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Biodiversity and biology of salt marsh and mangal Brachyura in Qatar.

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BIODIVERSITY AND BIOLOGY OF SALT MARSH AND MANGAL BRACHYURA IN QATAR

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بسم اللة الرحمن الرحيم

IN THE NAME OF ALLAH MOST GRACIOUS MOST MERCIFUL

TO

MY PARENTS IN MY MEMORY

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SUMMARY

Although there have been comprehensive ecological surveys of impacted mangal and salt marshes in the Gulf states, especially Saudi Arabia, no data exists regarding the mangal or salt marshes fauna of Qatar, where recent replanting has expanded the area of mangal . The first aim of the present investigation was, to study the biodiversity of the Brachyura and fish living within these habitats quantitatively together with relevant features of the abiotic and biotic environments of natural, replanted mangal and salt marsh so that the progress of recolonisation of the new habitat could be evaluated.

Measurements of sediment organic matter, grain size and moisture content indicate that natural mangrove areas have the finest grain size and highest organic and moisture contents while planted mangrove areas have a higher mean grain size, but lower organic and moisture content. Mean soil water pH within the natural mangrove areas was 7.21, in planted mangrove areas slightly higher with a value of 7.55, and 7.53 at the salt marsh, while sea water pH was 7.91 - 8.30.

Differences in brachyuran species in planted and natural mangrove areas were found, but biodiversity was similar in salt marsh and natural mangrove areas.

Nasima dotilliformis was the only species not to occur at any planted mangrove site, while *Serenella leachii* was missing from natural mangrove. Four crabs *Nasima dotilliformis*, *Metopograpsus messor*, *Eurycarcinus orientalis*, and *Macrophthalmus depressus* dominated natural and planted mangroves and salt-marsh, extending through the upper intertidal. *Ilyoplax frater, Manningis arabicum, Macrophthalmus depressus* occur in the mid intertidal zone. On the lower intertidal zone the two dominant species in all areas were *M. depressus* and *Metaplax indica*. In planted mangrove areas where sandy sediment dominates *Scopimera crabricauda* occurs between the upper intertidal to mid intertidal zone.

Fish surveys indicate that *Ablennes hians*, *Gerres oyena*, *Hemiramphus marginatus* and *Liza macrolepis*, enter mangroves using these as nursery areas and significant

differences occurred between sites demonstrating that mangrove areas, especially pneumatophores, form a special habitat for these small fish.

The first zoeal larval stage for 6 common intertidal crabs is described, and new generic diagnoses are erected for *Paracleistostoma arabicum* and *Cleistostoma kuwaitense*, crabs belonging to the Camptandriinae. A modified key based on Manning and Holthuis (1981) is constructed to separate these from other members of the subfamily.

The biological characteristics of 5 species of crab were monitored during a monthly sampling programme over the period June 1993-1994 including carapace width-weight relationship, size frequency, sex-ratio and breeding biology. Male:female ratios differed, indicating spatial and temporal variations by size-classes and season. The ovigerous females of *N. dotilliformis* and *S. leachii* were encountered over 7 months while those of *M. depressus* were seen almost throughout the year. *Metopograpsus messor* were ovigerous over a 5 month period and *E. orientalis* over 6 months. From size frequency modes and data on recruitment and ovigerous females it appear that late spring and summer is the ecologically-active season.

The mouthparts of 6 species of the family, Ocypodidae, 2 species of the family Grapsidae and 1 species of Xanthidae are described. These crabs were observed and collected from mangrove sites mud and saltflats between the midlittoral intertidal zone and supralittoral fringe. Detail of the mouthpart structure reveal differences between deposit feeders with spoon-tipped setae in sandy habitat dwellers and plumose setae in mud feeders, while spinose setae occur in omnivorous and carnivorous species. Scanning Electronic Microscope studies of the structure of proventriculus of these crab species again revealed different structures related to the type of feeding and particular type of sediment in which deposit feeding crabs live.

In conclusion this study has demonstrated that mangrove in Qatar whether natural or planted acts to conserve species and enhance diversity and abundance. As yet recently planted mangroves (10 y) have not reached the full brachyuran diversity seen in natural mangroves, and present work demonstrates that this is only likely to occur when full physical habitat comparability with natural mangroves is attained.

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CHAPTER 1

GENERAL INTRODUCTION

GENERAL INTRODUCTION

Aims of this Study

The fundamental objectives of this study were to:

(a) To quantify the abundance and biodiversity of key elements of macrofauna of salt marsh, natural mangroves and replanted mangrove areas at selected sites in Qatar.

(b) To compare the physical conditions, temperature, salinity, sediment particle size and organic content within these habitats to ascertain whether differences exist between natural and replanted mangrove habitats.

(c) To study aspects of the biology and ecology of the Brachyura in these habitats in an attempt to explain differences in distribution and biodiversity within these habitats.

The present chapter reviews the seasonal marine abiotic and biotic features of the Gulf and more specifically the distribution of salt marshes and mangroves. It also provides an introduction to previous research on the Brachyura occupying these habitats. In chapter 2 measurements of the physical conditions operating in selected salt marsh, natural and planted mangroves in Qatar are described together with the biodiversity and quantitative distribution of the brachyuran fauna occupying these habitats. This includes measurements of zonation patterns and seasonal changes in densities.

During present research it was found that at least one of the key crab species had been incorrectly diagnosed. Hence in chapter 3 new generic diagnoses are erected for *Paracleistostoma arabicum* and *Cleistostoma kuwaitense* (Jones and Clayton, 1983), crabs belonging to the Camptandriinae from the Arabian Gulf. A modified key based on Manning and Holthuis (1981) is constructed to separate these new genera from other members of the subfamily. In addition descriptions are provided for the first zoeal stage of six intertidal brachyurans from Qatar.

Chapter 4 describes the biology of 5 crabs as a result of field surveys conducted on the coast of Qatar during June 1993- June 1994. Population dynamics and breeding seasons are presented for *Metopograpsus messor, Nasima dotilliformis, Serenella leachii, Eurycarcinus orientalis, and Macrophthalmus depressus*. Finally in chapter 5 a detailed study of the mouth parts and proventriculus of 9 species of crabs using light and scanning electron microscopy is presented. This study was undertaken in an attempt to relate functional feeding morphology to observed distribution within the salt marsh and mangrove habitats.

Arabian Gulf region

The Gulf is a shallow semi-enclosed sea measuring some 1000 km in length and 200-300 km in width, covering an area of approximately 226000 km^{-2}. It is surrounded by semi-arid or arid land and connected to the ocean by the 60 km wide Strait of Hormuz.

The Gulf is characterized by three important features. Firstly, it is an extremely shallow sea, with an average depth of only 35m and a maximum depth reaching only 100 m. Surface temperature in coastal waters can range from 10°C in winter to 36°C in summer, and even well offshore the range is from 15°C to 18°C (off Kuwait) to 34°C between Qatar and United Arab Emirates (U.A.E.). A thermocline is marked only in summer and the difference between the surface and bottom temperatures only reaches 10°C even in shallow water. On a seasonal basis, most Gulf biotopes are therefore subjected to great temperature fluctuations.

Secondly, the Gulf is considered as a semi-arid or arid region, and the rainfall is low throughout the year. As a result the loss of water from the Gulf by evaporation far exceeds the input from rivers and run-off. The Gulf is considerably more saline than most other seas. The surface salinity range is 37-40 ‰ in the central part, 40-50‰ in the shallow parts of U.A.E. and it might exceed 70‰ in remote lagoons and bays such as the Gulf of Salwa. Salinity increases 2-4‰ with depth in the central part (Purse & Seibold, 1973). Salinities of water below the surface of sand and mud beaches (interstitial water) may reach 132‰ on the upper shore and some isolated high shore pools are over 200‰ and contain salt crystals (Jones, 1986).

Thirdly, the Gulf is connected with adjacent Indian ocean only by a narrow passage at the Strait of Hormuz. Consequently, the high salinities and wide temperature fluctuations of Gulf waters are not damped to any great extent by exchange of waters with neighboring seas (Basson *et al.*,1977).

Furthermore, the tidal regimes of the Gulf are complex, consisting of both diurnal and semi-diurnal components. The maximum annual tidal range is a round 2 m with the lowest spring tides occurring during the night in the summer months and during the day in the colder winter months (Vousden, 1987). It is becoming recognized that this is of great ecological importance for intertidal organisms.

Thus, all these physical factors are reflected not only in the salinity regime for this area but also in the presence and distribution of the intertidal fauna and flora. Reduced tidal ranges due to summer atmospheric conditions and the effects of Indian Ocean monsoon, wind-conditions and the diurnal tidal regime related to summer and winter spring tides all co-operate to ensure a reduced thermal stress to the intertidal biota during the hottest parts of the year. Mud is the predominate marine substrate in the Arabian Gulf. Over 52.1% of the bottom sediment is mud, 39.7% sand and 5.5% (rock, coral and gravel account for the rest). The distribution of these sediments is such that floor of the northern Gulf is almost entirely mud and muddy sand (Emery, 1956).

Depending on the coastal topography, similar sediments are exposed as intertidal flats. The Iranian side of the Gulf is bordered by tall cliffs and intertidal flats are only found in isolated pockets in such places as Bushire, Lingeh and Bandar Abbas (Blegvad and Loppenthin, 1944). The low coastal relief and shallow slope of the sea bed of much of the remainder of the Gulf coast results in the formation of extensive intertidal flats such as those found round the northern Gulf from Kuwait to Bandar Shapur. Lower down the Gulf intertidal flats are also found in the sheltered southeast of each major headland (Clayton, 1986). For a variety of reasons mangroves, so typical of intertidal flats of the Indo-Pacific, are only present to the east of Lingheh (Iran) and to the south of Tarut Bay (Saudi Arabia). To the landward side of the mangroves, marsh grass (*Phragmites spp.*) and halophyte zones can be distinguished (Basson *et al.* 1977) and these, but not the mangroves, are found bordering the northern intertidal flats (Emery, 1956). The relative abundance of these zones and their specific composition varies. In Kuwait, for example, marsh grass is very limited in its distribution whilst the halophyte (*Halocnemon* and *Salicornia* spp.) zone is widespread (Halwagy & Halwagy 1977). The shallow offshore in the south, but not the north of the Gulf, are fringed by a third ecosystem, the extensive sea grass (*Halodule Sp.*) beds. In terms of the overall biological economy of the marine environment, mangroves and grass beds are very important. Directly or indirectly they form a major food source for many marine animals including those of commercial value (Clayton 1986). But for the presence of the intertidal flats, which are themselves among the most productive of ecosystems (Odum 1971), the northern Gulf would be a much impoverished area .

In the Arabian Gulf, the eurythermal and euryhaline mangrove species, *Avicennia marina* is dominant, reflecting the high salinities (40 - >50‰) and extremes of water temperature (12°C-35°C). This mangrove reaches 6 m in Oman whereas in Qatar and Saudi Arabia it is poorly developed and often stunted (1-3 m). The high productivity resulting from mangrove leaf fall supports a host of detritus feeding animals such as molluscs, crustacean larvae, shrimps and fish. Broadly, mangal productivity of Arabian Gulf is generally low, and data on the productivity of mangroves trees are scarce for the Gulf. Sources of primary productivity within the mangal include: mangroves trees, blue-green algae, red algae and other algae, sea grasses and phytoplankton. Gross primary production rate in the Gulf may be at or below, the lower values generally cited (0.5 kg C m^{-2} Y^{-1}: UNEP 1985). Their overall contribution to Gulf productivity is minor, due to their limited area (Sheppard, *et al*, 1992).

However, mangals in the Gulf are significant not just biologically, but also in a historical context. They were the first mangroves ever to be reported in the world literature, by Nearchus and Theophrastus over 2000 years ago (Baker and Dicks, 1982). The mangroves of the Arabian Gulf, Indus delta and Red Sea have been quoted by Theophrastus (305 B.C.), Pliny (A.D.77) and Abdul Abbass El-Nebaty (1230). MacNae (1974) stated that mangrove forests were more extensive in the past, but practically all trees have been removed from the shores lying between Iran and Arabian peninsula. This indicates that in the Gulf areas may have been extensive but have been subject to severe deforestation in the past. Mangroves have been grown artificially on the northern Saudi Arabian Gulf coast at Ras Al Kafji at about 28° 30' N (Kogo, 1986), but the most northly limit to natural occurrence is thought to be at Dowhat ad Dafi 27° 08' N in Saudi Arabia. On Bahrain Island a few patches of mangroves occur at Ras Sanad, Al Ak infill and Khor Mugli with total area of 1 km^2. In United Arab Emirates (U.A.E.), according to Western (1989), mangrove is dominant in some tidal lagoons between Tarif and north of Abu-Dhabi Island, near Rams (Ras Al-khaimah Emirate) and most extensively at Khor Kalba (eastern coast). Despite the fact that all the localities of mangrove growth are coastal inlets or lagoons, there are several inlets and lagoons U.A.E. coasts which are devoid of mangrove (Khor Dubai, Khor Al-Khan and Khor Sharjah (Sharjah) and a small lagoon north by Fujairah port). These localities are characterized by features of deep water or encrusted tidal flats, which prevent mangrove growth (Embabi, 1993). In Oman, as in the rest of the Gulf only one species of mangrove plant *A. marina* occurs. Sheppard *et al* (1992) report that the densest stands in Oman are found further east towards and within the Gulf of Oman. At Al Qurm a moderate sized stand has been protected within a reserve. Some dense stands also occur in the region of Strait of Hormuz. In Iran, Sheppard, (1992) reports some 90 km^{-2} for the Khoran Straits. In Kuwait and Iraq, there are no mangroves, probably for climatic and biotic reasons.

