Helgoländer wiss. Meeresunters. 30, 295–314 (1977)

The mangal of Sinai: Limits of an ecosystem

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ABSTRACT: The northernmost mangrove forests of the Red Sea are described. Temperature and salinity conditions were found to be extreme, obviously reducing the diversity of the ecosystem and presumably setting the geographical limits of its distribution. The Sinai mangal grows on hard fossil coral bottom, without any influence of estuarine sedimentation. Primary production of the open Red Sea waters is extremely low, therefore, the rich biomass of the Sinai mangal is built up by an autarkic nutrient recycling system. Several biotic zones within the Sinai mangal are described following an inshore-offshore transect. Vertical zonation of algae and animals on the aerial roots of *Avicennia* is discussed. The Sinai mangal, "Shura" by its local name, is proposed as an ideal model for the study of trophic relations within the mangrove biome.

INTRODUCTION

The mangrove forests or "mangal" (MacNae, 1968) are a typical life community of the tropical shores. Although equal in importance to coral reefs, as far as frequency is concerned, mangrove forests have been little studied as integral ecosystems. Much has been written about the phytosociology of the mangrove trees, but studies including also algal and animal associates are rare (Walsh, 1974).

The Sinai mangrove was first mentioned by Ascherson (1887) and the mangroves of the Egyptian African coast by Kassas & Zahran (1967).

There is a difficulty in defining the ecosystem of the mangal. If the coral reef is a rich association of specific reef dwelling species which evolved and diversified on the high-productivity oases created by the scleractinian-zooxanthellae symbiosis – the situation of the mangal is different. Perhaps with the exception of the mangrove tree species, there is no species of alga or animal which is specifically bound to the mangal.

Mangal species of algae and animals are littoral quiet-water species, resistant to or requiring suspension-rich waters and silted bottoms; species resistant to considerable fluctuations in salinity and temperature. This is, therefore, a relatively limited diversity of marine species, as compared with the open seashore. The mangal is, however, one of the high productivity environments of the marine shore. Therefore, we can define the "mangal" as an ecosystem based on an accumulation of nutrients produced by the mangrove trees upon which lives a high biomass of a relatively low-diversity community of algae and animals – resistant to extreme environmental conditions.

This definition of the "mangal" becomes especially evident in the case of the Sinai mangrove. The mangal of the Northern Red Sea is a monospecific forest of *Avicennia marina* which lives under extreme conditions of high salinity, and low winter

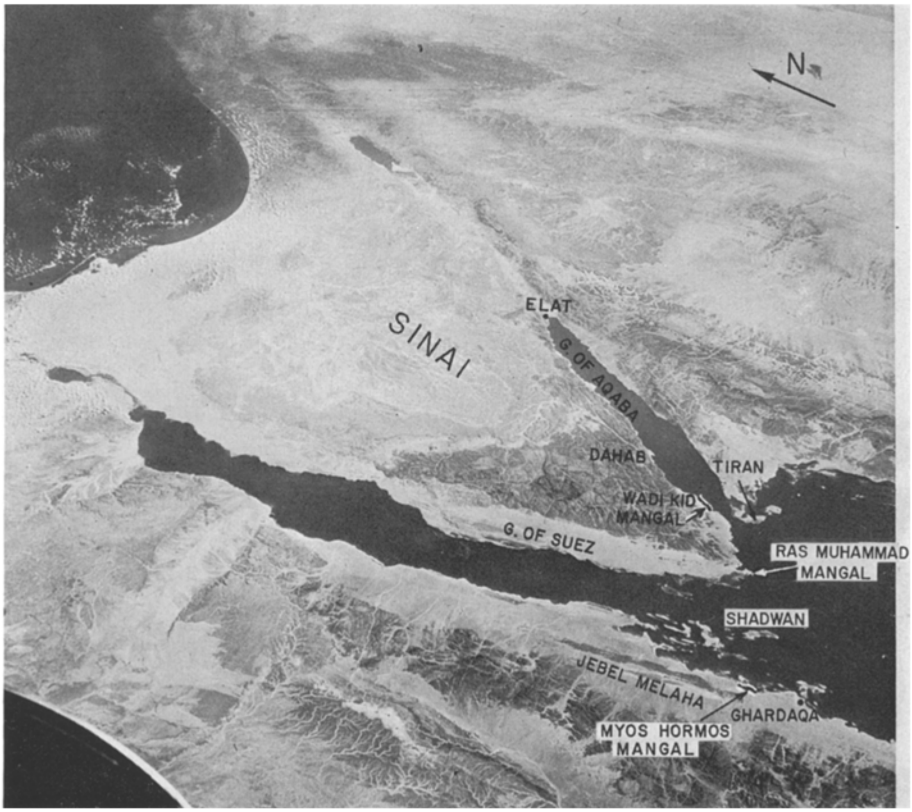

Fig. 1: Satellite photograph of Sinai (NASA, Gemini XI). Positions of the different mangal areas are indicated

temperatures. More important, it is an oasis of high biomass wedged in between the desert of Sinai and the blue oligotrophic waters of the Red Sea – one of the low productivity deserts of the world ocean. There is no import of nutrients through estuarine river influx or continental runoff; there is no enrichment from the sea. That the mangal is based on the recycling of the mangrove tree products – as emphasized by Odum & Heald (1975) – is obvious in Sinai. The few hardy and sheltered-shore algae and animals reach unusual population densities here.

GEOGRAPHICAL POSITION OF THE SINAI MANGAL

Mangrove thickets are found only on the south-eastern tip of the Sinai peninsula (Fig. 1). One small group of a few scores of *Avicennia* trees grows in the channel which cuts across Ras Muhammad – the southern extension of the peninsula. Four other mangrove thickets of more considerable density are found along a stretch of

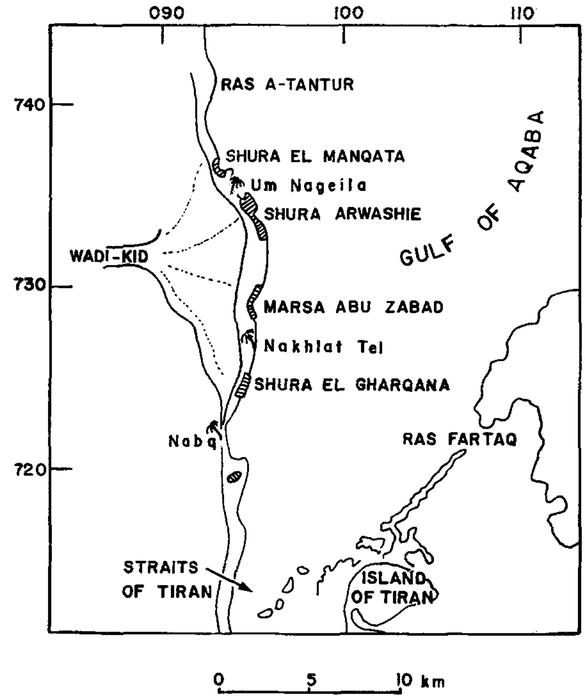

Fig. 2: Position map of the mangal areas of Wadi Kid (shaded areas)

coast of about 20 km length, which corresponds to the alluvial fan of Wadi Kid (Fig. 2) (between 28° 0,7′ N – 28° 18′ N), to the north of the small oasis of Nabq. The four groves are connected by stretches of sparse growth of dwarfed mangrove, and it stands to reason that some of the present thickets might have been contiguous in the past.

