size (> 10 cm) only in sandy bottom areas.
Catching spiny lobsters	Forbidden	Permitted Seasonally	Permitted only during the period September - January. Minimum individual size allowed 25 cm or 450 gm. No berried females (bearing eggs) to be taken.

Table 1. Regulations concerning artisanal fishing activities that apply to the no-take reserves and intervening fishing areas in Nabq Managed Resource Protected Area as enacted by the Egyptian Environment Affairs Agency in April 1995.

7.4 RESULTS

7.4.1. Effect of no-take (marine fishing) reserves

The abundance, mean size and population structure of commercially targeted piscivores was re-censused in August 1997, 28 months after the declaration of the reserve areas and 24 months after the previous census. Underwater Visual Census (UVC) was undertaken using the same methods and transects as described in chapter 4. Thus four transects were censused at each of 18 stations, and stations were distributed such that two were located within each no-take reserve, and two within each intervening fished area.

The result of the agreement with the fishermen was such that three of the no-take reserves were established in areas that were only lightly fished beforehand. This was because these sites were difficult to access and unsuitable for the deployment of trammel and gill nets. The remaining two no-take reserves, at Ras Atantour and South Ghargana, had been moderately fished prior to reserve establishment. Thus it was anticipated that the most useful comparison was likely to be between fish populations at these two sites in 1995 when they were still actively fished and 2 years after reserve establishment in 1997. Statistical comparisons of the two sets of data were performed using non-parametric paired samples test.

The mean biomass and mean population length of different species of grouper (Serranidae), emperor (Lethrinidae) and snapper (Lutjanidae) at different depths in 1995 and 1997 are compared in Figures 2 and 3. There is much variation in the differences between the UVC counts obtained for different species at different sites. The most interesting changes are increases at some of the no-take reserves in the abundance of

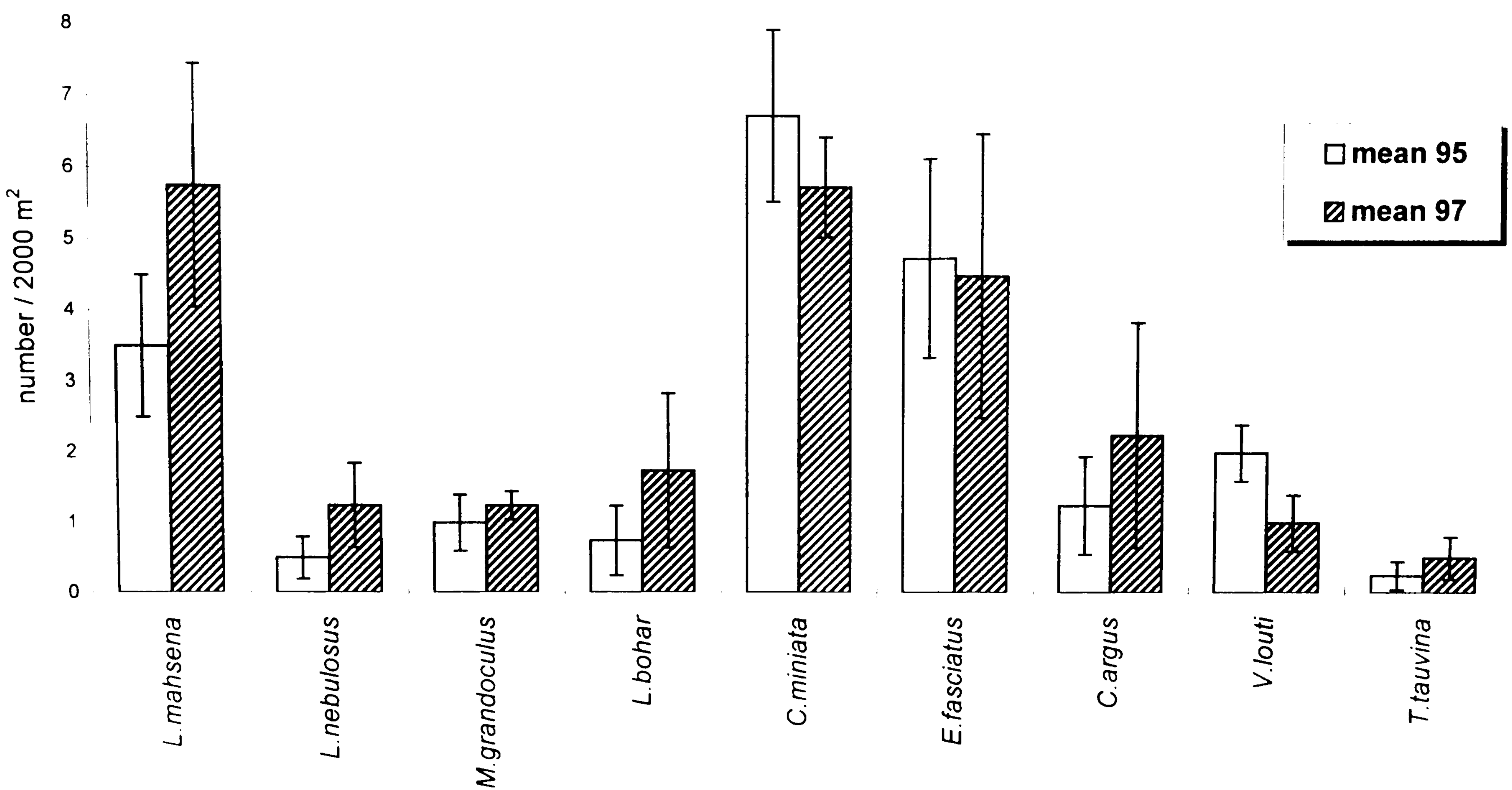


Figure 2. Mean abundance of different piscivore species per 2000m^2 inside reserve areas as compared before and after reserve establishment. Error bars represent S.E of the mean.