Jones (1994) stated that low winter temperatures (>5°C) are likely to be the limiting factor to range extension as salinities in Kuwait Bay, where other conditions for development are optimal, are lower than those found in Saudi Arabia. This is also borne out by the height of the trees, which rarely exceed 2 m in Saudi Arabia and

Bahrain, but reach a height of 6 m further south in Oman. Salinity controls growth so that on the west coast of Qatar at 60‰ salinity 8.5 year old trees reach only 45 cm in height, whilst on the east coast at 43‰ they grow to 200 cm over the same period (Suda and Al-Kuwari, 1989). The areal extent of mangrove stands throughout the region are given in Tab. 1.

Table 1: Areal extent of Arabian mangal.

Location	Area km^{-2}
Red sea	
Saudi Arabia	200
Arabian Gulf	
Saudi Arabia	4
Bahrain	1
Qatar	<5
UAE	30
IRAN	90
South East Arabia	
Oman	20
Yemen	30-50

Source: Sheppard *et al* (1992)

Salt marsh communities also develop intertidally in sheltered places within the Gulf region. Saltmarsh halophytes in the Arabian Gulf are characterized by low (up to 1m) salt-tolerant bushes, flowering herbs and grasses, fringing the coast above the limit of high tide inundation to limit of salt intrusion sometimes extending for tens of kilometers inland. In the region, saltmarsh halophytes are more prevalent than mangroves especially in the north and often form the only coastal vegetation.

Accordingly, they are of great regional significance. In, Saudi Arabia members of the Zygophyllaceae and Chaenopodiaceae are the dominant salt marsh families. Species common within a band extending 100 m landwards from MHW include: *Salicornea herbacea, Arthrocnemon macrostachyum* and *Halocnemon strobilaceum.* Halwagy and Halwagy (1977) described the vegetation of the coastal salt marshes in Kuwait in detail (Tab. 2).

Table 2 : Vegetation zonation of coastal salt marshes in Kuwait.

Zone	Community
Low inundated mud banks	*Salicornia herbacea* *Juncus arabicus*
Shoreline belt	*Halocnemon strobilaceum*
Further inland	*Seidlitzia rosmarinus*
Middle marsh beyond the reach of highest tides	*Nitraria retusa*
Elevated landward edge of the marsh	*Tamarix passerinoides Zygophyllum coccineum Phragmites australis* *Aeluropus lagopoides* *Cressa cretica* *Halocnemon strobilaceum Seidlitzia rosmarinus Zygophyllum coccineum* *Traganum nudatum* *Nitraria retusa*

Ground level, in relation to tide or to water table, plays a major role in determining plant distribution, possibly by affecting soil water and salt content. *Halocnemon* occurs on low, inundated marshes, *Nitraria* on places not reached by tides, and *Zygophyllum* on elevated coarse sandy sites away from tidal or water table influence. Jones (1994) reported that the salt marshes extend inland just beyond the zone of maximum salt intrusion into the soil and seaward to mean high water spring (MHWS), and so occur above mangroves where they occur together on the shore, as the latter are limited to zone between MHWS and high water neaps (HWN). Both habitats require shelter from wave action and accumulate mud. Salt marshes dominate in the north of the Gulf, co-exist with mangroves in central regions, and mangroves dominate on tropical southern Gulf shores.

Mangroves and Saltmarsh Brachyura of the Gulf

The first serious attempt to study decapod fauna in the region was initiated by Heller in 1861 (Stephensen, 1945; Haig, 1966b) in conjunction with his work on the brachyurans and anomurans in the Red Sea. Alcock (1895-1905) and Kemp (1914, 1916, 1922) reported on decapods that were in the Indian Museum, primarily those collected during various cruises into the Arabian Gulf. Nobili (1905a, 1906a) made the only concentrated study of the decapods of the Gulf region, until the Danish expeditions in 1937 and 1938. During this 30 year span there were few systematic investigations, and fewer reports of new decapods (Stephensen, 1945). The Danish expeditions investigated the northern parts of Arabian Gulf along the Iranian coast, including one side excursion to Bahrain Island. They produced the three most comprehensive and important works on decapods to come out of the Gulf area. Stephensen (1945) compiled previous brachyuran records from the Gulf and added these to findings of Danish expeditions to produce the only comprehensive work on the brachyurans of the Arabian Gulf. Haig (1966 b) did a very similar study on the smaller porcellanid fauna, as did Banner and Banner (1981) on the alpheid shrimp. The remainder of the decapod fauna of the Arabian Gulf has received very little attention.

Since the Danish expedition, small systematic investigations on localized decapods in the Gulf have occurred. Basson *et al*, (1977) carried out an investigation on the biota of Saudi Arabia, which identified many species of this area at least to the family level. Crabs associated with the mangal fall into six families (*Mictyridae*, *Grapsidae*, *Geocarcinidae*, *Portunidae*, *Ocypodidae*, and *Xanthidae*) although only two, the *Grapsidae* and *Ocypodidae* contribute large numbers. None of the genera are restricted to the mangal environment, and many species are only occasionally visitors (Jones, 1984). In Malaysian mangroves they occur virtually throughout the intertidal zone with peak abundance from mean low tide level to mean high water level of spring tides. There is a distinct zonation of genera and species reflecting adaptation to different degrees of terrestriality. On the muddy shores typical of mangrove-fringed estuaries in Malaysia representatives of the following common genera are encountered as one moves up shores: *Macrophthalmus*, *Metaplax*, *Ilyoplax*, *Cleistocoeloma*, *Uca*, and *Sesarma* (Macintosh, 1984).

Thus, ocypodid crabs are conspicuous members of species of the macrofauna of tropical and subtropical particulate shores. In Kuwait there are 18 species and 9 inhabit the extensive mud flats in the north of the country, although little is known of their ecology. (Jones and Clayton, 1983; Jones, 1986). Fiddler crabs *Uca* spp, found in Kuwait (Jones, 1986), have not been recorded along the Saudi Arabian Gulf coast. In Bahrain the *Avicennia* zone extends from high tide to just below mean sea level. Three crabs *Nasima dotilliformis*, *Metopograpsus messor*, and *Eurycarcinus orientalis*, extend throughout the zone with burrow densities of the latter reaching 40 m^{-2}. *Nasima dotilliformis* reaches highest densities on the landward fringe and disappears on the seaward side of the mangal. *M. depressus* burrows into the soft mud below the mangal and extends down to the low tide. *Ilyoplax frater* was found between mid-tide and low water with *Metaplax indica* merging in as a relatively rare species toward low water. The open mud-flat below the *Avicennia* at Ras Sanad is colonised by *Macrophthalmus depressus* (Vousden, 1987).

In Saudi Arabia the most conspicuously abundant crab of the mangrove belt is *Macrophthalmus depressus*. This crab, up to 3 cm in body width, occupies a more or less permanent burrow in the mud, and at low tide is usually seen just outside the entrance where it feeds on minute organic particles sifted out of the sediment. Other species, include *Manningis* sp., and 2 small species of *Scopimera* and *M. depressus*, deposit feeders belonging to the family Ocypodidae (Basson *et al.*,1977; Apel and Turkay, 1992).

Vousden (1987) contains lists of Grapsidae, Ocypodidae and Paguridae from Bahrain which corresponded well with the east coast of Saudi Arabia. But as results of Jones and Clayton (1983) from Kuwait show, the northern Gulf has some differences, even though similar habitats occur (Tab. 3).

Table 3: Distribution of the major crab fauna previously recorded within the Western Division of the Indian Ocean.

	Kuwait	Sudai Arabia / Bahrain	Oman	Red Sea	East Africa
Supratidal fringe			*Ocypode* sp. *Coenobita scaveola* *Uca inversa inversa*	*Dotilla sulcata* *Ocypode saratan*	*Neosarmatium smithi* *N. meinerti* *Sesarma eulimine* *S. ortmanni* *Cardisoma carnifex*
HWS (landward fringe)	*Sesarma plicatum*		*U. inversa* *U. lactea annulipes*	*Ocypode saratan* *U. inversa inversa*	*U.lactea annulipes* *U. inversa*
HWS to HWN (mangle)	*C. kuwaitense* *U. sindensis* *I. paludicola*	*I. paludicola*	*U. lactea annulipes* *P. guttatum* *Helice leachii* *S. leachii* *E. orientalis* *N. dotilliformis* *S. crabricauda*	*M. telescopicus* *M. depressus* *U. tetragonon* *U. lactea albimana* *I. paludicola*	*Helice ortmanni* *H. leachii* *S. guttatum* *N. meinerti* *I. paludicola* *Eurycarcinus natalensis* *U. lactea annulipes* *U. inversa* *U. chlorophthalmus*
HWN to MSL (seaward fringe)	*N. dotilliformis* *I. stevensi* *E. orientalis* *T. indica* *M. indica*	*N. dotilliformis* *I. frater* *E. orientalis* *M. messor* *M. indica*	*U. lactea annulipes* *Perisesarma guttatum* *S. leachii* *E. orientalis* *U. vocans vocans* *I. paludicola* *M. depressus* *M. thukuhar*	*M. telescopicus* *M. depressus* *M. messor* *Serenella leachii*	*M. depressus* *E. natalensis* *M. thukuhar* *I. paludicola* *S. guttatum* *N. smithi* *U. chlorophthalmus* *U. urvillei*
MSL to low water (channel)	*Macrophthalmus grandidieri* *Macrophthalmus depressus* *Macrophthalmus pectinipes*	*M. depressus*	*M. grandidieri* *P. pelagicus*		*N. meinerti* *N. depressus* *U. lacta annulipes* *U. vocans hesperiae*
Sublittroal fringe	*Portunus pelagicus*	*P. pelagicus*		*Scylla serrata*	*S. serrata*

Source: modified from Jones (1984), Sheppard *et al* (1992) and Hywel-Davies (1994).

Despite the vast array of mangal research conducted, there is still much to be learnt about the associated faunal communities. Quantitative work is minimal with the literature dominated by early descriptive studies (MacNae and Kalk 1962, MacNae 1963, 1968, Warner, 1969, Day 1974). Less is known about the Arabian mangal fauna than the other Indo-Pacific mangals, with the Red Sea and Arabian Gulf being the only areas previously researched. Similarities do exist between the faunal assemblages found in this region and other Indo-Pacific mangal. However, species diversity and population densities are notably lower for the Arabian mangal (Hywel-Davies, 1994).

Topography of Qatar

Qatar peninsula is situated halfway along the western coast of the Arabian Gulf (Fig. 1). The peninsula covers an area of about 10600 km^{-2} and lies between 50° 45' and 51° 40' E longitude and 24° 40' and 26° 10' latitude. The total area including a number of offshore islands is 11437 km^{-2}. Air temperatures recorded at Doha International Airport (Fig. 2) show that the highest air temperature recorded was 49°C in June 1962, while the lowest air temperature recorded was 3.8°C in January 1964. Generally, the lowest temperature records are those for January, with a mean of 17°C, a mean daily maximum of 21.7°C, and a mean daily minimum of 12.8°C. The temperature increases steadily from March with a rapid increase in May. The mean temperature in July is 34.7°C, the mean daily maximum is 41.5°C and the mean daily minimum is 29.1°C. Fig. 3 gives general features of soil and ground temperatures recorded at Doha for different depths. The highest temperature recorded is in summer and the lowest temperature in winter. Fig. 4 shows the mean insolation duration (h) recorded at Doha (1975-1993) with highest sun duration during June (11.4h). The predominant wind in Qatar known as *Shamal* helps to cool the temperatures in summer and blows from the north - west and north - north west directions, with some seasonal variations. The south east wind is hot and dry in summer and some times brings rain in winter. The average annual rainfall at Doha is 75.8 mm (31 years) (Fig. 5). The mean rainfall recorded at Doha shows that the rainiest month is February with 17.1 mm on average. The mean monthly rainfall is 13.1 mm in January, 15.7 mm in March, 8.6 mm in April and 11.7 in December, While in the other rainy months it ranges from 3.5 mm in May, 1.1 mm in October and 3.2 mm in November. The most important characteristic of rainfall in Qatar is that it fluctuates and is irregular from year to year.