The sketch map (Fig. 2) gives the popular bedouin names which should be used. The names have been obtained from Muhammad Audi, a local bedouin who makes his living around the mangrove. From south to north: (1) Shurat el Gharqana (Fig. 3); (2) Marsa Abu Zabad (in fact a group of smaller thickets on the shores of a bay); (3) Shura Arwashie (Fig. 4); (4) Shurat el Manqata (Fig. 5).

There is no doubt about the use of the name "Shura", which means mangrove to the bedouins. The names may differ in details or moreover, be differently spelled or transliterated in other sources.

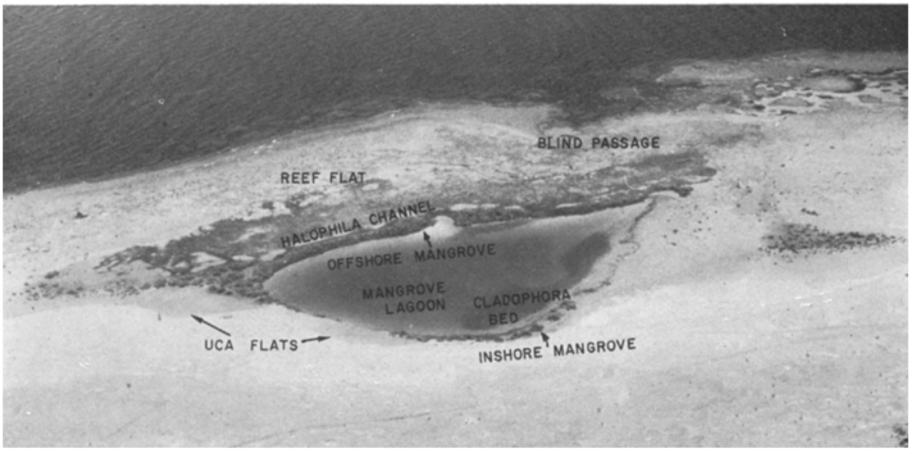

Fig. 3: Mangal of Shurat el Gharqana. Several features are indicated

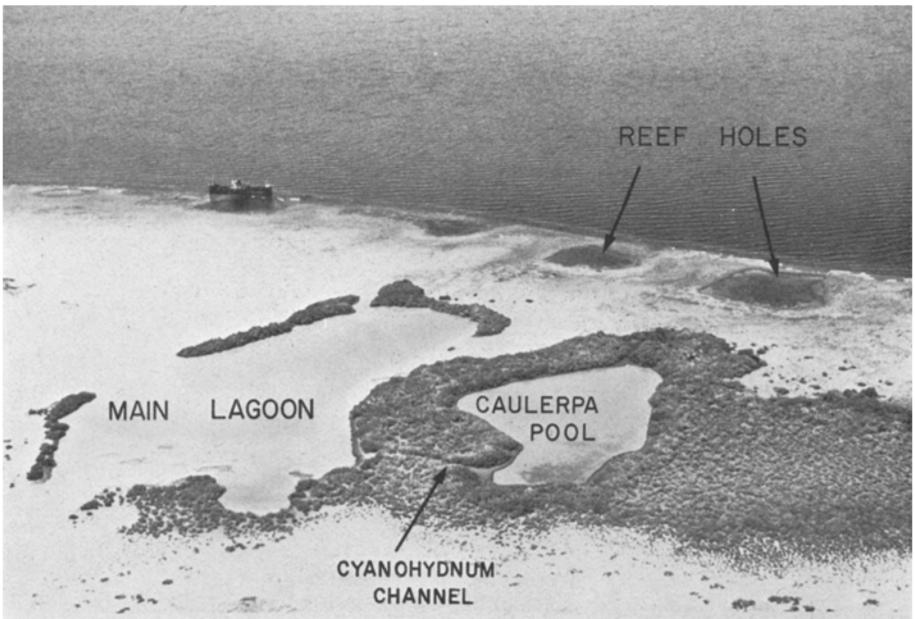

Fig. 4: Mangal of Shura Arwashie, with some topographic features indicated

Shura Arwashie is the biggest of the mangrove forests, and it has been selected for intensive research as being probably the most typical representative of the Sinai mangrove.

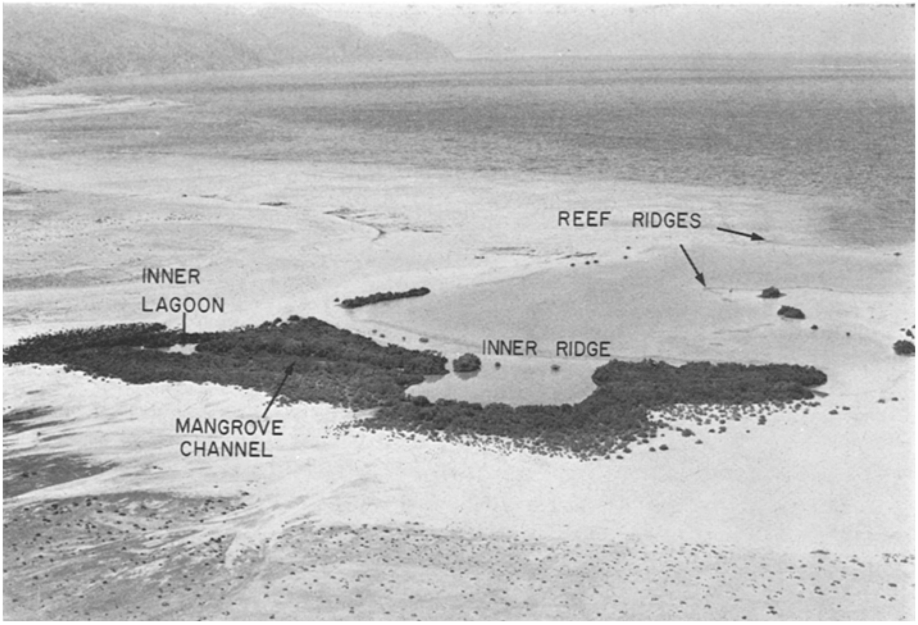

Fig. 5: Mangal of Shurat el Manqata. Some features are indicated. Cape Ras Atantur in the far back

TOPOGRAPHY OF THE SINAI MANGAL

Accepting the sparse mangrove of Ras Muhammad as an exception, the Sinai mangal can be characterized topographically as follows:

The tree growth develops in the shelter of a broad subfossil-reef flat which at low tide is only covered by a few centimeters of water or is dry. Behind this first line of fossil reef there are two to three other similar old reefs situated landward (Fig. 5).

Within the reef flats there are rows of roundish "reef holes" from ten to a few hundred meters in diameter. The reef holes of the seaward reef flat are not surrounded by trees. However, the "holes" of the second landward flat become true lagoons around which the mangrove forest develops. Subject to tidal fluctuations, the lagoons are 50–170 cm deep (Fig. 4).

The reef holes — with infralittoral or supralittoral edges are a specific feature of the Gulf of Aqaba (Elat) reef, and they are found also farther north beyond the boundaries of the mangal (see Por & Dor, 1975 a).