several large species of grouper and a few species of emperor, these being the species that are most frequently caught by hand-lining over the reef slope. None of the differences between years in mean abundance of different species or families was statistically significant, either across all the no-take reserve sites or across only those reserves that were previously fished at some moderate fishing levels. However a comparison of mean changes in abundance across all species within individual no-take reserves and fishing areas showed a significant overall increase in fish abundance in the two previously fished reserves at Ras Atantour and South Ghargana.

Figure 3 compares mean population length of larger species of Lethrinidae, Lutjanidae and Serranidae between 1995 and 1997, both in the no-take reserves, and in the fishing zones. While there was no significant change in mean length across the fished areas, there was a considerable and statistically significant increase in mean length of the serranids *E. fasciatus* and *C. argus*, and the lethrinids *L. nebulosus, L. bohar and M. grandoculis* across the no take areas. There was also a noticeable decrease in mean length of some other species even though their abundance had increased over the two years since the establishment of the no-take reserves.

The catch per unit effort (CPUE) obtained at the fishing sites adjacent to and interspersed between the no-take reserves was also compared between the periods April - June 1995 and April - June 1997. Mean CPUE was found to have increased during the two years following the closure of the no-take reserves. In 1995 mean CPUE was 0.84 +/- 0.19 S.E (N = 31 landings), while in 1997 it was found to be 1.01 +/- 0.24 S.E. (N = 47 landings), though the difference was not statistically significant.