Sea Temperatures: Previous records of offshore water around east coast of Qatar during the winter of 1979-1980 vary between 20°C - 22°C. South of the east coast, the water temperatures were uniform, both at the surface and at 15m depth; the temperature recorded was 21°C.

For 1m depth off the coast the mean sea temperature recorded at Doha port (1979-1989) was 26.3°C. Fig. 6a shows the absolute highest sea temperature from June-September (34°C - 36.5°C), and the lowest temperature recorded during the winter from December - March between 18°C - 21.2°C.

For 2.5m depth off the coast the mean sea temperature recorded at Doha (1994 - 1995) was 26.6°C. Fig. 6b shows the highest sea temperature from August - September has (33.6°C - 34.7°C). Comparison of temperatures shows that 2.5m was permanently lower than 1m depth.

Currents and Tides: There is a surface current running clockwise in a line parallel to the United Arab Emirates coast towards the Qatar coastline. The current regime around Qatar is of a rather complex nature. The prevailing wind which is mainly N - NW direction and attains a force between 7 and 10 on Beaufort scale during the winter months, supplies much of the energy which drives the surface water movements. The speed of the surface currents is between 1 to 3 knots h^{-1}. Wind speed rarely exceeds 20 knots in a north - easterly direction, but this creates a current which moves towards the south and southwest. This current is greatly affected by the tidal currents in the area, which , in narrow Khors, attains a speed of more than 3 knots (Beltagy, 1983).

The tidal regime of the Qatar peninsula is semi - diurnal in the west coast and diurnal on the east coast. The daily tidal range is an average of 1.0 m on the eastern coast and up to 1.5 m on the west coast.

Salinity: The offshore sea surface salinity ranges from 37‰-42‰ and maximum salinity recorded was 45‰ near Doha. In the coastal water at the north of Qatar (Al-Gharia) a salinity of 44‰ was recorded. West of Qatar from the Bay of Salwa northward to the open Gulf, the water has much higher salinities than the Gulf waters east of the Qatar peninsula with 58‰ in the south decreasing gradually northward, where salinities range from 55‰-46‰. Salinity may exceed 70‰ in enclosed bays and lagoons such as the Gulf of Salwa. The salinities off the east coast of Qatar increase from the north to the south. Beltagy (1983) reported a lowest salinity of 39.5‰ on the north east of Doha, and a highest of 59.9‰ in what seemed to be in a small shallow trough, which lies in the area between Doha and Halul Island.

Dissolved oxygen: The dissolved oxygen in the inshore waters of Qatar is high in winter due to the mixing of the sea water and has a level around 2.5 - 3.9 ml. l^{-1}, but is lower in summer (1.0 - 2.5 ml. l^{-1}).

Mangroves and Salt marshes

In Qatar *Avicennia marina,* known locally as Qurm, occurs naturally and is confined to an area between Al-Khor and Al- Dhakhira along the east coast of Qatar. It is found on sheltered muddy shores and by trapping sediment helps to build and extend tidal flats with interlacing creeks and drainage canals. One feature of the land build up through the deposition of silt and mud is that it does not form hard ground. The back of the mangrove area intermingles with the salt marsh vegetation which is usually inundated during the highest high tides. Although original mangroves occur in Al-Khor and Al-Dhakhira, *Avicennia marina* has been introduced since 1981 on the west and east coast where there are inlets and / or creek areas. The best development of these newly planted areas is found on the coast of Umm Al-Hul and Al-Mafjar. Introduction of new species of mangrove into Qatar have also been attempted (Suda and Al-Kuwari, 1983; 1990). These, which have made little progress, include *Rhizophora stylosa* planted in March 1990 and in April 1992 at Umm Al-Hul, Al-Wakrah and Fuwairit and *Lumnitzera racemosa* planted in April 1992 which survives in Al-Wakrah and Al-Khor.

The structure of the mangal in Qatar varies from a poor scrub of about 0.5 m high to trees of 3.0 m high or more. The total natural mangrove areas in the north of Qatar at Al-Khor and Al-Dhakhira are 8.6 km^2 calculated during this study, and with other planted sites now reaches 9.9 km^2 in total (Tab. 4). In addition, a further 2.5 million m^2 more are under cultivation with 8 intertidal and 3 land nurseries.

Table 4 : Approximate estimated area of natural and planted mangroves (using Magellan GPS NAV 5000D) along the east coast of Qatar.

Location	Status	Area (Km^2)	Trees No. 10 m^{-2}	Tree Height (m)
Al-Khor	Natural	3.2	29	1 - 4
Al-Dhakhira	Natural	5.4	32	1 - 4
Umm Al-Hul	Planted	0.5	25	0.5 - 3
Al-Wakrah	Planted	0.1	35	0.5 - 1.5
Fuwairit	Planted	0.4	30	0.5 - 2
Al-Mafjar	Planted	0.3	19	0.5 - 1.5
Total		9.9		

The dominant salt marsh halophytes behind the mangal and tidal-flat areas in Qatar form communities of *Arthrocnemum glaucum*, *Halocnemum strobiolaceum*, *Halopeplis perfoliata*, *Suaeda vermiculata*, *Limonium axillare*, *Aeluropus lagopoides*, *Halopyrum mucronatum* and *Sporobolus arabicus*.

A review of the available literature reveals that the mangal crabs and intertidal fauna of Qatar has not been dealt with until recently. Jones (1985) reported some notes on intertidal and shallow subtidal fauna and flora species which occurred in Ras Laffan to the north of Qatar, and his collection contained *Macrophthalmus depressus, Scopimera crabricauda, Metopograpsus messor, Ocypode rotundata,* and *Portunus pelagicus*. Mohammed and Al-Khayat (1994) reported the common marine intertidal mollusca at 7 sites on the east coast and 2 sites on the west coast of Qatar and produced a preliminary check-list covering living and dead shells collected from the coast lines.

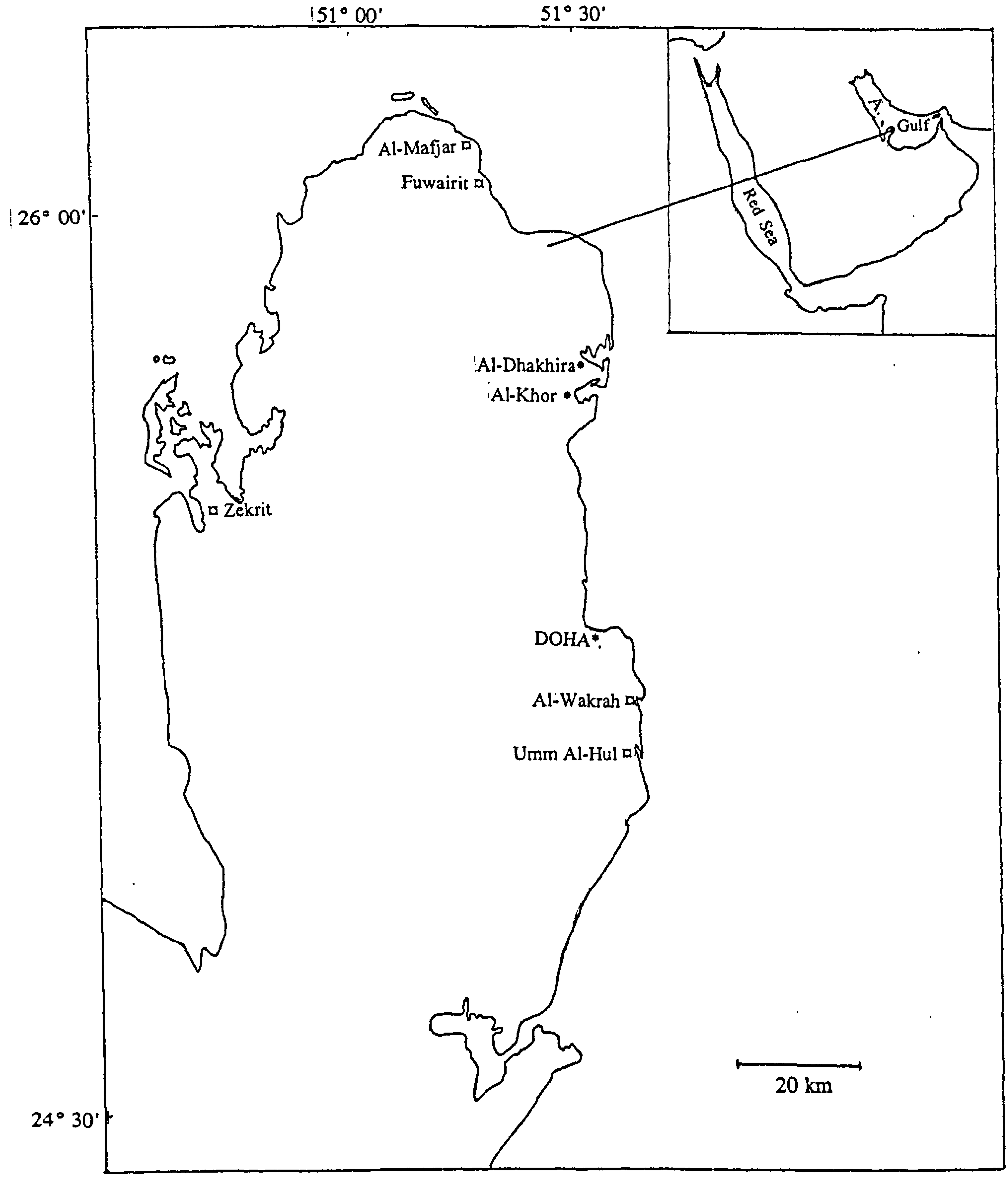
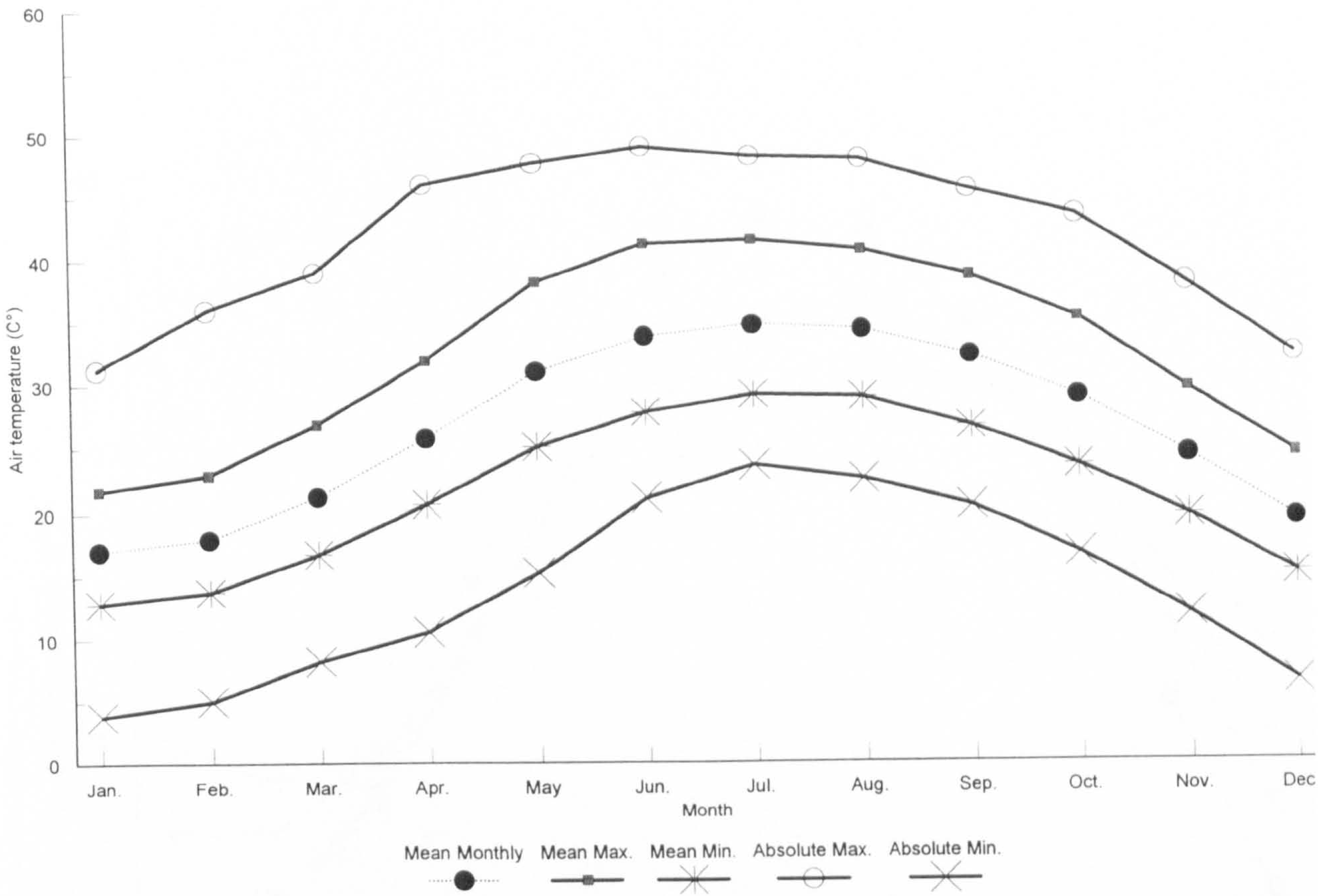


Figure 1: Map of The State Of Qatar showing the study sites which include natural mangroves •, planted mangroves ¤ and salt marsh *.