Owing to the presence of a rocky reef bottom and lagoon-like pools around which the Sinai mangal develops – it can be characterized as a "reef mangrove" with some elements of a "peat mangrove" – following the terminology of Chapman (1940) and Rützler (1969). Reef mangroves were first mentioned by Tobler (1914) and Walter & Steiner (1936) from East Africa, and the fauna associated with this type of mangrove was described by Stephenson et al. (1931) from Queensland, Australia.

Here it is important to emphasize that the old reef-holes which turned into mangrove lagoons receive a permanent influx of water by seepage through the coralligenous rock. In this sense the mangrove pools of Sinai are "seepage pools" as several others along this coast (Por, 1975). There is an influx of seawater into the pools and there are indications that at Shurat el Gharqana there is also an influx of fresh-groundwater.

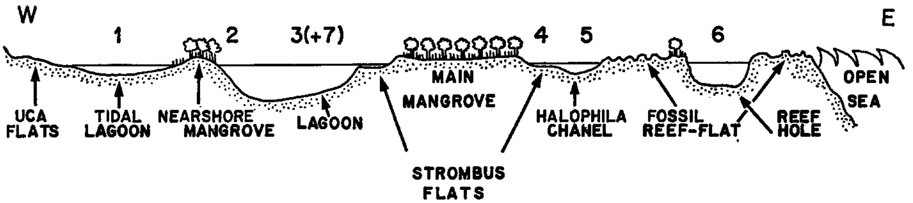

Fig. 6: Schematic section through the mangal of Shura Arwashie at low tide. Elevations are exaggerated. Numbers indicate hydrographic sampling stations

A section through the mangal of Shura Arwashie is presented (Fig. 6). The successive fossil reef flats (called also "*Strombus* flats" and "*Uca* flats") and "pools" and lagoons are shown. In the aerial photograph of Shurat el Manqata (Fig. 5) three successive coralligenous rock bars appear delimiting three consecutive pools. Mangrove growths are sparse on the seaward coral flat and are found especially on the shoreward rock platforms and around the inner pools.

A last feature to be emphasized is that of the seagrass channel – "*Halophila* channel" – a slightly deeper trench which runs in a longshore direction and separates the "outer" mangrove from the seaward coral platform and remains submerged at low tide.

HYDROGRAPHIC CONDITIONS

The mangrove shore of Sinai is very flat: where the mangal is best developed, at Shura Arwashie, about 600 m are in the range of the tidal action. Tides are semidiurnal, usually with ranges of 50–70 cm. Sometimes spring tides can reach 1 m. The more frequent neap tides have a range of as few as 20 cm. The tide is cotidal for the whole Gulf of Aqaba (Elat). Wave action is an important environmental factor. Storm winds, with a few exceptions, come from N-NE. Protection from this direction is necessary for the establishment of the Sinai mangrove. However, because of the extreme climatic conditions – chiefly, summer heat – flushing from the north is necessary especially in the period of neap tides. Stormy seas can sometimes penetrate the mangrove as far as the *Uca* flats and homogenize the physico-chemical parameters of the waters.

Evaporation values in Sinai are extremely high: over 300 cm/year. The almost permanent northerly winds considerably increase evaporation. Also temperatures and salinities in the waters of the mangal are very much influenced by evaporation and the dry winds.

Temperatures and salinities were measured at 7 stations representing a transect through the Shura Arwashie mangal (Fig. 7). Station 7 is an additional station, in "*Caulerpa* pool" – representing the special condition of this closed lagoon.

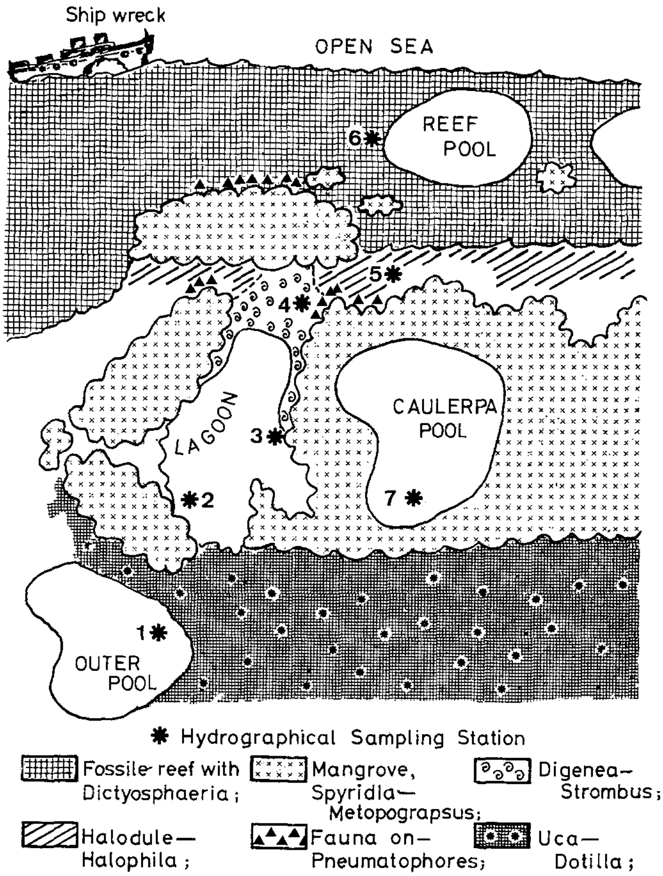

Fig. 7: Schematic drawing of Shura Arwashie mangal, with indication of the main biotopes. Numbers indicate hydrographic sampling stations

The stations were covered 8 times between July 1975 and May 1976, and the temperatures and salinities were measured at high and low tides of two or three semidiurnal cycles.

Temperature fluctuations are found along the profile, and they are considerable in a diurnal cycle. Seasonal fluctuations are also very marked and the alternance of windy and calm days, and of high and low tides is also expressed in strong and irregular fluctuations. The temperature curves for the seven stations are presented in Figure 8.

Simultaneous differences of up to 4° C between the stations have been found, but usually the differences are small. Differences between day and night temperatures are very extreme: for instance, on July 22, 1975 water temperature at Station 5 changed from 36.2° C to 28° C within less than 6 hours when the high tide brought in cooler water from the open sea. On March 2, 1976 water temperature at Station 1 was 9.1° C at 02.00 h and 12 h later was 20.3° C. It appears from Figure 8 that large scale diurnal fluctuations are found especially in the shallow stations and during high summer and on extreme winter days.

The range of seasonal temperature fluctuations reaches 27 ° C at Station 1, and even at the seaward Station 6 it is as high as 20° C (Fig. 9).

While the extreme summer temperatures are constant for a period of many months (May–October) the extreme winter lows are of short duration. Between March and April 1976 temperatures increased in Station 2 for example by 17° C in less than a month's time.

A stormy wind on a cold winter day, as it happened on March 2, 1976, can cause a maximal decrease of temperatures to 9° C. At the same time air temperature was 13.6° C (02.00 h). A day earlier at high tide (18.00 h) water temperature at the same station (St. 1) was 13° C while air temperature was 16° C.

In the summer, on windy days, water temperatures can be lower than air temperatures, but on calm days they are considerably higher.

The low absolute temperatures of 9–13° C in March 1976 should be emphasized as well as the seasonal and short-term fluctuations reaching ranges of 20° C and more than that.