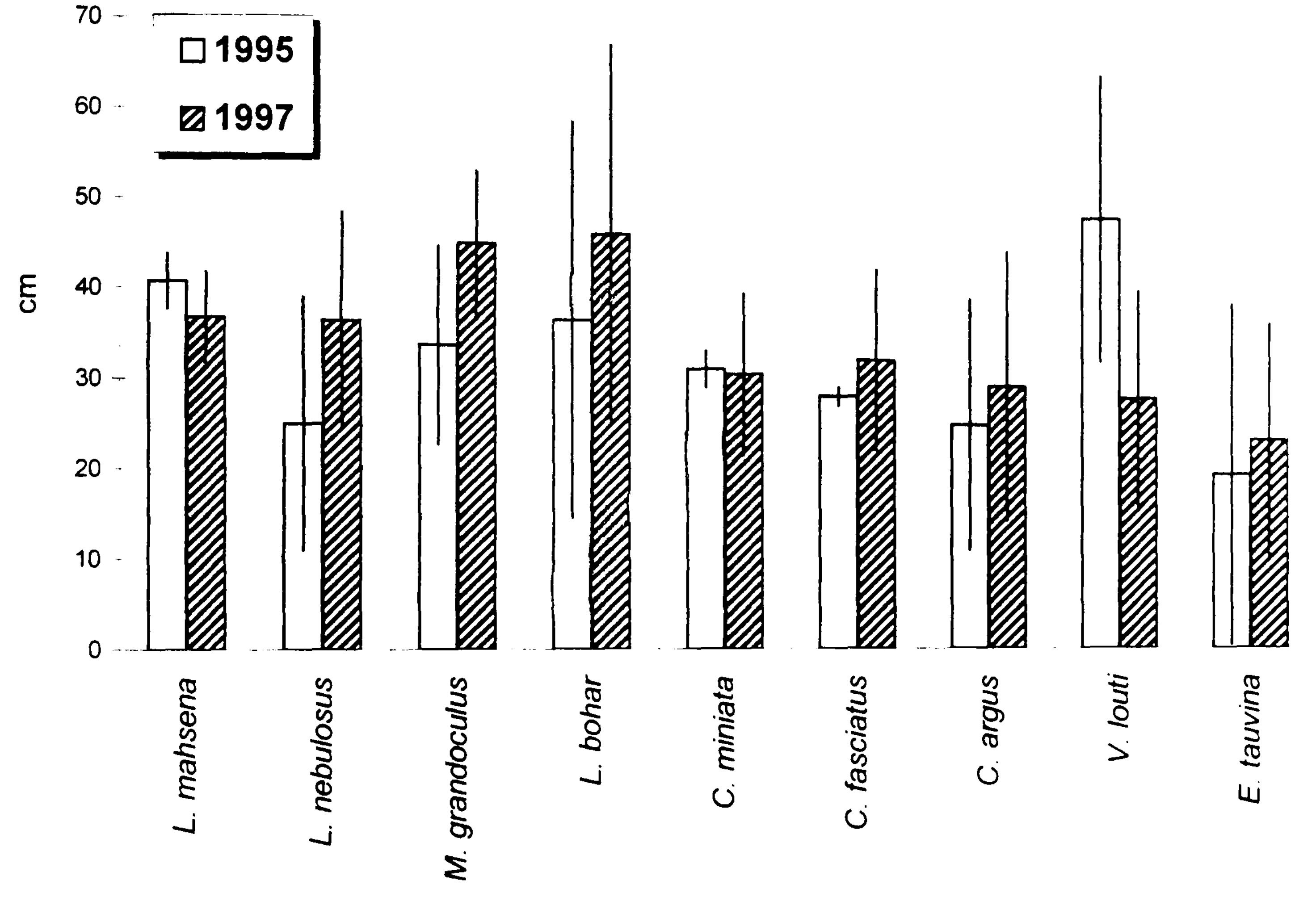


Figure 3. The mean population length for piscivore species inside reserve sites before and after reserve establishment. Error bars represent S.E. of the mean.

7.5. DISCUSSION

In Nabq fishery the establishment of a marine no-take reserves has been coupled with the implementation of more standard traditional fisheries measures, such as the introduction and enactment of restrictions on minimum mesh size and the prohibition of destructive fishing practices. In practice it was found that the use of a network of no-take fishing reserves as a means of regulating fishing effort was more socially acceptable to the fishing community than was the alternative of introducing more severe regulations involving monitoring and restricting fishing yield or effort. Further, the no-take reserves provided insurance against overfishing of breeding stock, as well as achieving conservation of habitats and diversity within their boundaries (Rowley, 1994).

In recent years it has come to be expected that the elimination of the fishing mortality within marine fishing reserves will increase stock biomass and mean population size. An increasing number of studies have shown in particular an increase in the abundance of the larger predatory species previously targeted by fishing following establishment or enforcement of no-take reserves (Russ, 1985; Ayling and Ayling, 1986; McClanahan and Muthiga, 1988; Buxton and Smale, 1989; Watson and Ormond, 1994). Thus in particular they appear to maintain stocks of the more vulnerable K-selected species that are easily overfished even with fisheries management schemes of quotas and mesh size regulations.

An increase in fish numbers may be apparent relatively soon after removal of fishing mortality. White (1988a) and Russ and Alcala (1994) detected that fish abundance in coral reef reserves in the Philippines increased within a few years of their establishment. In the Caribbean, Polunin and Roberts (1993) found that 4 years of protection from exploitation allowed apparent recovery, and Roberts detected a 60% increase in biomass within 2 years of protection in Saba Marine Park. In general, it has been suggested by

Roberts (1993) that 2-3 years of reserve protection is usually sufficient for influences upon the abundance and biomass of commercially targeted stocks to become evident. This suggestion in consistent with the present study in which UVC indicated that after two years fish stocks were showing signs of increasing in areas where moderate fishing pressure had been curtailed.

Increased catches in adjacent fishing grounds have been suggested by White (1986), Roberts and Polunin (1991) and Rowley (1994). Further several studies (Russ and Alcala, 1989; Alcala and Russ, 1990; Rakitin and Kramer, 1996) have provided evidence of such benefits. The rise in mean CPUE at fished sites at Nabq two years after establishment of no-take reserves, although not statistically significant, is in keeping with such evidence.

An increase in stocks in areas adjacent to marine reserves could be due to either emigration or spill-over of adults from the protected area, or to enhanced recruitment following improved spawning success. As stocks build-up within protected areas, increasing population pressure appears to promote emigration to nearby fishing grounds (Russ and Alcala, 1994). In their study Alcala and Russ (1990) found a positive correlation between the distance from the reserve boundaries and the density of commercially targeted fish species, supportive of such an effect.

An increase in reproductive potential is also expected because an increase in abundance of species targeted by the fishery will provide a larger numbers of spawning individuals. In particular a shift in population size structure is expected to greatly increase spawning potential, since fecundity and larval production of fishes typically increases exponentially with increase in fish size. However the extent to which local recruitment is enhanced will depend on patterns of water movement (Doherty and Williams, 1988) and the timing and length of the pelagic larval period for any species. This has been reported by Thresher and Brothers (1985), Victor (1986), Wellington and Victor (1989) and Thresher and Brothers (1989) to vary between 2 and 11 weeks, although the precise duration of the dispersal phase may depend on geographical area and other conditions (Sale, 1980; Munro and Williams, 1985; Brothers *et al.*, 1983; Victor, 1986). Depending on the duration of this stage, larvae may be transported over large distances, influencing biogeographical distribution patterns (Leis, 1986). On the other hand larval transport may be moderated by vertical movement of larvae in the water column (Leis, 1991 and 1993), and there is increasing evidence from some studies of at least some regional retention of larvae. Without further studies, the degree of local or regional retention of larvae from Nabq would be difficult to estimate.