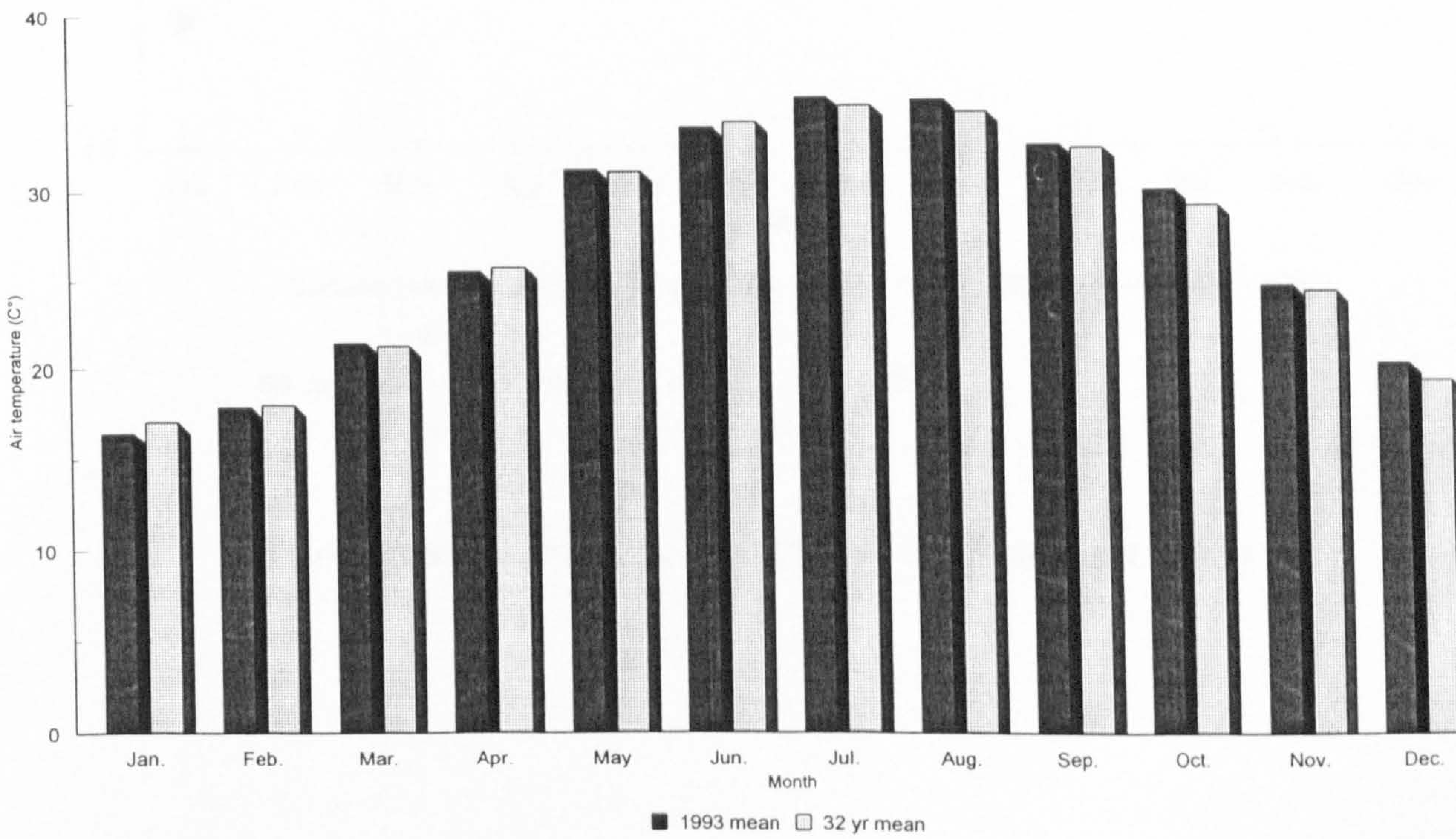


Figure 2 : Air temperature records at Doha airport for 31 years (1962 - 1993).

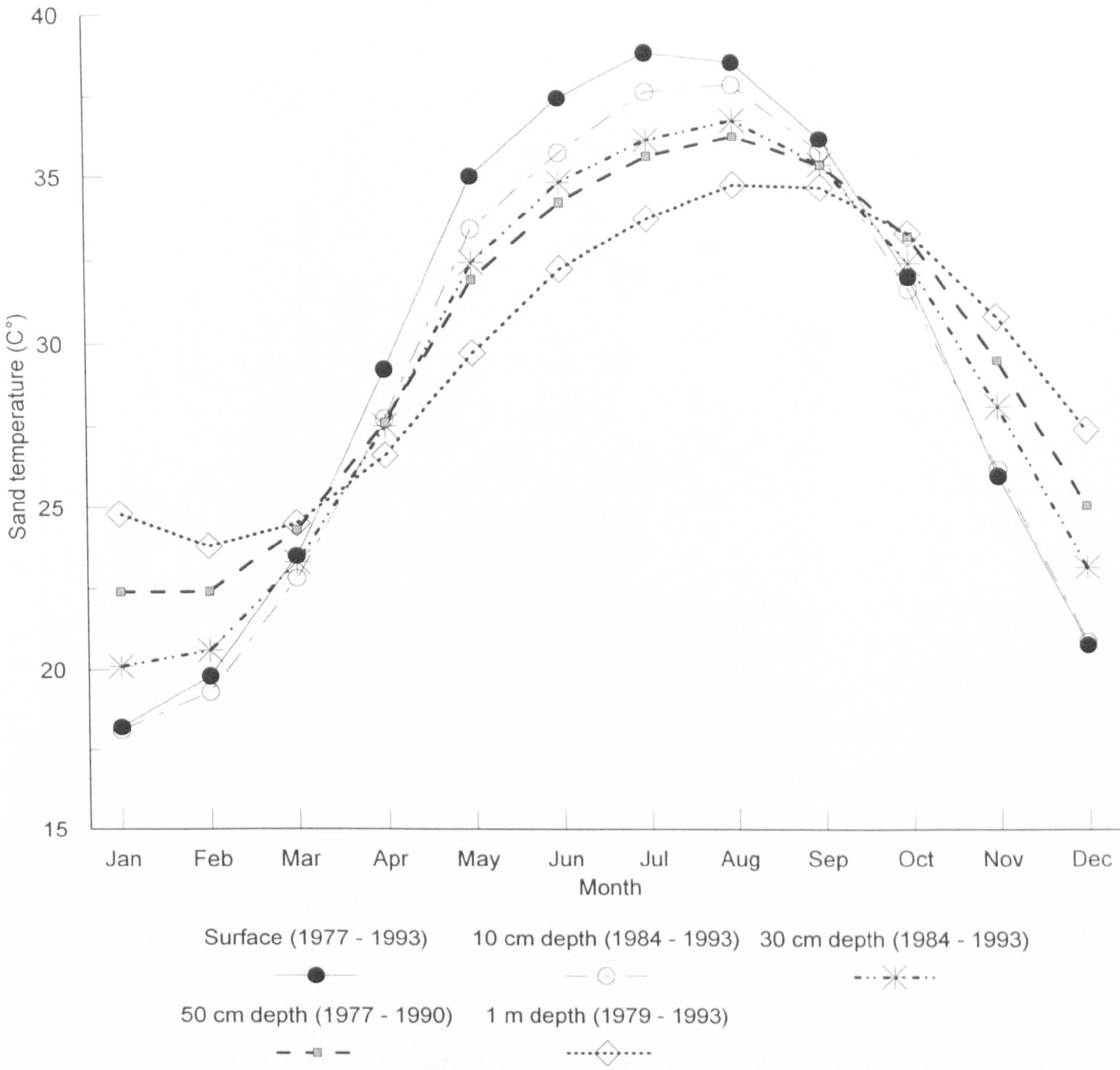


Figure 3: Sand temperature records at Doha for different depths.

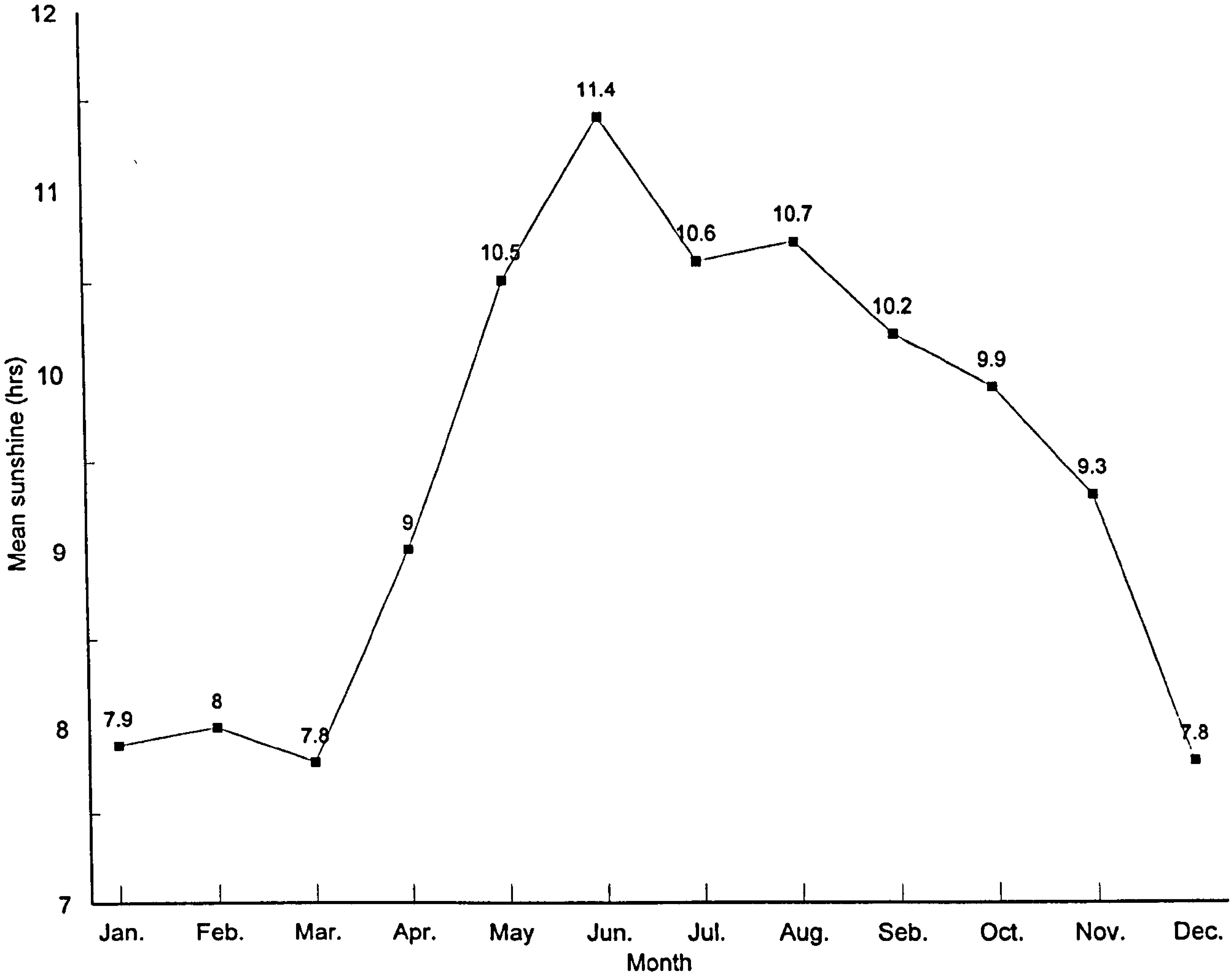


Figure 4 : Mean insolation duration(h), records at Doha during 18 years (1975 - 1993).