The lowest value measured was 40.29 ‰ S. This corresponds to the salinity in the open sea opposite the mangrove (St. G, Klinker et al., 1977). The upper value in the mangal was 47.00 ‰ S at Station 1 (August 17, 1975; Fig. 10). Much higher salinities were found in isolated puddles among the mangrove trees. In tidal channels, such as the so-called "*Cyanohydnum* channel" of Shura Arwashie, 58.18 ‰ S was found in August 1975.

The differences in salinity along the profile are very marked and are in the range of 4–5 ‰ S and form a more constant gradient than the temperature differences. In the winter months the differences are minimal, but still consistent with the general pattern of landward increase.

The seasonal range of salinities also increases landward. In Station 1 it is 6 ‰ S and at Station 6 about 2.5 ‰ S. The decrease from the high summer values is steeper in the inshore stations than in the offshore stations. In the closed lagoon (St. 7) the diurnal range is small, the annual range of about 3.5 ‰ S and the differences between seasons are relatively small.

The high salinity period is that of June-September. This is however a conditional conclusion. August 1975 yielded high salinity values, but on 22–24 September the sea was stormy and salinity was unusually low in the wave flushed mangal.

Using a term coined by Hedgpeth and used by Por (Por, 1972) the Sinai mangal is a m e t a h a l i n e e n v i r o n m e n t established at salinities between 41–47 ‰ S. The σT values of the mangrove water fluctuate between 33.4 and open sea values of 27–28.

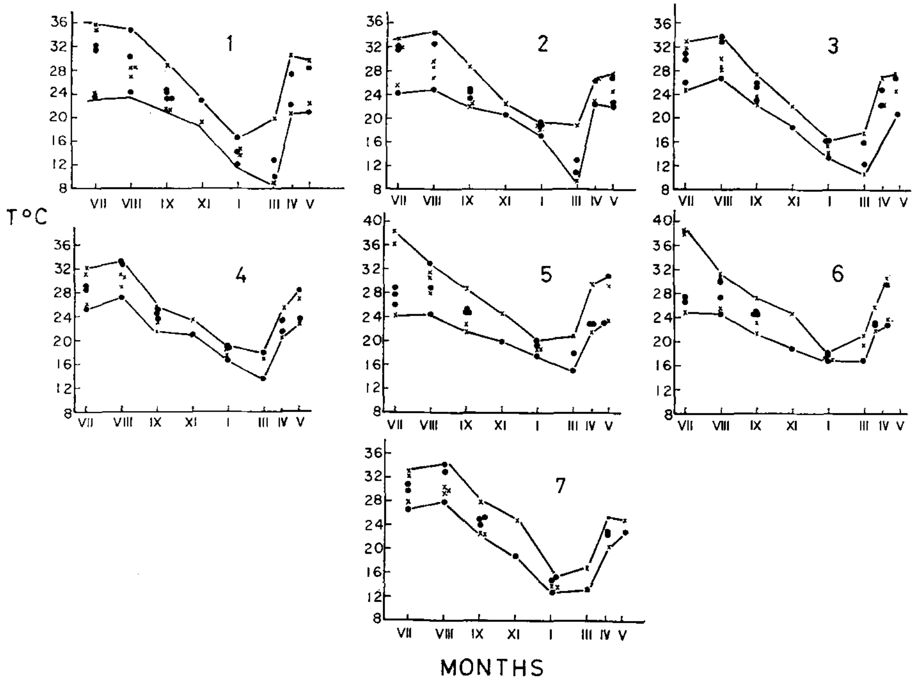

Fig. 8: Temperature curves of the seven sampling stations (between July 1975–May 1976) in Shura Arswashie ● – high tide; X – low tide

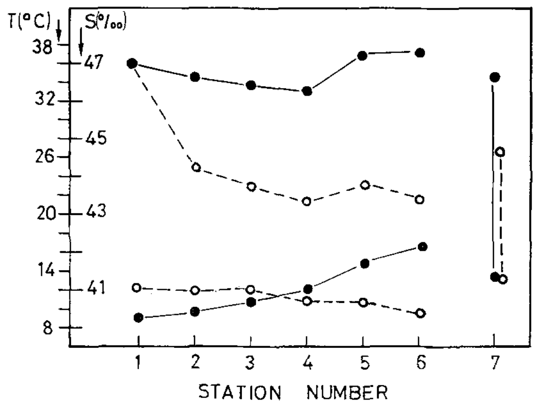

Fig. 9: Maximum and minimum temperature (●) and salinity (○) values in the seven sampling stations of Shura Arwashie (VII. 1975–III. 1976)

Other chemical parameters have only tentatively been measured. pH values are in the range of 8 to 7 (M. Shilo, pers. comm.).

Oxygen is often depleted in the lagoon waters during the night low tides. Figure 11 shows the curve of oxygen on 26–27 July 1976 at a point between Stations 2 and 3 in the lagoon. From values of supra-saturation at noon, O_2 content drops rapidly during the night low tide and reaches values near zero; the incoming tide brings oxygenated water, which is in turn rapidly depleted, till in the morning hours photosynthesis starts again. It is evident that this type of diurnal curve happens only on very calm days and probably only at high summer temperatures. However, this is

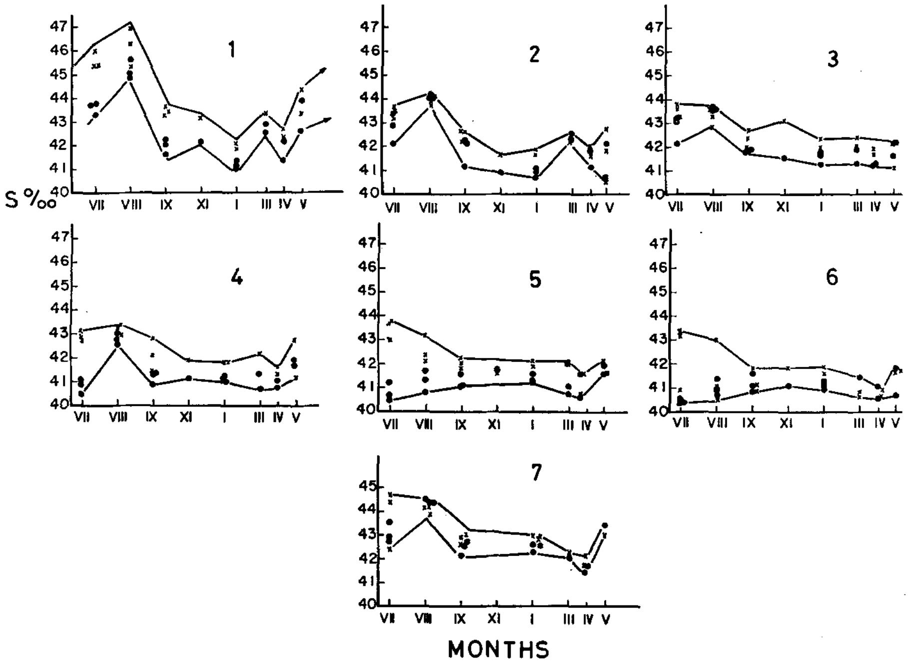

Fig. 10: Salinity curves of seven sampling stations (between July 1975–May 1976) in Shura Arwashie. ● – high tide; X – low tide

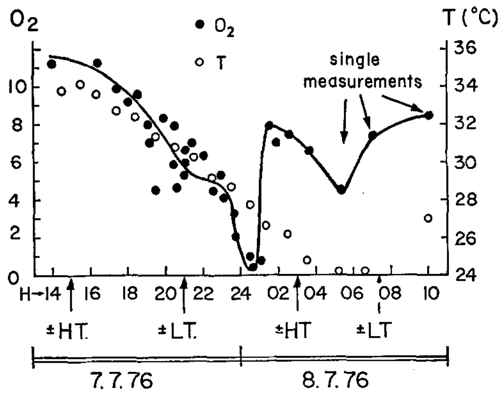

Fig. 11: Oxygen (mg/l) and temperature values of one continuous recording in Shura Arwashie lagoon (July 1976)

highly significant in indicating that the mangrove lagoons, despite their relatively large water mass can become anoxic for short periods and that the living world has to be adapted to such periods of anaerobiosis.