Originally about 20% of the coastline of the Nabq protectorate was virtually unexploited by fishermen, because of difficulties of access. Following the establishment of the no-take reserves this figure has increased to approximately 60%. This proportion is high compared to the percentages recommended by IUCN and WWF, which range between 10-35%. Thus on the one hand this higher than normal proportion should enhance the likelihood of differences in fish abundance being detected between fished and unfished areas. On the other, the intensity of fishing, even at the heavily fished sites, is not severe compared to that in some other countries, so that only a relatively small difference in standing stock and CPUE might be observed?

The arrangement of no-take reserves at Nabq was decided with several considerations in mind. First as discussed above the areas had to be acceptable to the fishermen themselves; understandably they wanted that sites convenient for trammel and gill netting should remain open to fishing, but were content that sites with hard access should be formally designated as reserves. Further the largest of the no-take areas extends for approximately 8.5 km which was the maximum that would be accepted by the fishing community whose integration into the decision making process was vital for the successful implementation of the fisheries management plans. More generally the acceptability of the no-take reserves to local fishermen may be linked to the Bedouin traditions of conserving natural resources such as trees or areas of grazing, in part as an insurance against hard times.

Second it was decided to establish several small no-take areas rather than one large one in order to encourage any spill-over effect to adjacent fishing grounds. As suggested by

Rowley (1994) movements of adult fish from no-take reserves to exploited areas will be influenced by a number of factors including perimeter to area ratio and edge porosity. It has been also suggested by Roberts (1994) that no-take reserves that range between 1 and 3 km in length could be quite large enough to be effective in benefiting a wide range of coral reef fish species. For example, the size of the Sumilon reserve in the Philippines is 0.4 km^2, Saba Marine Park in the French Antilles is 0.9 km^2, and the central section of Hol Chan marine reserve in Belize is 2.6 km^2.

Third, there are theoretical reasons why a network of small reserves might be expected to be more effective for fisheries management than a single large one (Holland *et al.* 1993): different types of spawning area may be preferred by different species in a multi-species fishery, and there is likely to be a greater probability of successful recruitment to nearby fishing grounds if they are located in different directions and at different spacings from a network of reserve sizes and reef types. With such considerations in mind the largest of the no-take areas was established at the far northern end of the Nabq Protected Area, so as to increase the probability that larvae and new recruits could be carried to the adjacent fishing grounds towards the south by the prevailing northerly water currents.

Fourth, marine reserves also protect habitats and other species against habitat degradation and loss of biodiversity that occurs in most exploited reef areas (Dayton *et al.*, 1995). A network of reserves is more likely to provide protection of different representative coral reef habitats, and hence to provide for better conservation of biodiversity, since different species may be present in different areas (Holland *et al.* 1993; McClanahan, 1994).

Fifth, social factors affecting the location, size, and extent of the no-take reserves included the need for fishing areas to be accessible to different groups of fishermen living or fishing in different parts of the protected area.

And finally it was intended to establish a series of no take reserves of different sizes so that the effectiveness of different sizes in maintaining stock numbers and supporting spill-over could be investigated. Thus four of the reserves ranged between 1 and 2 km in length, while the longest extended for 8 km. However, given the time taken to implement the scheme, and for fish stocks to essentially build-up and spill-over into fishing grounds, it was not expected that an effect of size of no-take reserves could be detected during the present study. It is hoped that more detailed monitoring of fish populations adjacent to boundaries of different sized reserves can be undertaken in the near future.

The initial period of introductory fisheries management activities which lasted for about a year and included interviews and informal discussion with local fishermen and community leaders, including attendance at social events, was considered essential in gaining social acceptability for the establishment of the no-take areas and the enforcement of gear restrictions. This and the subsequent organisation of frequent meetings with the fishing community and the community rangers proved extremely time consuming, and greatly reduced the time available for other research and management activities. On the other hand the co-operation and assistance subsequently provided by the fishermen was probably indispensable, besides which the community rangers played an invaluable role in patrolling the coast and assisting in the collection of catch and effort data. The author is indebted to all of them.

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CHAPTER 8

General Discussion

8.1. CONCLUSIONS

The intention of this study, as described in chapter 1, was to initiate research and monitoring which would enable the conservation authorities to take management decisions on the basis of scientific evidence. Effective management of coral reef and associated coastal resources requires an appropriate ecosystem approach. A comprehensive, well co-ordinated management effort requires effective science, effective institutions, and policies that encourage the type of enforcement required.

In particular research and monitoring was required as a scientific basis for determination of sustainable levels of use of renewable resources within the Nabq Protected Area and thus enhancing the decision making capacity of Park managers. Hence the major concern of the present research was to quantify both the standing stock biomass of the most important renewable resources, and the levels of impacts upon them including existing levels of human exploitation. Such work presents an essential preliminary step towards the environmental evaluation of the protected area's ecosystems and resources that is urgently required to plan and implement for sustainable coastal zone management schemes.

The data collection involved in resource assessment highlights ecological questions and management issues that should encourage further research that aims to replace reactive management procedures with predictive management policies to facilitate sustainable use of natural resources within Protected Areas.