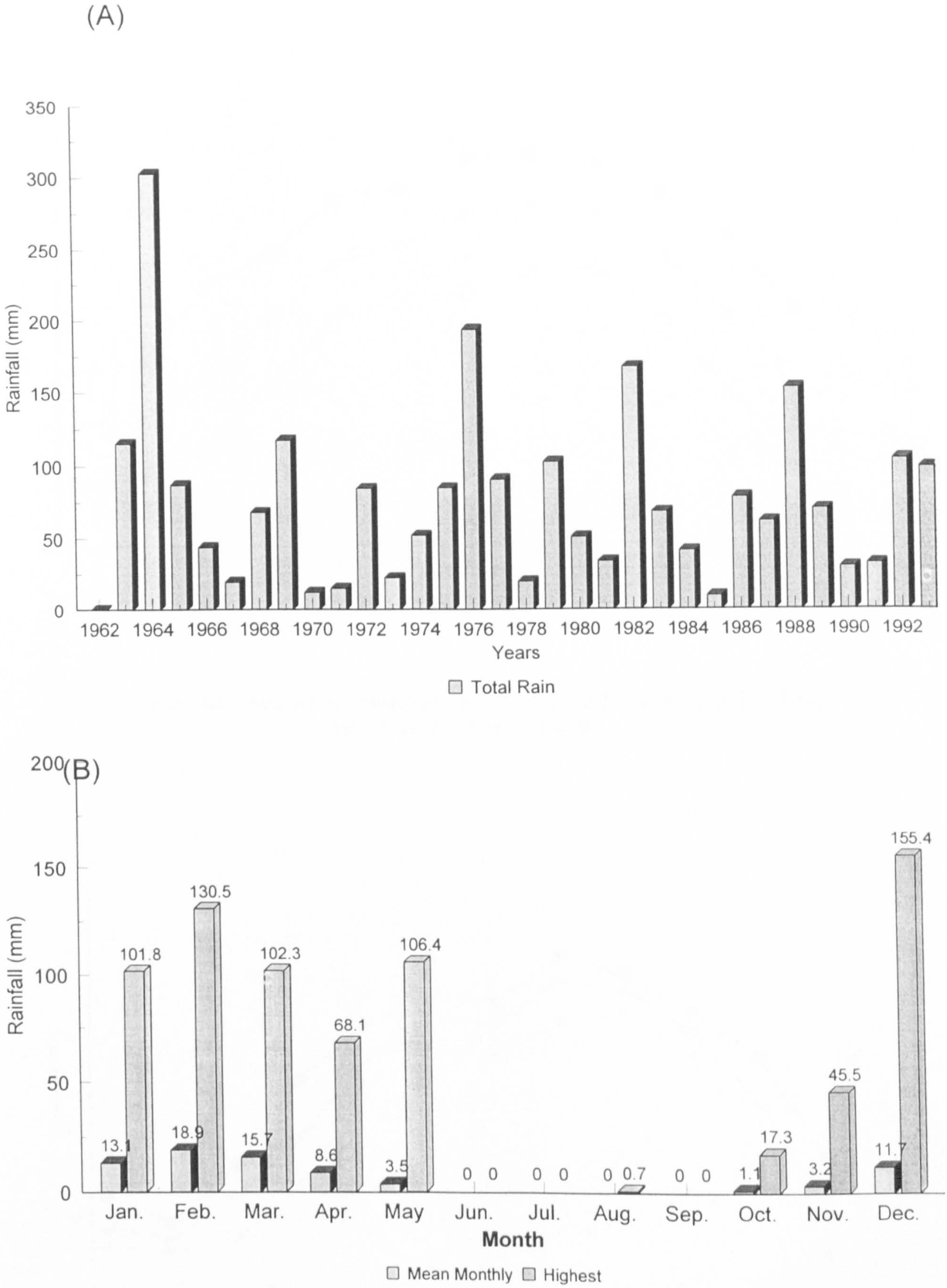


Figure 5: (A) Annual rainfall at Doha during 31 years (1962 - 1993) and (B) Monthly mean rainfall at Doha during 31 years (1962 - 1993).

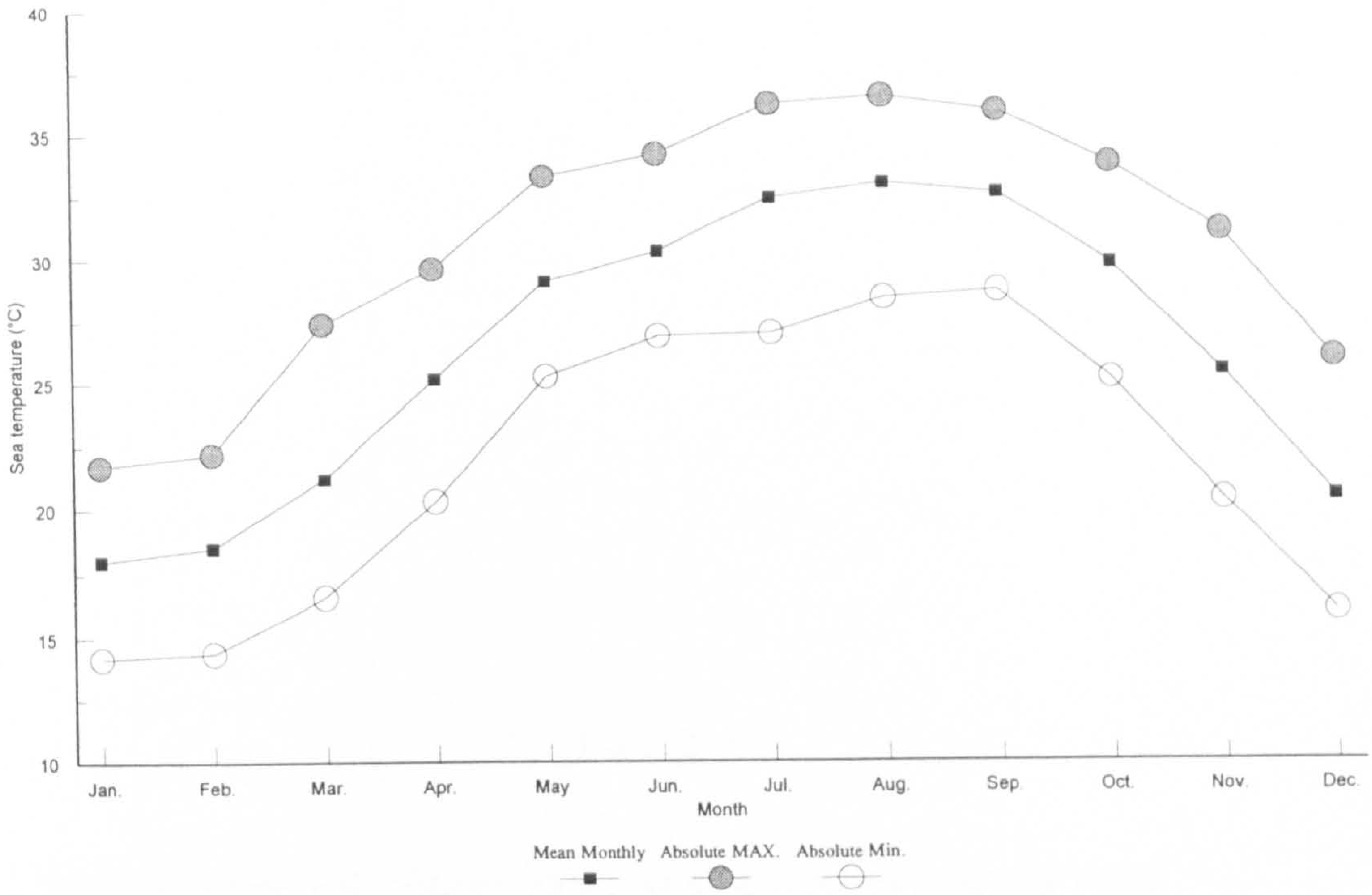


Figure 6a : Sea water temperature recorded at Doha port at 1m depth for 11 years (1979 - 1989).

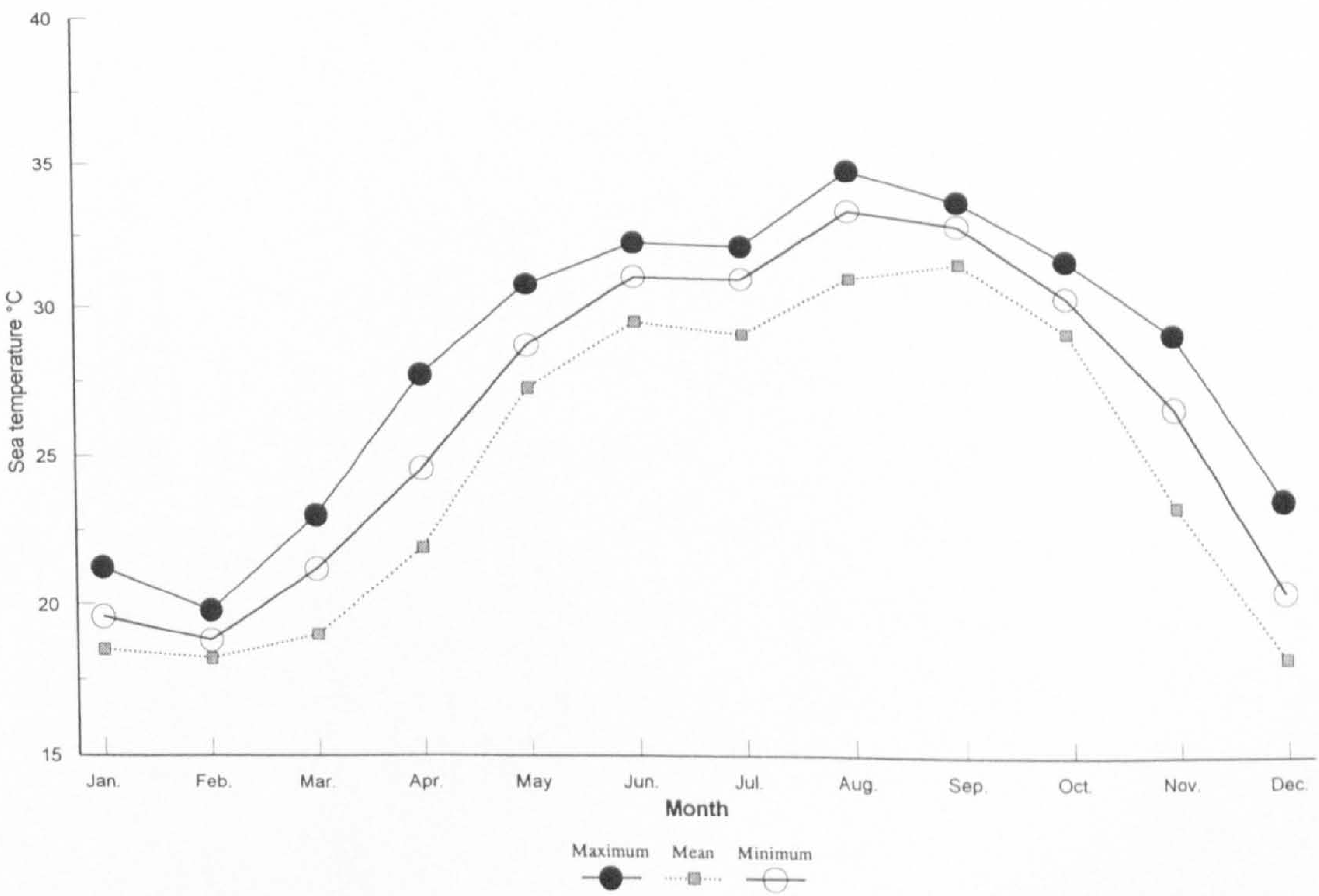


Figure 6b : Sea water temperature recorded at Doha at 2.5 m depth (1993 -1995).

CHAPTER 2

ECOLOGY OF BRACHYURA AND ASSOCIATED FAUNA OF MANGROVE AND SALT MARSH IN QATAR

INTRODUCTION

Brachyuran crabs especially the family Ocypodidae form a major component of the macrofauna of the intertidal zone on the Arabian Gulf. Most ecological studies on ocypodids have concentrated primarily on fiddler or ghost crabs (e.g. Haley, 1972; Crane, 1975; and Icely & Jones 1978). Whilst there has been some research on the other genera (e.g. *Dotilla*: Hartnoll, 1973; Hails & Yaziz, 1982), *Macrophthalmus*: Simon & Jones, 1981; *Scopimera*: Yamaguchi and Tanaka, 1974; Wada, 1981), little has been written on the ecology of *Tylodiplax* and *Ilyoplax*, species which can numerically dominate the shores on which they occur (Al-Taher, 1990; Snowden *et al.*, 1991). However, recently work from the Arabian Gulf has appeared, on the population and ecology of *Ilyoplax stevensi, N. dotilliformis* and *I. indica* which are dominant macroscopic organisms on mud flats above MTL (Clayton, 1986; Jones 1986; Apel, 1994; and Snowden & Clayton, 1995).

The majority of crab species living on the substratum beneath mangroves are burrowing forms (MacNae, 1968), living in burrows constructed by other fauna (Warner, 1969) or predatory forms foraging across the surface at low tide or high tide. Most crab faunal zonation is limited by the three dimensional ecosystem provided by the mangrove trees, changing ground texture with the presence of channels and pools complicating this interaction. These factors together with the widely varying degree of development of mangals in different regions has led to somewhat differing classfications of the mangal zones (Jones, 1984). Lewis (1964) reported that the main factor controlling zonation on the sheltered shore is exposure to air due to receding tides, although many other factors may modify zonation patterns. When considering tidal exposure in relation to the distribution of crabs on shores covered by mangroves providing shelter and high humidity, zonation patterns are not always clear (Jones, 1984).