There are only a few nutrients measurements for the mangrove lagoon of Arwashie, indicating oligotrophic levels of N and P in the water (Sournia, in press; Dor et al., in press). The waters are rich in seston, but very poor in plankton. According to Sournia the seston content is of 7 mg/l as compared with 0.3–0.6 mg/l in the open sea near Elat. Chlorophyll *a* content in the water of the mangrove lagoon is 0.3 mg/l. On the other hand there are 2–4 μg/l chlorophyll *a* per g dry sand of the lagoon (Sournia, in press). The sediment exhibits therefore a much higher productivity than the open water.

AQUATIC FLORA AND FAUNA

The biota of the Sinai mangal contains some species which are typical for the Indo-Pacific mangal – although many of them do not live under the extreme conditions of Sinai. Another group of organisms characterizes the shallow lagoons of Sinai – salinity and heat resistant organisms. There are some representatives of the shoreward reef environments: species resistant to turbidity and reduced water circulation. Finally, on the aerial roots of *Avicennia* a number of species of supra- and midlittoral protected shores are found. A list given in Table 1 enumerates the animal species identified to date in the Sinai mangal.

A number of biotopes are listed below and will be treated separately: (1) the *Uca* flats; (2) the *Spirydia-Metopograpsus* community of the mangrove woods; (3) the *Digenea-Strombus* flats; (4) the *Halophila* channel; (5) the mangrove lagoon; (6) the pneumatophore of *Avicennia;* (7) the seaward fossil reef flats.

Not all of these biotopes are present in all of the Sinai mangals. Figure 7 shows the succession and approximate extent of some of these biotopes in Shura Arwashie. The sampling stations for hydrographic data have been selected in order to characterize the environmental conditions of some of these biotopes.

The *Uca* flats

This landward belt (Station 1) bordering directly on the desert association of *Zygophyllum* and *Anabasis* is a sand and mud covered area devoid of *Avicennia* or only with isolated and dwarfed shrubs of the tree. The *Uca* flats are situated on coral-stone bedrock; the thickness of the sediment layer varies. At low tide the entire belt is dry.

Besides blue-green algae in the sandy-muddy sediment – there is no algal vegetation in the *Uca* belt. A permanent but not specific element of the *Uca* flats is the amphibious snail *Pirenella cailliaudi* which appears in patches of hundreds of

Table 1

Preliminary list of animal species in the Sinai mangal

Foraminifera (det. Z. Reiss)
Peneroplis planatus
Spirolina arietina
Amphisorus hemprichii
Sorites orbiculus
S. orbitolitoides
Amphistegina lobifera
Cymbaloporella tabellaeformis
Ammonia beccarii "group"
Pararotalia calcar
Elphidium striatopunctatum

Porifera (det. M. Tsurnamal)
Haliclona ? tenuiramosa
Spongia sp.
Dysidea sp.
Tedania anhelans
Biemna ? fortis
Spirastrella sp.

Coelenterata
Dynamene sp.
Cassiopeia andromeda
Boloceroides mcmurrichii
Clavularia hamra
Acabaria pulchra (det. M. Grasshoff)
Stylophora pistillata (det. Y. Loya)
Siderastrea lilacea (det. Y. Loya)
Palythoa sp.

Polychaeta (det. J. Hylleberg-Kristensen)
Euclymene oerstedti
Axi othella obochensis
Leiochone sp.
Glycera tesselata
Nainereis quadraticeps
Scoloplos chevalieri
Notomastus latericeus
Heteromastus filiformis
Pista sp.
Nephtys sp.

Insecta (det. H.-E. Schmidt)
Halobates hayanus
H. mangrovensis

Crustacea Copepoda (det. F. D. Por)
Ridgewayia sp.
Neocyclops salinarum
Cannuellina insignis
Scottolana inopinata
Peltidium hawaiiense
Dactylopodia tisboides
Paradactylopodia brevicornis
Stenhelia longifurca
S. aff. *inopinata*
Rhyncholagena josaphatis
Amphiascopsis cinctus
Robertsonia salsa
Metis ignea
Lourinia armata
Orthopsyllus linearis
Enhydrosoma vicinum
Heterolaophonte quinquespinosa

Crustacea Cirripedia
Balanus amphitrite
Tetrachthamalus oblitteratus

Crustacea Decapoda
(det. Ch. Lewinsohn)
Palaemon debilis
Callianassa bouvieri
Calappa hepatica
Metopograpsus messor
M. tukuhar
Dotilla sulcata
Paracleistosoma leachii
Macrophthalmus telescopicus
M. grandidieri
M. depressus
Uca (Thalassuca) tetragonon
U. (Celuca) inversa inversa
Cryptodromia sp.
Menaetius monoceros

Mollusca (det. H. Mienis)
Crassostrea cucculata
Quadrans rugosus
Diplodonta sp.
Littorinopsis scabra
Nassarius pullus
Nerita forskalli
Cerithium scabridum
C. coeruleum
C. ruppelli
Clypeomorus clypeomorus
Pirenella caillaudi
Fusinus marmoratus
Volema pyrum
Strombus tricornis
S. mutabilis
S. gibberulus
Onchidium sp.

Bryozoa
Bowerbankia sp.
Schizoporella ? errata

Echinodermata
Asterina wega
Ophiocoma scolopendrina
Echinometra mathaei
Tripneustes gratilla

Table 1 (cont.)

Ascidiacea	*Tylosurus crocodilus*
Ecteinascidia cf. *herdmanni*	*Elops saurus*
Diplosoma cf. *listerianum*	*Crenidens crenidens*
Didemnidae gen. sp.	*Diplodus noct*
	Rhabdosargus haffara
Pisces (det. I. Paperna)	*Mulloidichthys samoensis*
Dasyatis uarnak	*Lutjanus fulviflama*
Arothron hispidus	*Monodactylus argentatus*
Crenimugil crenilabis	*Holocentrus* spp.
Mugil cephalus	*Lethrinus nebulosus*
M. subviridis	*Ronciscus stridens*
Valimugil seheli	*Aphanius dispar*
Liza carinata	

specimens. While the two *Uca* species and *Dotilla* are active at low tide, another ocypodide, *Macrophthalmus* sp., seems to be active at high tide.

Landward on the permanently dry shore lives another ocypodide – *Ocypode saratan,* as well as the terrestrial hermit crab *Coenobita rugosa. Dotilla, Ocypode* and *Coenobita* are not specific to mangrove areas and can be found also elsewhere along the Gulf of Aqaba (Elat).