8.1.1. Mangrove vegetation

This study has fulfilled the aim of describing the character and zonation of the mangrove stands of Nabq, and of estimating biomass and rates of leaf litterfall. The regenerative capacity of the mangroves has also been investigated. This was despite a number of constraints imposed by the need to employ only non-destructive methods (with limited exceptions). Thus, estimates of production had to rely on measurements and leaf counts on tagged branches and twigs, rather than on harvesting methods that would require consecutive cutting of large numbers of branches to sample different cohorts of trees. However, not only did the methods employed in this study appear to give reliable estimates of leaf production, but also they very probably provide a more practical approach for the rapid assessment of this mangrove habitat. This is when compared to those estimates based either on harvesting, monitoring rates of oxygen or carbon dioxide exchange or radio-labelled carbon isotope incorporation, or methods based on estimates of light absorption by the canopy. In addition to the destructive nature of harvesting methods, they also tend to assume that the damage caused by the harvesting process does not affect the production of the plants. They are also impractical to apply for short-term assessments, as accumulation of biomass, especially in mature slow growing habitats, is typically reduced. Methods based on short-term estimates of rates of photosynthesis requires complicated and expensive equipment that was impractical for the rapid assessment of such mangrove stands. Further, these methods can not easily allow for the considerable variation in rates and patterns that occur on both a daily and seasonal basis. And an approach involving a comparison of light levels within and outside the mangrove stand could not be reliably employed because much of the stands consisted of scattered scrubs and trees whose canopy was typically at ground level. Further, the interpretation of such data would rely on assumptions about the relationships between light interception and productivity that, being derived from studies of mature forests in other tropical regions, were unlikely to be practical for application to *A. marina* trees in Nabq.

Using the methods adopted, above ground biomass values equivalent to 0.54 to 7.4 kg m^{-2} were obtained, notably less than those for *A. marina* in some other tropical regions. The results from this study thus confirm the suggestion made by Duke (1990) and Lugo and Snedaker (1974) that a reduction in structural development and biomass in *A. marina stands* may be expected at higher latitudes. The rates of growth and production of leaf biomass were also at the low end of the range of values reported for *A. marina* even when compared to those from the relatively similar arid environments of the southern Red Sea (Saifullah *et al*, 1989). It may be expected that net productivity is limited by rates of water supply to the canopy, and the larger proportion of the energy budgets required are allocated to manage osmotic relations and other physiological adaptations under conditions of hypersaline soils and low temperatures as suggested by various workers including Lugo and Zucca (1977), Por *et al*, (1977), Tomlinson (1986) and Clarke and Allaway (1993).

Thus there is good reason to believe that *A. marina* at Nabq may be surviving at, or close to, their physiological limits. The high salinity environment experienced by *A. marina* at Nabq was discussed by Por *et al.* (1977), and their regulatory mechanisms have been described by Leshem and Levison (1972). The observations of flooding and ground water salinity described in chapter 2 suggest that the survival of mangroves at these locations is probably dependant on the supply of brackish water to specific sites. The present study thus supports the view that the pattern of fresh water input from inland to coastal sediments is one of the critical factors determining the distribution of mangroves in hypersaline environments (Por *et al.*, 1977; Semeniuk, 1983). The data described in chapter 3 also indicate that ground water supply is also a critical factor limiting sapling growth and survival. Extensive recolonisation within existing stands or colonisation of new areas was apparent in rare years when there is much greater rainfall than normal in the Wadi Kid and Wadi Addawy catchments.

Underground fresh water seepage into the mangrove soil could also be significant in providing inorganic nutrients, which are also known to be a significant control on growth of mangrove trees. The mangrove stands in turn probably contribute to the productivity of the subtidal and marine zones, both through input of leaf litter, and as a result of nitrogen fixation within the mangal in Nabq.

The importance of flood water drainage into the mangrove stands for maintaining their productivity and hence biodiversity draws attention to the need not only to protect the mangroves *in situ*, but to protect the catchment which is the origin of the ground water supply and occasional flooding. The catchment needs to be carefully protected from possible sources of human-induced pollution, as well as any activities likely to interrupt the supply of water. Conservation of the ground water supply is also important, since excessive pumping could result in a failure of the supply to the shore habitats. The extraction of ground water requirements by the local Bedouin population should be managed for sustainable supply. Management of the catchment to protect the existing ecosystem is also compatible with the conservation of the indigenous vegetation zones that are either important as grazing for wildlife and livestock, or of conservation value.

The uniqueness of the Nabq mangrove environment throughout the Gulf of Aqaba suggests that management should ensure their protection on conservation grounds as well as their sustainable use on resource management grounds. There may also be a case for their conservation on the grounds of the genetic resources they represent, since it is possible that the variety of *A. marina* found at Nabq may differ genetically from the typical Indian Ocean form in a way that enables it to cope with the extreme conditions of temperature and salinity. Conservation of the Nabq mangroves is compatible with carefully regulated extraction of timber for firewood or construction by the local Bedouins. However it appears that the growth and production of the trees must vary considerably from year to year due to the ecophysiological adaptations of the plants for these extreme environmental conditions. Consequently the amounts of timber that can in principle be taken will also vary from year to year. In order to manage mangrove exploitation therefore it will be important in future studies that both the rates of timber production as well as ground water input to the stands are regularly monitored.