However, Jones and Clayton (1983) recorded that both *Nasima* and *Manningis* were only found associated with sheltered sand / mudflats in Kuwait where mangroves are absent, and were absent from the open coast beach where *Ocypode rotundata* (Forsk.) and *Emerita holthuisi* Sankolli dominate. *Manningis arabicum* (Jones & Clayton 1983) has the widest distribution, colonising sandy mudflat areas of saltmarsh, while *Nasima dotilliformis* and *Leptochryseus kuwaitense* (Jones & Clayton 1983) appear to be restricted to areas where sediments are finer. The same authors reported that *L. kuwaitense* shows a clear pattern of zonation centred on high shore, at approximately the same level as *Uca lactea annulipes* (H. Milne Edwards). Their distribution overlaps with the lower edge of zone of Cyanophycea which is invariably present on the surface of the mud between HAT and MHHW on Gulf shores. *Manningis arabicum* and *Nasima dotilliformis* (Alcock) are found slightly lower on the mudflats, the latter species extending onto the wet mud zone which marks the appearance of the water table on the surface at low tide.

Jones (1984) reported that most mangal associated crabs burrow down to the water table to ensure a constant means of preventing desiccation. Although this is not the case for all species. In Oman, Hywel-Davies (1994) reported that on the highest spring tides the salt flats are inudated in parts, up to 50 m back into the marsh. At this time *U. inversa inversa* was recorded in this area. The equivalent zone in the Arabian Gulf, though tidal heights are lower (2-2.5 m) (Boër, 1994) is also inundated for a short part of each tidal cycle, and is densely burrowed by *Nasima dotilliformis*. Basson *et al* (1977) report that this species is strictly confined to the halophyte zone, but Vousden (1989) found less dense populations in the *Avicennia* zone. Apel (1994) found the largest population of *N. dotilliformis* in the upper intertidal zone, just below the halophyte zone, but noted that specimens were predominently juveniles.

Serenella leachii extends onto the lower shore in low densities, in areas that are water logged at low tide (Hywel-Davies, 1994). However, *E. orientalis* extends upwards from this zone in the Arabian Gulf, and also inhabits the landward fringe (Vousden, 1989; Apel, 1994). *Scopimera crabricauda* Alcock is centered at HWN and has a preference for dry , sandy substrates (Hartnoll, 1973; Basson *et al*, 1977). The distribution and zonation of *M. depressus* has been extensively documented throughout the region (MacNae & Kalk, 1962; Basson *et al*, 1977; Por *et al*, 1977; Clayton, 1986, Vousden, 1989; Apel, 1994), as being a dominant lower shore species. The finer muddy substrates of the Arabian Gulf appear to be preferable for for filter feeding techniques of this species (MacNae, 1968). *Macrophthalmus grandidieri* Milne Edwards was lowest on the shore, recorded on a sand bank in a channel only exposed at low tide just below MSL level. It expands upwards on the Kuwait mudflats to MLHW (Clayton, 1986) and occurs in the mid littoral zone of Inhaca island, Mozambique (MacNae & Kalk, 1962). Day (1974) reported that *M. grandidieri* and *M. depressus* can found at any level as long where there are suitable seepage channels, ensuring the substrate remains muddy and waterlogged. *Metopograpsus messor* (Forsåkl) is commonly reported in the Gulf region and has wider zonation which occurs from the mangal up into the saltmarsh and landward fringe (Basson et al, 1977; Vousden, 1989; Apel, 1994).

In Malaysian mangals, Sasekumar (1974) found that grapsid crabs are more successful at colonising higher levels than ocypodids, some of the former occuring in areas with over 90% exposure to air. This is not true of New World crab populations (Warner, 1969), where many of the ocypodid genera are absent (Crane, 1975). The lack of clear zonation for some crabs within the mangal may be attributed in part to the limited vertical range of the mangal itself, but more importantly to the way in which the mangroves act to modify the effects of tidal exposure (Jones, 1984). Icely and Jones (1978). MacNae

(1968) and Sasekumar (1974) have shown how substratum particle size, organic content and salinity, may modify effect of tidal exposure to the extent that they may be the most important factors governing zonation of deposit feeding crabs. Soh (1968) has shown how several species of *Sesarma* replace each other according to salinity gradients operating between the open sea and hill streams. These physical conditions operating within the mangal do not always remain constant (Jones, 1984), and Fishelson (1971) records a typical sand fauna including *Dotilla* and *Calappa* from established mangroves, where a change in the physical environment drastically increases the partical size of the substratum.

Crabs have a role in recycling of organic nutrients within mangrove ecosystems (Robertson, 1986), by feeding on fresh and dead leaves and seedlings (Malley, 1978). The early trophic analyses by Odum and Heald (1972), suggesting that initial detritus processing occurred in the subtidal zone, cannot be applied to Indo-Pacific mangals where herbivorous crabs dominate. It has been suggested recycling of nutrients occurs in the mangal which acts as a sink for organic detritus (Rodelli *et al*, 1984) with limited export of material to coastal zones (Flores-Vergudo *et al*, 1987; Alongi, 1990). The retention of organic matter within the ecosystem provides a stable food source, which would be specially important in arid regions which have a limited input of terrestrial nutrients to the ecosystem. Hence the feeding ecology of mangal ocypodids will also influence species zonation within the mangal ecosystem. As crab distribution is related to sediment particle size and organic content (e.g. Hartnoll, 1973; and Jones and Simons, 1982), which are in turn influenced by the presence of mangroves it is important to determine whether replanting programmes stimulate the return of the natural crab fauna.

The aims of the present study were to see if physical and biological conditions in natural mangroves, planted mangroves and salt-marshes differ and whether the fauna, particularly the decapod brachyura, show associations related to specific biotic or abiotic features of these habitats.

MATERIALS AND METHODS

Survey organization

A survey was carried out from June 1993 - June 1994 to investigate the mangrove, salt-marsh and tidal flat communities around the coast of Qatar. In each survey area, measurements were made of the physical characteristics (air and water temperature, water and pool salinities, sediment distribution) and the biotopes were described and sampled quantitatively for their brachyuran communities.

Investigation sites

The study areas covered are confined to three main sites (see Fig. 1, chapter 1): Al-khor (N1), Al-Dhakhira (N3) and Umm Al-Hul (P1); the former two sites are natural forest and located in the north of Qatar, while the latter is a recently planted forest to the south of Qatar. These major areas were visited and sampled monthly. Further representative sites were chosen and sampled as follows :

(1) Planted areas: Al-Wakrah (P2) four times / year (Jan-94, Mar., Apr., and Jun-94) , Doha (S) from Dec-93 to Jun-94, Fuwairit (P3) four times / year (Nov-93, Jan-94, Apr. and Jun-94), Al-mafjar (P4) three times / year (Jan-94, Apr. and June) and Zekrit (P5) once / year (May-94).

(2) Natural mangrove areas : Al-Dhakhira (N4) sampled four times / year (Jun-93, Jan-94, May-94, Jun-94) and Al-Dhakhira (N5) sampled once (Jun-94).

Transect profiles

11 transects at 11 sites were run from the MHHW to MSL and all these transects had sampling stations at the same tidal heights. These were surveyed using a theodolite and pole. Figs. 1 to 11 display the shore heights, the positions of the faunal sampling stations and zones along the individuals transects.

Recording and sampling

At each site, permanent transect lines were used for counting crab burrows (no. of burrows 0.5 m^{-2}) with 3 replicates. Crabs were collected by hand, hand-net and digging up burrows. Measurements of tree height, total area of mangrove and tide level were recorded.

Preserving samples

The crab samples and all other specimens were preserved in 4% formalin / sea-water and brought to the laboratory. After 24 h the formalin was decanted off and the crabs were then carefully placed in a new jar and preserved in 70% ethanol alcohol, and as far as possible identified to species.

Physical characteristics

Temperature

A mercury bulb thermometer was used to determine air, sea water, and pool temperatures on a monthly basis. Readings for air temperatures were made both in sun and shadow. readings for surface water temperature in shallow waters were usually made at 0.5 m depth, while pool temperature reading were made at depths of 5 cm.

Salinity

A portable salinity meter was used to determined sea and pool salinity. Both surface and pool salinities for the main sites was determined on a monthly basis; readings were obtained both from shallow water of 0.5 m depth and pool water of .5 cm depth.

pH - Hydrogen - ion concentration

A pH meter with digital display was used to determine hydrogen-ion in sea water and soil water. pH for each main site were determined on a monthly basis for surface shallow waters (0.5 m) and pool waters (0. 5 cm).

Oxygen concentration

A portable oxygen meter was used to determine oxygen concentration in open sea water and in soil of planted mangrove, natural mangrove and salt marsh areas. The soil water was measured after digging holes to allow ground water to seep but preventing entry of sea water.

Sediment samples

Sediment samples were collected along transects at 10 sites in salt- marsh, planted and natural mangrove areas. These sediment samples were analyzed to determine the size of particles using the sieve method Buchanan (1971). Seven percentiles (ϕ5, ϕ16, ϕ 25, ϕ 50, ϕ 75, ϕ 84 and ϕ 95) were graphically extracted from the cumulative weight curves for each sample and their values substituted in the formula suggested by Folk and Ward (1957). These values include mean grain size (Mz), Sorting (Standard deviation) (σ1), Skewness (SKI), and Kurtosis (KT).

The four statistical parameters were calculated by using the following equations (Folk, 1965) :

(1) Mean grain size (Mz):

$$Mz = \frac{\varnothing 16 + \varnothing 50 + \varnothing 84}{3}$$

(2) Sorting (Standard deviation) (σ i):

$$\sigma i = \frac{\varnothing 84 - \varnothing 16}{4} + \frac{\varnothing 95 - \varnothing 5}{6.6}$$

(3) Skewness (SKI):

$$SKI = \frac{\varnothing 16 + \varnothing 84 + 2\varnothing 50}{2(\varnothing 84 - \varnothing 16)} + \frac{\varnothing 5 + \varnothing 95 + 2\varnothing 50}{2(\varnothing 95 - \varnothing 5)}$$

(4) Kurtosis (KG):

$$KG = \frac{\varnothing 95 - \varnothing 5}{2.44(\varnothing 75 - \varnothing 25)}$$

These parameters were calculated using a FORTRAN IV run on a PC program.

Moisture and Organic Content Analysis

One hundred grams of sediment sample were dried for 24 h at 105°C, and then reweighed to determine the weight of water evaporated. For organic matter, triplicates of the samples (5g) were washed to remove salt and placed in preweighed crucibles. They were then weighed again. The replicates were ashed at 450-500°C for 30 min. in the muffle furnace. It was important that the temperature be kept constant, as Paine (1964) has shown that calcium carbonate decomposes at a temperature above 550°C. If the calcium carbonate content is oxidised, incorrect readings result. After cooling in dessicators, they were reweighed. The organic content was estimated as the loss of weight after ignition and was then expressed as a percentage of the dry weight prior to ashing.

Biological characteristics

Mangrove fish

The first fishing experiment was carried out in June 1994 at 5 selected sample sites as follows: 2 mangrove sites (N1 & N3); 2 planted mangrove sites (P1 & P4); and 1 salt-marsh area (S). The second fishing experiment was carried out in August 1995 at 3 selected sampling sites N1, P1 and SS (this is sandy beach area). The same method of fishing was used in both experiments. This method consisted of a hand net (0.7 cm mesh size) and torch used at dusk and fishing for a fixed time period. The sampling targeted mainly small juvenile or small fish which inhabit relatively shallow portions of the intertidal at the sites selected and specially near the pnematophores of *A. marina* at mangrove sites. Analysis of the hand net data to find the relationship of species caught between the 5 sites of the first experiment and the 3 sites of the second experiment separately was conducted using Tukey- test on the number of total species caught.

Larger fish which moved in amongst natural mangrove, planted mangrove and salt-marsh at high tide were sampled with a gill net (20 m '1.5 m with 7 cm stretched mesh), and seine net (15m '1.5 m with 5 cm mesh size). The gill-net was set 1 h before the high tide and was removed on the following low tide which allowed it to fish for 6 h.

The seine net was stretched across a creek in natural mangrove and planted mangrove areas and dragged 10-20 m with an average cover of 30 m^2 of selected area bottom by two people before being closed off and removed from the water. The seine net sampled benthic-dwelling species as well as small juveniles and adults of pelagic taxa. The fish collected from all nettings in each site were preserved in 10 % formalin-sea water solution and sorted and identified in the laboratory to species level following the available literature (Silvasubraminiam and Ibrahim, 1983).

Associated Fauna

Fauna associated with the natural mangrove , planted mangrove and salt-marsh were obtained at 7 selected sites at above areas. Sampling was undertaken along transects in each site . The specimens were preserved in 5% sea water formalin and returned to the laboratory for sorting and identifying.