The *Spirydia-Metopograpsus* community of the mangrove woods

As soon as a water cover of a few centimeters remains around the aerial roots even at low tide a carpet of the red alga *Spirydia filamentosa* covers the bottom (Station 2). This alga is mainly found along the edges of the *Avicennia* canopy and disappears in the darker inner parts of the woods. At places which are bared at low tide or where salinity is too high, crusts of blue-green algae cover the bottom (*Phormidium, Aphanocapsa,* etc.). In the highly saline tidal channel in Shura Arwashie, between the open lagoon and the closed lagoon ("*Caulerpa* pool") where salinities in summer exceed 50 ‰ S – there is a rich development of the free-rolling pebble-like growths of the blue-green alga *Cyanohydnum* (Dor, 1975). The macrofauna is quantitatively rich. The most obvious elements are the grapside crab *Metopograpsus tukuhar,* the prawn *Palaemon debilis,* the water-striders *Halobates hayanus* and *H. mangrovensis,* and the medusa *Cassiopeia andromeda.*

In a few cases, tidal streams cut through the mangrove soil – as in the case of Shurat el Manqata (Fig. 5) – and banks of felt-like turf are bared. On the shaded and protected vertical walls of the turf there is abundant growth of the alga *Halimeda opuntia* and *Caulerpa lentillifera.* Interwoven with the many rootlets of the turf are many colonies of the red sponge *Tedania anhelans.* In a few places where big *Avicennia* trees facing the open sea provide ample shading, there grows a peculiar assemblage of algae: *Valonia macrophysa, Hormophysa triquetra* and *Halimeda opuntia.*

The *Digenea-Strombus* flats

Wherever rock bottom rises through the sediment of the mangrove lagoons and especially in the area of the second or third landward coralligenous bar, a typical rocky flora and fauna becomes established (Station 4). The dominant alga on these surfaces is the red alga *Digenea simplex* – but in lesser amounts there appears also *Laurencia papillosa;* on slightly deeper bottoms *Cystoseira myrica.* Among the algae, the red tubes of the sponges *Spirastrella* sp. and *Biemna* cf. *fortis* appear frequently.

The big snail *Strombus tricornis* is especially common on the *Digenea* surfaces, together with the cerithids *Clypeomorus clypeomorus, Cerithium coeruleum* and *C. rüpellii.*

When the *Digenea* flats are bared at low tide – the marine pulmonate, the slug *Onchidium* sp. is active and creeps over the dry algal cover.

The *Halophila* channel

Between the mangrove and the seaward coral platform there is usually a shallow trench, almost always water carrying, in which mangrove peat and sand accumulate (Station 5). Here grow the seagrasses: *Halodule uninervis, Halophila stipulacea* and *H. ovalis.* The most frequent species is *H. uninervis,* which grows on shallower bottoms, more exposed at low tide. *Halophila* and the other species usually occupy the deeper parts of the channel.

There is a rich associated fauna of molluscs: the shells of the genus *Pinna,* two species of *Strombus: S. gibberulus* and *S. mutabilis; Volema pyrum* a gastropod with a very big creeping foot, and the predatory snail *Nassarius pullus.* Two crabs are found in this association: *Calappa hepatica,* the boxing crab, and the mangrove crab *Scylla serrata.*

The mangrove lagoon

The lagoons are permanently water filled, even if sometimes at low tides they are completely separated from the sea (Station 7 and in part also St. 3). The bottoms are about uniformly deep – 0.80–1.50 m at high tide. The bottom is covered by a layer of mud a few millimeters thick, followed by a deeper level of coarse organogenic sand intermixed with mud. The mud is chiefly mangrove-mud, but there is also a component of calcium carbonate. The coarse fraction is almost exclusively composed of foraminiferans, chiefly *Sorites.* The sediment is poorly mixed and poorly oxidized. According to Thane (1973) the grayish colour of the sediment indicates deficient oxygenation.

Generally, the bottom of the mangrove lagoons is bare of macrofauna. In the "*Caulerpa* pool" there is a dense growth of *Caulerpa racemosa* – a peculiar form of erect, fern-like growth – along the edges of the muddy lagoon bottom. In the lagoon of Shurat el Gharqana there is a cover of loose strata of *Cladophora* sp. However, the lagoon bottoms have a diversified micro-flora of blue-green algae: *Aphanocapsa* sp., *Gloeocapsa* sp., *Schizothrix* sp., *Chroococcus* sp., *Microcoleus* sp., *Phormidium* sp., and *Oscillatoria* sp. have been preliminarily identified.

Foraminifera of the Miliolaceae which harbour endosymbiontic algae, are extremely frequent (Reiss, pers. comm.). The species *Amphisorus hemprichi* and *Sorites orbiculus* are abundant in the lagoon of Shura Arwashie, along a transect from the shore to 1.5 m depth.

In the meiobenthos the Nematoda clearly predominate, and under extreme conditions they become nearly exclusive, together with the Oligochaeta. The fauna of the Copepoda Harpacticoida is very diversified and the genera *Canuellina, Stenhelia, Robertsonia* and *Enhydrosoma* predominate (Por, in press).

The macrobenthos of the lagoons is poor. According to Jørgensen (1973) and Hylleberg-Kristensen (1973) a clear predominance of detritus-feeding Polychaeta can be found. The Maldanidae are numerous, especially the species *Euclymene oerstedti* and *Axiothella obochensis*. The bivalve *Diplodonta* sp. and the ghost shrimp *Callianassa bouvieri* are also to be found.

The aerial roots and the mangrove trunks

It is difficult to give a general characterization of the algae and animals which inhabit the *Avicennia* aerial roots. The picture, as presented graphically in Figures 12 and 13, is based on a very broad generalization. The epiphytic flora of blue-green algae has been briefly described by Dor (1975). The terrestrial blue-green alga *Scy-*

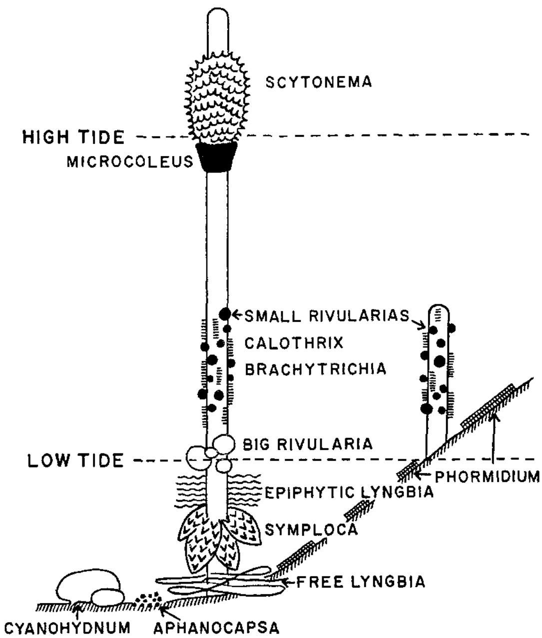

Fig. 12: Schematic zonation of the Cyanophyceae on the aerial roots of the Sinai mangal

tonema sp. covers the tip of the aerial roots, and a sole marine animal species lives in the supralittoral: the periwinkle *Littorinopsis scabra.*

The midlittoral belt of the aerial roots has a vegetation composed exclusively of blue-green algae – belonging to four or five genera (see Fig. 12). The intertidal fauna is composed of the mangrove oyster *Crassostrea cucullata* and the barnacles *Balanus amphitrite,* and *Tetrachthamalus oblitteratus* (Fig. 13).