8.1.2. Inshore coral reef fisheries

The fishery at Nabq may be characterised as a multi-gear multi-species artisanal fishery subjecting stocks to moderate fishing intensity. The principal aim of the research into this fishery, as outlined in chapter 1, has been achieved. The abundance, distribution and diversity of commercially targeted species has been described; it was not expected to be able to investigate the abundance and diversity of non-commercially targeted coral reef fish species. The current spatial and temporal patterns of fishing effort were quantified for different gear types, and landings sampled to investigate catch composition and weight. And in particular the area based surplus production models applied to the yield/effort data has provided an estimate of the probable levels of maximum sustainable yield (MSY).

The relationship of yield to effort indicates that effort levels do not typically exceed intensities beyond those producing maximum sustainable yields, except at two sites, Ghargana and Manquatta, which are more heavily exploited. These two sites are those adjacent to the Bedouin village of Ghargana and to the largest fishermen's encampment around Shora Al Manquatta. While CPUE at these sites appears to have declined, fishermen may still exploit these sites more than others because of the smaller cost (vehicle and fuel) and time (especially if walking) required getting to them. Therefore, while the CPUE curve falls off at these sites, an economic evaluation of catch per unit time and resources (costs) against effort would probably not do so.

The establishment of marine fishing reserves north and south of these two fishing grounds should provide insurance that the stocks at these sites are less likely to collapse due to growth or recruitment overfishing. Nevertheless it would be desirable avoid any increase in fishing intensity than the present levels at these sites. One essentially effective management approach would be the introduction of a fishermen-licensing system inside the Protected Area that could limit the fishing effort at these two sites to local families with traditional rights. This should ensure the stability of the fishing effort.

Although the relationship across sites between yield per unit effort and effort has suggested an approximate range of values for MSY, more detailed information about rates of recruitment, mortality and migration, as well as data on variation in stocks and catch from year to year, would allow more confident estimates of MSY to be developed. To achieve this, landings and catch per unit effort should in future be sampled on a regular basis by the community rangers in order to closely monitor the effects of marine fishing reserves upon catches at different fishing grounds. Studies over an extended period of time will also allow investigation of any cumulative time-based effects of moderate levels of fishing upon CPUE and yield. This will also permit development of fisheries production models that could give more specific estimates of the levels of sustainable exploitation in different habitats. Continuing research is desirable in order to refine the present conclusion and enhance the decision-making capacity of fisheries managers.

Further research is also needed on another specific fishery at Nabq, concerning the spiny lobster (*Panulirus penicillatus*). These populations have been previously described and studies at the nearby reefs of Dahab by Plaut and Fishelson (1991), Plaut (1993) and along the northern Saudi Arabian reefs (Hogarth and Barratt, 1996). They have all suggested that the population is smaller than those in other regions, which could be attributed to the geographical isolation of these populations. Further, this species was observed to be heavily fished, as elsewhere along the Egyptian coastline of the Gulf of Aqaba, and local fishermen have reported a considerable decline in individual size over the last few years. Indeed, very small individuals (< 15 cm) were often observed to be mature and carrying eggs, an effect supporting the interpretation that this resource is being overexploited. Further such individuals were being caught and marketed, despite the existing size regulations and the principles which were widely accepted by the local fishing community. It seems that poaching occurs during the summer, when typically younger visiting fishermen infringe the seasonal closures and size limits (pers. obsrv.). Enforcement of the lobster fishery regulations could be favoured by the application of a complete ban on the marketing of spiny lobsters during the closed season, and on the sale of individuals below the legal limit throughout the South Sinai Governorate. Studies on the population levels, and growth and recruitment rates of this species are essential to provide information on sustainable levels of exploitation.

The marine fishing reserves that were established in Nabq aims to provide management of fisheries at the ecosystem level rather than at the species level. As described in the last chapter some of the benefits predicted for this system of fisheries management have been confirmed by a number of relatively recent studies in several different coral reef fisheries. Further, theoretical studies suggest additional benefits that are based on good reason, as discussed in chapter 7, but have yet to be proven. The extent of these benefits will be influenced by the fact that following the establishment of the no-take marine reserves approximately 60% of the Nabq Protectorate coastline is effectively unfished, taking into account that other sites outside the reserves are typically unfished because of access limitations. Thus there is every hope that by application of the combination of closed areas, gear limitations and a licensing system for fishermen, the sustainability of the fishery can be ensured. The anticipated benefits of this management regime were discussed in more detail in chapter 7.

The integrating of the local Bedouin fishermen within the fisheries management process as well as with other conservation and management activities has proved essential to the successful implementation of management plans. The social acceptability of restrictions on exploitation was found to be substantially raised by education. An understanding of the inevitable outcomes of over-exploitation and of the linkages between different habitats within the coastal ecosystem not only secured their support for the setting up of the no-take reserves and the prohibition of destructive techniques, but also added to the personal satisfaction and well being of the fishermen as well. Similarly the employment of several socially respected individuals from the fishing community as part-time community rangers not only helped to gain support for conservation measures, but also was important in enhancing the status of these individuals and activities as well.