Cluster analysis was used to demonstrate the similarity relationships amongst the faunal communities of natural mangrove, planted mangroves and salt-marsh, using species presence-absence data. Results are presented using the single linkage method by means of the MTW (Minitab for windows 10.2) computer program.

RESULTS

Physical Environment

Profiles

Figs. 1 - 11 shows the profiles and sampling sites used an all permanent transects during the survey together with positions of saltmarsh halophytes, algal mat cover and mangroves (*Avicennia marina*) plotted on each transect. The location of the sites used in the survey is given in Tab. 1 together with main features.

Air and Hydrographic Analyses

Data on air and hydrographic factors were obtained for 3 main sites, Umm Al-Hul (P1), Al-Khor (N1), and Al-Dhakhira (N3). Ranges were quite high, due to daily variation in air temperature, water temperature and water salinity which were recorded at the time of each field visit and data collection.

Umm Al - Hul (P1)

Temperature

The monthly direct and shade air temperatures, surface water and pool water temperature values at the time of collection of data are shown in Fig. 12. Direct air temperatures were slightly higher than shade air temperatures. The maximum air temperature was recorded in June (45°C) and the minimum air temperature in January (13°C). A sharp drop in air temperature occurred in November and after January 1994 it increased gradually to reach a value of 35° C in May .

The surface water temperature varied from 10° C to 36° C. The maximum was recorded in June 1993 and the minimum in February 1994. Pool water temperature attained minimum values in winter during January and February (1994) respectively. Highest temperature was recorded in June and July.

Salinity:

Fig. 13 gives details of the monthly surface water salinities for both shallow water and pool water at the Umm Al-Hul site. The overall trend in shallow sea water is for lowest salinities (34 - 43 ‰) to be recorded between December (1993) and March (1994), and the highest value of 57 ‰ was recorded in August (1993). Pool water salinities show greater fluctuations, and the values varied from 44-59 ‰, with the highest value recorded during the hottest month (August).

pH:

The pH value of open shallow water varied from 7.84 - 8.62. The lowest value in pools was 7.80 and highest value recorded was 8.64.

Al-Khor (N1)

Temperature

Fig. 14 shows details of air temperatures obtained both for direct sun and shade at Al-Khor. Direct air temperatures varied from 18.5 - 41° C. The maximum high temperature was recorded during June (1993) with value of 41° C although the hottest month was August. Direct air temperatures in Al-Khor attained their coolest in January and February with a values of 21 and 18.5° C respectively.

The difference between direct air temperature and shade air temperature was 3° C in summer and 1° C during winter.

Surface water temperature and pool water temperature attained their minimum values in winter during January and February (1994). The temperatures increased thereafter and attained their maximum values during June (1993) for surface water and during May (1993) for pools, although the highest temperature recorded for both was of 37° C during June 1993.

Salinity:

The plot in Fig. 15 gives details of the monthly surface water salinities for both shallow sea water and pools at Al-Khor.

Both show the same pattern of fluctuation, lowest surface water salinities were in the range of 42 - 44 ‰ between November and April and the highest value was 56 ‰ during August (1993).

Pool salinities follow the same general trend, higher in summer and lower in winter. The lowest salinity was in November (44 ‰), while the highest value was (59 ‰) during August (1993).

pH:

Generally, pH of the surface sea water varied from 7.91 - 8.30, and was 7.85 - 3.60 in pool sea water.

Al-Dhakhira (N3)

Temperature

The plot in Fig. 16 gives details of the monthly values for direct air temperature and shade temperature taken during the time of collecting data at the survey site at Al-Dhakhira. The air temperature values varied from 21-42°C during the study period. The highest records of direct air temperature were observed between June - August (1993) with values of 42-41.5° C respectively. After November they decreased gradually to reach the lowest values of 21°C during February and March (1994), and then steadily increased to reach the highest value of 38°C. Highest shade temperatures are usually 1-4.5° C less than those of direct air temperatures throughout the period of work.

Surface water temperature and pool water temperature attain their minimum values in January and February (1994), and attain their maximum values between July - September with value range 33.5 - 35° C in surface water and between 35 - 37° C in pool water.

Salinity:

Monthly water salinities for both surface water and pool water shown in Fig. 17. The maximum surface salinities was recorded during June (1993) with values of 54 ‰ and the minimum was recorded with values of 43 ‰ in June (1994). This might be due to time of collection and probably to change in the sea water level in that time. The pool salinity values varied between the range of 50 - 55 ‰.

pH:

The sea water pH values varied from 7.91 8.21 and for the pool water 7.85 - 8.60. The highest values for the sea and pool water were recorded in June, and the lowest values were observed in March.

Sediment characteristics

The results of grain size analysis and statistical parameters of the 48 sediment samples collected from the salt marsh, planted and natural mangroves sites at the 10 studied sites are given in Tabs. 2 and 4, while the sediment characteristics are given in Tab. 4. These results are described for each site separately :-

Al-Khor (N 1)

The intertidal deposits at Al-Khor along the transect consist of fine sand at stations 1,4,3 and 6 whilst very fine sand is present at stations 2, and 5. The sediments over the greater part of the transect are poorly sorted. The central stations along the transect (stations 3&4) have nearly symmetrical distributions whilst the other stations have very negatively skewed sediments.

Kurtosis along the transects consists of two type, mesokurtosis at stations 2,3 and 5 and leptokurtosis associated with stations 1,4 and 6.

Sediment in the natural mangrove area at this site show highest organic content at station 4-5 located inside the mangrove area with range of 3.0-3.13% and also with highest moisture content with range of 23.74-23.56 g respectively (Tab. 4).

Al-Khor (N 2)

According to the mean particle size (Mz), the sediments at this site consist of fine sand at stations 1 and 2 while medium silt is found at stations 3 and 4. The sediments at this site are made up mainly of a high proportion of sand (92.36 to 88.59%) at station 1 and 2 respectively, whilst stations 3 and 4 have a low percentage of sand (26.43-27.12%) and silt (27.58-29.45%) but a high clay content (46.09-43.43%) respectively (Tab. 4). The highest percentage of silt and clay at these stations led to an increase the proportion of organic content with range of 3-4.25% and also moisture content.

The degree of sorting is very poor at stations 3 - 4 while stations 1 -2 are poorly sorted.

Very negative skewness is found at stations 1 - 2 and the sediments at station 3 - 4 are almost negatively skewed.

The samples collected from this site show three kurtosis values, mesokurtic sediments at station 1, leptokurtic sediments at station 2 and very platykurtic sediments at stations 3.

Al-Dhakhira (N3)

The results of the mean particle size for sediment samples at stations 2 -5 reveal these are medium silt, and station 1 and 6 of fine silt.

The sediments at this main site are made up mainly of high proportions of silt with range of 35.19-73.87% and a high proportion of clay with range of 13.76-54.99%. The moisture content and organic content are increased with the percentage of silt and clay at stations located inside mangrove area (Tab. 4). The majority of the stations (1,2,3,4, and 5) show a very poorly sorted sediment. Samples from stations 1,2,4, and 5 have very negatively skewed distribution whilst stations 3 and 6 contain very positively skewed sediments. This site has a high content of silt and clay so that station 2,4, and 6 have a very platykurtic values, whereas stations 1,3, and 5 have mesokurtic sediment values.

Al-Dhakhira (N4)

The majority of the stations (1 - 4) have a mean particle size falling within the range of fine sand while station 5 consists of very fine sand. The sediments consist of high proportion of sand and less of silt. The lowest organic content (1.86%) and moisture content (6.69 g) found at station 1 which located at high shore, while a higher organic content (3.67%) found at station 3 (Tab.4).

The sediments at all stations are poorly sorted, but there is considerable difference in skewness between stations. Stations 2 and 3 are negatively skewed while stations 1,4, and 5 are nearly symmetrical.

The values of kurtosis obtained for the samples range from platykurtic at station 1, mesokurtic at stations 2 -3 and leptokurtic at stations 4 - 5.

Umm Al-Hul (P1)

Analysis of samples from this site shows a pattern of decreasing mean particle size (Mz) from the upper intertidal zone to the lower intertidal zone (Tab. 2). As a result, median sands are found in the first station, then from station 2 to 4 the site is dominated by fine sand, whilst the finest sediments (very fine sand) are found at station 5 on the transect.

The sorting parameter (σ i) over the greater part of the investigated site shows that the sediments are poorly sorted and negatively skewed (SKi range -0.22 to 0.19). The stations along the transect at this site show three distinct types of kurtosis (KG). Leptokurtic sediments are found in station 1, mesokurtic sediments in stations 2 and 5, while the remaining stations (3 & 4) contain platykurtic sediments. Sediments in the planted mangrove area at Umm Al-Hul show highest percentage of silt (35.54%) with a highest organic content of 3.67% at station 4, while the second highest percentage of silt (27.55%) and organic content (2.60%) was found at station 3. Both stations are situated in the middle of mangrove where also a higher moisture content has been recorded (Tab. 4).

Al-Wakrah (P2)

Station 1 consists of medium sand and this becomes finer toward station 2 and 3. Sediments on this planted mangrove area are made up mainly of a high percentage of sand (96.67%) with low silt (3.33%) found at station 1 situated at the upper shore and organic fraction of this station around 1.88g. Station 2-3 which is located in mangrove with a percentage of 96.08% - 96.29% sand and 3.92%-3.71% silt respectively, while the organic content 2.14% at station 2 and 2.0% at station 3, and the moisture content increased from the upper shore towards the lower station (Tab. 4).

The sediment samples at all stations along the transect are found to be moderately sorted and they are very negatively skewed. Station 1 and 2 show mesokurtic sediments while leptokurtic sediments are found at station 3.

Fuwairit (P3)

The sediments samples from station 1 to 5 have a mean particle size falling within the range of fine sand. The sediment at this site consists of a high proportion of sand (>90%) and less silt. The moisture content with range of 17.63-20.87g and organic content with range of (2.0-2.89%), the lowest percentage of moisture and orgainc content found at high shore stations (Tab. 4).

The samples studied in this area have poorly sorted values. Station 1 & 2 consist of negatively skewed sediments, while stations 3 to 5 are very positively skewed sediments. The majority of the samples collected from stations 2 to 5 are leptokurtic, but station 1 is platykurtic.

Al-Mafjar (P4)

The majority of samples collected from stations 1 to 5 consist of fine sand. The sediments at this site have a high percentage of sand (>79%) and small percentage of silt (between 8.71 - 20.94%). The sediment samples collected from stations 1 to 5 are poorly sorted sediments.

The general distribution of kurtosis along the transect shows very negatively skewed values at stations 1 to 4 and only positively skewed at station 5. The sediment samples at four station (1,3,4 and 5) are platykurtic while station 2 is mesokurtic.

An organic content 2.89 - 2.63% and moisture content with range of 20.86-23.30g is found at stations located inside the mangrove area, while the lowest proportion of these at station 1-2 where the highest percentage of sand with range of 88.5-91.29% respectively (Tab. 4).

Zekrit (P5)

The mean particle size indicates that all stations are within the range of fine sand. The sediment at this site consists of a high proportion of sand and low proportion of silt and they have poorly sorted values (Tab. 4).

Sediment samples show negative skewness values at all stations while the .values for kurtosis range from very platykurtic (stations 1 & 2), to leptokurtic at station 3.

The highest proportion of organic content (3.29%) and highest proportion of moisture content (25.57g) was found at station3 (Tab.4).

Doha (S)

At this site medium silts are found at stations 1,2,4, and 5. At station 3, which is situated on the bottom of the inlet, medium sand was found whilst very fine sand is found at station 6.

Sediments on the salt marsh stations 1,2, 4, and 5 are dominated by silt and clay (Tab. 4). Station 1 consists of 78.45% silt, 12.89% clay and low percentage of sand (8.66%), and station 2 consists of 82.03% silt, 9.82% clay and 8.15% sand, while station 4 with a range of 11.93% sand, 71.80% silt and 16.27% clay. Station 5 consist of 21.19% sand, 69.20% silt, and 9.61% clay. Sediment at stations 3 and 6 are made up mainly of a high percentage of sand 96.59% - 94.28% with a low silt of 3.41-5.72% respectively. The latter stations show a low organic content (2.13-2.5%) and also lowest moisture content, while stations 1,2,4,5 with highest organic content (3.17 - 5%) have a higher percentage of silt and clay and also moisture content (Tab. 4).

The sediments at this site, are poorly sorted sediments. The degree of negative skewness increases at stations 2,4,5,6, while the sediments are very positively skewed at station 3, which is situated at the bottom of the inlet. The kurtosis patterns at stations 1,4,5 and 6 has a mesokurtic distribution, while stations 2 and 4 have a platykurtic distribution.

Tides

The tides are semi diurnal and irregular, and the tidal range is 2 m, with the MSL range 0.90 - 0.95 m at all sites situated along the east coast, while site P5 on the west coast has only 0.35 MSL (Tab. 3). Mean highest water (MHHW) marks the upper limit of the stands with the lower limit being defined by the pneumatophores fringing the edge of the channels, which correlates with mid sea level (MSL). The salt flat that backs the mangal is only inundated during the highest spring tides of the year (Tab. 3).