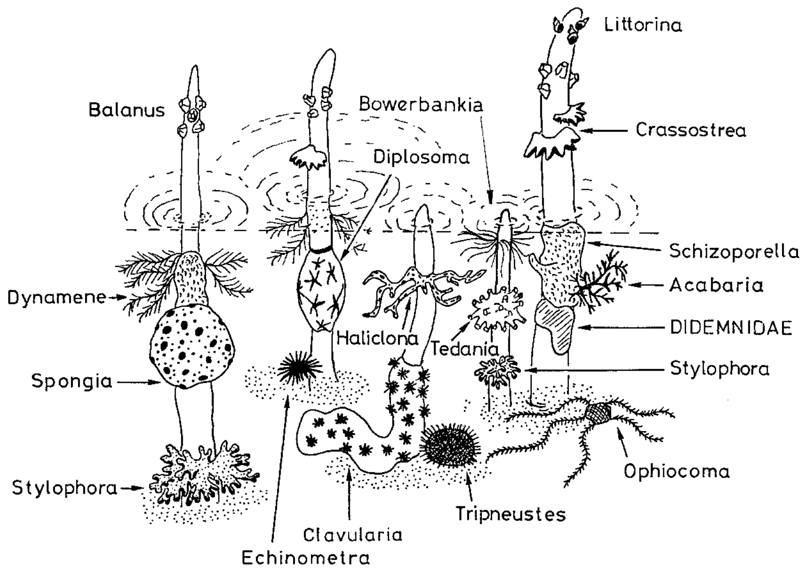

Fig. 13: Schematic zonation of sessile and semi-sessile invertebrates on and around the aerial roots of the Sinai mangal. Low tide level is indicated

The low tide level is marked by the ball-like colonies of the blue-green alga *Rivularia* and the spongy rounded masses of *Cladophoropsis.*

From the infralittoral sessile fauna, the hydrozoan *Dynamene* sp. and the bryozoan *Bowerbankia* sp. seem to be very resistant organisms since they are widespread in the inner mangrove channel of Shurat el Manqata where salinity reaches more than 45 ‰ S.

In the infralittoral proper there are several more blue-green algae species: for example, *Symploca* and *Lyngbia; Spirydia filamentosa* located directly below the low tide level; *Digenea* and *Laurencia* follow below it.

A common occurrence is the dark green sponge *Haliclona tenuiramosa* which has long, branched sea-weed like colonies, and the reddish-orange sponge *Tedania anhelans.*

In shaded places, the gorgonarian *Acabaria pulchra,* the "swimming" anemone *Boloceroides* sp. and colonies of *Stylophora pistillata* (the scleractinian coral) may also be found.

A crusty calcareous bryozoan preliminarily identified as *Schizoporella* sp. is found on almost every aerial root. The crusty dirty-greenish colonial ascidian of the Didemnidae is also present on a majority of roots, while another synascidian *Diplosoma* cf. *listerianum* is rather rare.

Around the roots, the sea urchin *Echinometra mathaei* is common, locally accompanied by another sea urchin, *Tripneustes gratilla.* The non-sessile animals of the *Avicennia* roots have not been investigated in detail.

The seaward fossil reef flat

The raised reef flat is in fact not part of the mangal hydrosere. However, a brief account is necessary to give a complete picture of the whole environment. The flats which delimit the mangal from the open can reach a width of 150 m and are as a rule exposed at low tide when the sea is calm. At neap tide and calm seas they may remain dry even at high tide. On the flat there are many residual pools in which some coral growth continues.

Typically the reef flat is covered by the crusts of the green alga *Dyctiosphaeria cavernosa.* In the residual pools there are several other algae and also sea grasses. The fauna is very diverse and it is, therefore, hard to point out a few dominant animals. The upper crust is a *Lithothamnion* formation with a predominance of the mussel *Modiolus auriculatus* and the zoantharian *Palithoa* sp.

Fishes of the Sinai mangal

The fish fauna of the Sinai mangal has been investigated by Paperna (pers. comm.), however, almost exclusively in the northern mangrove of Shurat el Manqata. The list of the species found is given in Table I – together with all the presently known taxa of the Sinai mangal. However, a few facts need to be emphasized. The only autochthonous population is that of the small cyprinodont *Aphanius dispar.* For many other species the lagoons are nursery grounds – especially for euryhaline or estuarine species: *Mugil subviridis, Valimugil seheli* and other species of mullets, as well as the Sparidae *Crenidens crenidens, Diplodus noct* and *Rhabdosargus haffara.* On the coralligenous rock of the Manqata lagoon, three species of *Holocentrus* live; also *Monodactylus argentatus* and *Elops saurus* which have not been reported elsewhere in the Gulf. The skate *Dasyatis uarnak* is fairly frequent. Among the pneumatophores is the puffer fish *Arotron hispidus* and an unidentified morey eel.

GENERAL DISCUSSION

Geomorphology and history

The Sinai mangal is not older than the end of the Pliocene – the period when the Gulf of Aqaba opened up. The parallel rows of fossil reef flats appeared probably as a consequence of successive stages of uplift of the Sinai peninsula.

The mangrove lagoons can be seen as reef holes in the uplifted reef flat. Similar holes became isolated pools: the Solar Lake near Elat and the pool of Di Zahav (see Por, 1972, and Por & Dor, 1975a). According to Krumbein & Cohen (1974) the isolation of Solar Lake from the open sea occurred 2,500–3,000 years ago. In the absence of age measurements in the Sinai mangal proper, we can assume that this last uplift eventually gave the present structure to the mangrove lagoons.

The Sinai mangal, with the exception of that of Ras Muhammad, is situated on the alluvial fan of Wadi Kid. Fresh ground-water flows through the sediment and it is tapped by bedouins in the small oases of Nabq, Nakhlat et Tel and Um Ngeila. There is every reason to suppose that the mangrove lagoons reach below the ground-water level and that influx of freshwater prevents their becoming hypersaline pools.

The "Shura"

The Sinai mangal – and probably most of the mangal of the Red Sea – is a type of mangal which grows on hard bottoms without being connected with a riverine estuary. The mangrove in Sinai is a monospecific *Avicennia marina* forest, and it seems that this species predominates also in the Red Sea mangals, although *Rhizophora mucronata* and *Ceriops tagal* are also present.

Instead of adaptation to low salinities the Sinai mangal lives – without exception – under conditions of salinity higher than the open sea ($>$ 40.2 ‰ S). It is a metahaline mangal instead of a "mixohaline" – brackish or "euryhaline" marine one. High salinity is probably the main factor restricting the number of mangrove species and also of some algal and animal species usually associated with the mangal: the mud-skipper *Periophthalmus,* several species of *Uca* and the algae forming the "Bostrychietum". On the other hand, the hard-bottom high-salinity mangal of Sinai is a meeting ground for reef-dwelling species with mudliving ones.