8.1.3. Other issues

To date the implementation of a fisheries management regime has been successful, and research on the development and growth of mangrove stands provided data on which a sustainable management programme may be based. However it should be emphasised that there are other management issues affecting both marine and terrestrial resources within the Nabq Protectorate which require further investigation.

The reefs and sea-grass beds adjacent to the recently established small-scale shrimp farm established near the mangrove stands near Ghargana requires careful monitoring in order to detect and prevent any impacts to the surrounding interrelated ecosystems, especially in view of the enlargement of the shrimp farm currently on progress.

Tourism activities may also be expected to intensify as coastal development extends from the Ras Nasrani area towards the protected area. In particular a large complex of hotels and leisure facilities is now under construction at the area, which is immediately adjacent to the southern boundary of the Nabq Protected Area. To date the numbers of visitors has been limited, and the work of Park managers and rangers has been effective in protecting habitats. However, incidental impacts may be expected to increase in the face of mounting pressures from tourist activities. Particular impacts that will need to be monitored and regulated are: damage to halophyte vegetation and compaction of beaches and soils due to increased numbers of 4WD vehicles driving off the marked tracks; increased disturbance to wildlife such as nesting egrets and osprey, and gazelles whose numbers inside the protected area are just beginning to increase; and possible increased damage to vegetation through casual collection for fuel or fodder. On the one hand the dispersal of activities within the protected area is probably to be encouraged, for example by the provision of amenities at different sites. On the other hand zoning plans, that allow for specific uses and activities in different areas, should be developed, and a portion of the protected area set aside as a strict scientific reserve, in order to preserve biological and genetic diversity.

8.2. FUTURE MANAGEMENT OPTIONS

Detailed recommendations are not appropriate to this academic study, but will need to be developed through an appropriate process of consultation and review in the near future. However some preliminary suggestions may be advanced.

8.2.1. Management of mangrove stands

Consideration should be given to developing a management regime that will permit some sustainable use of mangroves. The data described in chapter 3 provide an indirect estimate of the rate at which timber should be produced by *A. marina* in these stands. However it is clear that production rates vary considerably between different zones and from year to year. In addition it must be emphasised that the rate at which timber can be harvested will be significantly less than these production rates, since even with careful selection of material, part of the production will be compensated for by natural mortality of trees and branches. A harvesting quota implied by the Park managers will need to distinguish between fallen timber, dead branches that may be cut, and live branches selected for thinning.

Such a harvesting regime should not be introduced except on a trial basis at a few sites and the effects of harvesting on tree growth and litter production closely studied. In practice such experimental work will be the best ways to determine the most likely sustainable yields. Probably such trial harvesting should be focused on the lower-middle intertidal zone. Trees in the inland part of the mangrove are living close to their physiological limits and probably have very low rates of production. Further the habitat and food they generate plays a role in supporting the faunal community of insects and small vertebrates that occur in the supralittoral zone, and the plants themselves help stabilise the shoreline. Equally the trees in the middle-lower intertidal zone, both because they are best developed, and closest to the open reef, probably play the most significant role in supplying leaf litter and organic nutrients to the other parts of the coastal reef ecosystem. Also this zone is the most used for roosting and nesting by birds, and the most difficult for people to access and exploit.

Even if a management regime allowing sustainable exploitation can be identified in the future, which is less likely to occur, it will be important that a significant proportion of each stand is set aside for strict protection, in order to conserve habitat and species diversity, and provide comparative areas for scientific study and monitoring.

8.2.2. Management of reef fisheries

The present management regime of imposing certain restrictions on fishing activities and protecting a network of no-take reserve needs to be maintained and enforced, at least for the foreseeable future. The results and conclusions of work to date need to be explained to the fishing community in order to secure their continued support for this proposal. Further research is also essential, to monitor catch and effort in the fishing areas, and to examine in more detail the effects of the no-take reserves. It would also be of value to implement a tagging (capture / re-capture) programme which could provide data on the rates of growth and extent of movement between reef areas of key exploited species.

One option which may be considered is to open for a strictly limited period one or possibly two of the no-take areas. There is an experimental justification for such a measure, since it would enable the catchability of fish within the no-take area to be determined, for comparison with that in fishing areas. It would also provide local fishermen with some tangible benefit in return for their restraint in observing the no-take zones. In addition however other ways of providing benefit to the fishing community should be explored.

In summary, the Nabq Protected Area incorporates a biologically diverse assemblage of habitats and communities with abundant ecological interactions. These also represent valuable renewable resources; in particular for the local Bedouin community that traditionally have exploited them on a sustainable basis. In the face of the recent enormous expansion of tourism and residential areas in South Sinai there is an increasing threat of overexploitation of these resources, leading to degradation of habitats and loss of biodiversity. Research undertaken for this thesis has indicated how at least two of these resources, the mangrove stand and the reef fishery, may be managed on a sustainable basis.

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APPENDIX

Figure . The different intertidal zones in Nabq where the mangrove *A. marina* grow. The figure shows that mangroves also survive in sites with high micro-topograpgraphic elevation above sea level at the upper intertidal zone.

Figure 2. The mangal ecosystem in Nabq support a wide range of gastropod and micro-algal species. Figure shows that branching of the mangrove *A. marina* in Nabq could occur well beneath sea-level

Figure 3. The relatively heavy rainfall in the mountain catchment during 1994 led to flooding of rain water from the catchment through the inland wadis towards the coastal zone. Surface flood water run-off was apparent throughout the mangrove stands in 1994 and in a similar flooding event in 1996.

Figure 4. Recolonisation of new saplings of *A. marina* in Nabq towards the southern margin of the stand of Shora Al Rowaisseya. This site was notably flushed by flood water surface run-off from the inland wadis during two major flooding events in 1994 and 1996. In addition, a relative reduction in ground water salinity of the mangrove soil was also detected at this site.

Figure 5. The inter-related coastal habitats in Nabq include halophytic salt marsh, mangal and coral reef ecosystems. Local Bedouins exploit these natural resources with moderate levels. The figure shows the typical encampments used by Bedouin fishermen as landing sites for their catches.

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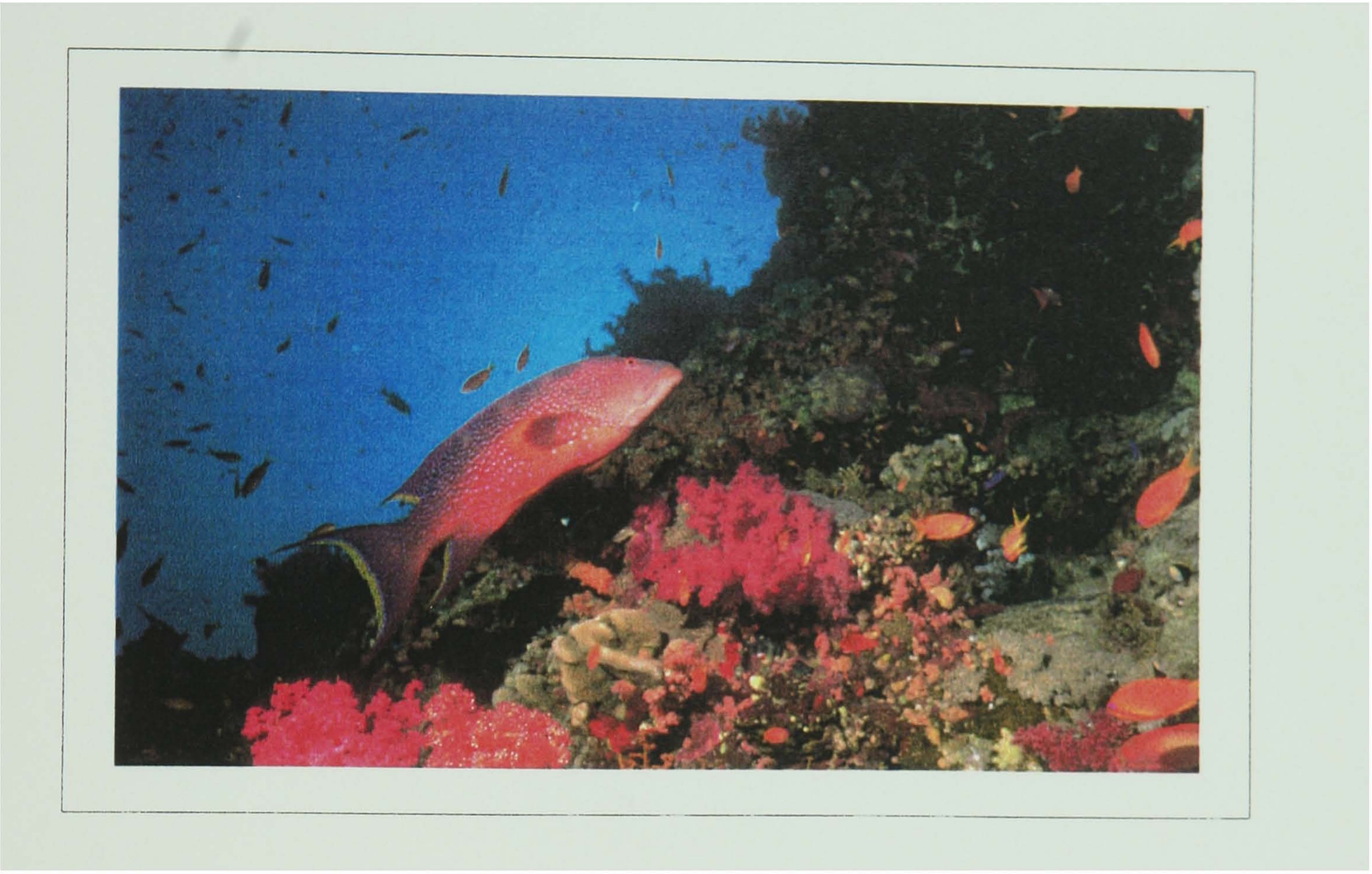

Figure 6. During UVC the abundance and size class of different commercially targeted species were recorded. For example, the serranid species *Variola louti* shown in figure was included in the counts at a depth of 17m and its size class was categorised as ¾ grown individual.