Similar Indo-Pacific hard-bottom mangals have been mentioned by Tobler (1914) and Walter & Steiner (1936) in East Africa and by Stephenson et al. (1931) in the coral islands of Australia's Great Barrier Reef.

We suggest calling the "reef mangroves" of high salinity and hard substrate "Shura" after the popular Arab name of the Sinai mangrove forests, typical represensatives of this type of mangal.

Environmental limits

The Sinai mangal is the northermost mangal of the Indo-Pacific at 28° N. It is evident that the limit reached in Wadi Kid is not determined by increased salinity but by the decrease in temperature.

The few days with temperatures below 10° C in the mangal of Sinai are probably still subliminal. One can suppose that northward, along the coast of the Gulf of Aqaba, the number of such cold days increase, at least in a secular average.

The protection provided by Cape Ras Atantur against northern winds may be of noticeable importance. According to Klinker et al. (1977) Ras Atantur delimits a southern basin in the Gulf, in which a surface anti-clockwise current exists. It may be assumed that an import of floating mangrove seeds from the open Red Sea, coming with the current, hits the shore in the Wadi Kid area.

The Sinai mangal reaches a sudden and northward limit at Shurat el Manqata, a "Shura" which is still fully developed. No mangrove, even in the most depressed form, grows north of it. Neither do some of the associated animal species (*Uca* spp., *Metopograpsus tukuhar, Onchidium* sp., etc.) occur further north. It is a subject for further study to understand this sudden limit reached by a "worldwide" biome like the mangal.

The abundant biomass of the Sinai mangal

The Sinai mangal is an oasis of teaming life wedged in between the barren desert and the nutrient depleted waters of the Gulf of Aqaba. Besides the rich arborescent vegetation, there are extensive meadows of algae and sea-grasses. Some animal species reach large population densities; for example, *Palaemon debilis, Metopograpsus tukuhar, Strombus tricornis, Onchidium* sp., etc.

It is evident that the mangal is an autarkic nutrient-saving and accumulating ecosystem. Since import from the open sea is also negligible, we have here an independent ecosystem, an excellent object for trophic studies. However, such studies have not yet been performed in the Sinai Shura and we can only point out what the presumed sources for primary productivity are: (1) the plant biomass of the leaves and stems of *Avicennia;* (2) the algal and sea-grass beds; (3) the nitrogen fixing and photosynthesis of the bacteria and unicellular organisms of the lagoon bottoms.

With the increasing interest which has recently concentrated on mangrove research, we would like to draw attention to the good opportunities offered by the Sinai "Shura", as a relatively simple and small-scale model for mangals at large.

Acknowledgements: Thanks are due to the colleagues who identified the collected organism for us: Z. Reiss (Foraminifera); M. Tsurnamal (Sponges); M. Grasshoff *(Acabaria)*; Y. Loya (Scleractinia); H. Mienis (Mollusca); Ch. Lewinsohn (Decapoda); I. Paperna (Fishes).

LITERATURE CITED

Aschersohn, P., 1887. Reisebriefe aus dem Nil-Delta und Sinai-Halbinsel. Verh. Ges. Erdk. Berl. **14** (5), 313–322.

Chapman, V. J., 1940. The botany of the Jamaica shoreline. Geogr. J. **96**, 312–323.

Dor, I., 1975. The blue-green algae of the mangrove forests of Sinai. Rapp. P.-v. Réun Commn int. Explor. scient. Mer Méditerr., **23** (3), 109–110.

— Sournia, A., & Por, F. D. Preliminary data on the productivity of the mangrove environment of Sinai. Rapp. P.-v. Réun Commn int. Explor. scient. Mer Méditerr. (In press).

Hylleberg-Kristensen, J., 1973. Notes on the identification and zoogeography of the Red Sea polychaetes. In: Elat, the Red Sea, report on a study tour. Ed. by T. Fenchel & J. Hylleberg-Kristensen. Zool. Inst. Univ. Aarhus, Aarhus. 135–169 (mimeo).

Jørgensen, C. B., 1973. The macro-infauna of the Nabeq lagoon. In: Elat, the Red Sea, report on a study tour. Ed. by T. Fenchel & J. Hylleberg-Kristensen. Zool. Inst. Univ. Aarhus, Aarhus. 88–94 (mimeo).

Kassas, M. & Zahran, M. A., 1967. On the ecology of the Red Sea littoral salt marsh, Egypt. Ecol. Monogr. **37**, 297–315.

Klinker, J., Reiss, Z., Kropach, Ch., Levanon, I., Harpaz, H., Halicz, E. & Assaf, G., 1977. Observations on the circulation pattern in the Gulf of Elat (Aqaba), Red Sea. Israel J. Earth-Sci. **25**, 85–103.

Krumbein, W. E. & Cohen, Y. 1974. Biogene, klastische und evaporitische Sedimentation in einem mesothermen monomiktischen ufernahen See (Golf von Aqaba). Geol. Rdsch., **63**, 1053–1065.

MacNae, W., 1968. A general account of the fauna and flora of mangrove swamps and forests in the Indo-West-Pacific region. Adv. mar. Biol., **6**, 73–270.

Odum, W. E. & Heald, E. J., 1975. Mangrove forests and aquatic productivity. In: Coupling of land and water systems. Ed. by A. D. Hasler. (Ecological Studies. Vol. 10.) Springer, New York. 129–136.

Por, F. D., 1969. Limnology of the heliothermal Solar Lake on the coast of Sinai (Gulf of Elat). Verh. int. Verein. theor. angew. Limnol. **17**, 1031—1034.

— 1972. Hydrobiological notes on the high-salinity waters of the Sinai Peninsula. Mar. Biol. **14**, 111–119.

— 1975. A typology of the nearshore seepage pools of Sinai. Rapp. P.-v. Réun Commn int. Explor. scient. Mer Méditerr. **23**, 103.

— The benthic Copepoda of the Sinai mangrove. Rapp. P.-v. Réun Commn int. Explor. scient. Mer Méditerr. (In press).

— & Dor, I., 1975a. Ecology of the metahaline pool of Di Zahav, Gulf of Elat, with notes on the Siphonocladacea and the typology of near-shore marine pools. Mar. Biol. **29**, 37–44.

— — 1975b. The hard bottom mangroves of Sinai, Red Sea. Rapp. P.-v. Réun Commn int. Explor. scient. Mer Méditerr. **23** (2), 145–147.

Rützler, K., 1969. The mangrove community, aspects of its structure, faunistics and ecology. Mem Simp. int. Lagunas Costeras (UNAM-UNESCO, Mexico) **1967**, 515–536.

Stephenson, T. A., Stephenson, A., Tandy, G., & Spender, M. A., 1931. The structure and ecology of Low Isles and other reefs. Scient. Rep. Gt. Barrier Reef Exped. **3** (2), 17–122.

Sournia, A. Notes on primary productivity of coastal waters in the Gulf of Elat (Red Sea). (In press).

Tobler, F., 1914. Die Mangrove der Insel Ulenge (Deutsch-Ostafrika). Bot. Jb. **50**, 398–411.

Walsh, G. E., 1974. Mangroves: a review. In: Ecology of the halophytes. Ed. by J. R. Reimold & W. H. Queen. Acad. Press, London. 51–174.

Walter, H. & Steiner, M., 1936. Die Ökologie der Ost-Afrikanischen Mangroven. Z. Bot. **30**, 65–193.

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