Substrate moisture and Organic Content

Substrate moisture content and organic content vary in relation to substrate type (Newell, 1970). Tab. 5 shows the percentage of water content and organic content of different stations at sites. The finer substrates of natural mangroves contained more water and organic material (Figs. 18 to 20) than the coarser substrates of other sites at planted mangroves and salt marsh.

Soil Hydrogen-ion concentration

Mean soil water pH within the mangrove areas was pH 7.21 and at the planted mangrove areas slightly higher with value of pH 7.55, while it was in the range of pH 7.53 at the salt marsh (Fig. 21). Overall, the ground water of natural mangrove, planted mangrove and salt marsh areas were moderately alkaline (pH 7.11 - 7.55), while sea water pH was 7.91 - 8.30.

Oxygen concentration

Tab. 6 shows that the degree of saturation with dissolved oxygen generally tends to be lower in soil water from the inner part of the natural and planted mangrove sites. The concentration of dissolved oxygen in the open sea water was 3.81 ml l^{-1} and this value was considered as 100% of oxygen saturation. All samples collected from natural mangrove areas had oxygen saturation values between 7.09% to 18.06% and planted mangrove areas showed 9.72 - 17.39% of oxygen saturation. The salt marsh (S) was between 8.34% - 16.68% oxygen saturation and reached the highest value (33.36%) at station 6 at this site on the upper shore. Overall, all stations in natural and planted mangroves areas on the higher shore had highest oxygen soil content, while those stations located in mangroves showed the lowest oxygen content. Very dark subsurface soil, the presence of sulphides and H_2S indicate anaerobic conditions. However, at all sites the sediment colour was grey to light grey reflecting the good conditions surrounding the mangroves where no dead plants were found during the investigation.

Mangrove Tree, Pneumatophore and Burrow Relations

No plants grow when the soil is too reduced due to water stagnation. Tidal action and soil macropores for drainage seem to be indispensable for growth of mangroves. Most macropores are animal burrows so that mangrove plants and burrowers can be considered mutualistic Wada and Takagi (1988). To test whether this supposion was tenable for mangroves in Qatar the average pneumatophore densities, height, and burrow densities 0.25 m^2 vs. tree height were examined for natural and planted mangrove areas. Figs. 22 & 23 indicate that there are no relationships between the mean number of burrows vs. tree height, pneumatophore height vs. tree height, and pneumatophore numbers vs. burrow numbers. The only positive relationship was between tree height and pneumatophore numbers in natural mangrove areas and at planted mangrove areas. It was noticed that as the density of pneumatophores increased so did the number of burrows (Fig. 23).

Burrow Temperatures

Comparison between air, ground surface and burrow temperatures was made during August 1995 at Al-Khor N1. *Nasima dotilliformis* burrows were chosen and the temperature values were taken between 10.00 - 15 h (low tide). Fig. 24 shows that the highest air temperature value of 38°C was recorded at 13.00 h, while the lowest was 36°C. Burrow temperature at 10.00 h (29°C) increased steadily with increase in air temperature to reach a highest value of 32°C. Burrow temperature value differed by 1°C to surface temperature and 3-4°C to air temperature. Burrow temperatures obtained from the upper intertidal zone were high and might be lower if readings had been taken in the mid intertidal zone. Tab. 7 gives the monthly values for air temperatures and burrow temperatures for different crab species taken during visits to the 3 main sites (i.e., N1, N3 and P1). At site P1, a minimum burrow temperature of 13°C - 14°C was recorded for *M. depressus* during January and February 1994 respectively. The lowest burrow temperature was also recorded for *S. crabricauda* during the same period. The highest air temperature 43°C (14.25 h) recorded at P1 was reduced by 7°C - 15 °C within *S. crabricauda* and *M. depressus* burrows respectively. At site N1, burrow temperatures of 5 crab species were recorded and a drop of 2°C - 9°C from air temperatures was seen. The highest air temperature was 40°C (09.18 h) while the burrow temperatures for *S. crabricauda* and *E. orientalis* were 4°C and 6°C lower for *M. depressus* and *M. indica* burrows. During April 1994 at 14.20 h a value of 9°C less than air temperature was recorded in burrows of *N. dotilliformis, M. depressus* and *M. indica*. The lowest burrow temperature was 15°C during February 1994 (09.15 h) recorded for *S. crabricauda* and 14°C for the rest of the crab species. At site N3, burrow temperatures of 6 crab species differed from air temperature by 1°C - 11.5°C. Overall, the values of burrow temperatures for mid and lower shore species were usually lower than those taken on the upper shore.

Biota

Fauna

Although there are no previous records of mangrove and saltmarsh fauna or biodiversity in Qatar, this survey is primarily concerned with identifying the macrofaunal species which are characteristic of the intertidal substrates within the mangal. Brachyurans were of primary concern and other fauna such as mollusca are given less priority.

The horizontal zonation patterns from HWS to MSL, were investigated for crabs and an estimation of the population density is attempted. Mangrove and salt marsh communities at 11 study sites include a faunal assemblage of many species with crustaceans contributing 17 species, molluscs 19 species, annelids 7 species and fish 30 species. Tab. 8 and Tab. 9 illustrate the species recorded at different sites. The crab species exhibit clear zonation (Tab. 10) whereas some other species are just visitors (mostly fish), but the majority of species are residents in the mangroves. The mud skipper *Boleophthalmus boddarti* is found only in natural mangrove areas at the north of Qatar and at Doha (S) in the salt marsh, but was absent in all planted mangrove areas. Although all the above species found in this study from natural, planted mangrove and salt marsh are new records for Qatar, they are species which have been described from elsewhere in the Arabian Gulf (Jones 1980, 1986; Vousden 1989; Apel 1994). It is notable, however, that *Serenella leachii* has not been recorded in the north Arabian Gulf (Kuwait, Saudi Arabia and Bahrain).

Tab. 10 gives a list of intertidal crab species zonation at different sites. *Scopimera crabricauda* and *M. messor* are present at the upper intertidal zone at all sites. Zekrit site (P5) on the west coast is unique in the low number of crab species due to high salinity (60-90‰). *Nasima dotilliformis* is restricted only to natural mangrove and salt marsh sites, and this species is absent from all planted mangrove sites where there is no habitat as most of available habitat was sand. *Ilyoplax frater* is only absent from P1, P4 and P5 sites and present at other planted mangroves, all natural mangrove and saltmarsh sites in the mid - intertidal zone where there was a high proportion of silt and clay. *Serenella leachii* prefers mud banks and during the present survey was found only at P1, P2 and S at high abundance (eye observation), but absent from all natural mangrove and other planted mangrove sites. Overall, there were 15 brachyuran species recorded, 8 ocypodids, 2 grapsids, 2 portunids, 2 xanthids and 1 leucosiid, 1 anomuran species was also recorded. Two sandy / mud and sandy / rocky sites were selected for comparision during August 1995 to determine species with a general intertidal occurrence. From Tab. 11 it is obvious that crab species inhibiting sandy-rocky sites differ apart from *M. messor* and *P. pelagicus* which also inhabit mangrove and salt marsh.

Zonation

It is widely accepted that intertidal species distribute themselves according to tidal height and substrate type. The zonation of the intertidal species of brachyura recorded at different study sites is presented at Tab. 10. Although, not all quadrat sampled species were found on every transect, when the same species did occur (Tabs. 9,10 & 11), they were always zoned at the same level. For this reason the data for all transects are pooled.

Landward fringe

This zone is characterized by well developed salt marsh and with strong growth of *Halocnemum strobiolaceum* and *Arthrocnemum glaucum* and replaced further down by *Salicornia europea*. Tidal inundation occurs at spring tides, at these times the crabs are frequently seen feeding on the surface. These zones were also visited when there had been no inundation during neap tides and at these times the area appeared uninhabited. Characteristic fauna included *Scopimera crabricauda* which digs burrows in sandy areas; the omnivorous or predatory species *Metopograpsus messor* and *Eurycarcinus orientalis* and in softer muds *Nasima dotilliformis*. These species occur above the *Avicennia marina* zone, but were not found at the planted mangrove P5 on the west coast. The only dominant species at this site are *Scopimera crabricauda* and *Metopograpsus messor*. The landward fringe of all transects which are located at planted mangrove areas backs onto a sandbar separating the mangal from the sea. Hence at P1 to P4 large burrows belonging to *Ocypode rotundata* were found. This zone has the lowest population overall.

Avicennia zone

This extends from high tide to just below mean sea level. It was commonly populated by 7 crab species and the substrate was heavily pitted with burrows. The dominant faunal element is the ocypodid crab *Nasima dotilliformis*, which builds conspicuous burrows in this zone. An average 10 - 20 burrows m^{-2} were counted, but the total number of individuals is probably higher, since juveniles are often found associated with adult burrows (Jones & Clayton 1983; Apel 1994). Besides this, other characteristic fauna included *S. crabricauda* in sandy parts of this habitat, and *M. messor* and *E. orientalis*. The mid littoral zone seems to harbour maximum numbers of brachyuran species. The dominant representatives of this zone are *S. crabricauda, E. orientalis, S. leachii, M. arabicum, N. dotilliformis, I. frater and M. depressus*.

Nodilittorina glabrata and *Planaxis sulcatus* are common on the leaves and trunk of *Avicennia marina*. The mud gastropod *Cerithidea cingulata* reaches highest densities for juveniles on the landward side and for adults on the seaward fringe of the *Avicennia*.

Lower intertidal

This zone of the open mud flat below the *Avicennia marina* is colonised predominantly by *Macrophthalmus depressus* and *Metaplax indica*, with the latter, although present in the mangrove zone, only in small numbers nearer low water. Where sandy areas occur at similar level on the shores (P1 to P4) *M. depressus* and *S. crabricauda* are present. The infauna inhabiting this zone such as polychaetes, bivalves, and interstitial fauna are abundant, providing rich feeding grounds for birds, penaeid shrimp and juvenile fish.

Seasonal distribution

The brachyuran seasonal distribution at the different tidal levels along the different transects at different sites is presented in Figs. 25 to 35. Along each of these transects 3 to 6 stations were sampled at monthly intervals for N1, N2, N3, P1 and S, while other sites (N4, N5, P2, P3, P4 and P5) were sampled between 1 to 4 times / year. For sites studied at monthly intervals and others, brachyuran population abundances are described in more detail as follows:

Al-Khor N1

Over all mean abundance of crab species at the different levels was collected from June 1993 - June 1994 along the transect at this site are illustrated in Fig. 25. The most common species at the upper intertidal level are *S. crabricauda* and *N. dotilliformis* throughout the study period. *Scopimera crabricauda* was observed with highest values of 22-25 individuals 0.25 m^2 during June-July 1994, while the values decreased in August to reach the lowest value of 11 individuals 0.25 m^2 during January 1994. The abundance of *S. crabricauda* increased again from February 1994 to 28 individuals 0.25 m^2 during June 1994. The second species of importance at the upper intertidal was *N. dotilliformis*, with high numbers during September- October 1993 (9-7 individuals 0.25 m^2 respectively) and March-April 1994 (12 - 9 individuals 0.25

m^2), reducing to 0-3 individuals 0.25 m^2 during winter months. In the mid-intertidal 3 ocypodid species occurred in different proportions. *Scopimera crabricauda* reached 11-27 individuals 0.25 m^2 in summer and lowest values were recorded in winter. The second species of importance at this level was *Nasima dotilliformis*, with a high abundance during March-April 1994. *Eurycarcinus orientalis* was less important with an average of 1-7 individuals 0.25 m^2 throughout the study period and lowest levels during winter months. In the lower intertidal *M. depressus* and *M. indica* occur, the former most abundant with 14-19 individuals 0.25 m^2 during summer months and 3-10 individuals 0.25 m^2 during winter months. *Metaplax indica* was usually very rare and absent between November 1993 to April 1994, but occurred at 1-4 individuals 0.25 m^2 during summer months.

Al-Khor N2

Of the 4 stations established at this site, 2 of these stations were located on the upper and 2 stations at the mid intertidal. *Scopimera crabricauda* was present only in the upper intertidal with 4 - 8 individuals 0.25 m^2 during summer and 0 - 1 individuals 0.25 m^2 during autumn-winter. *Nasima dotilliformis* dominated over all upper and mid intertidal with values reaching 25 individuals 0.25 m^2 during March 1994 dropping to 16-19 individuals during winter months (Fig. 26).

Al-Dhakhira N3

Fig. 27 shows the seasonal distribution of the 6 crab species collected from June 1993 - June 1994 along the transect at this site. Stations 1-3 have a well developed saltmarsh characterized by *Arthrocnemum glaucum*. *Nasima dotilliformis*, dominated building conspicuous burrows on this site with average of 23-31 individuals 0.25 m^2. The situation in the mid intertidal was more complex, with 4 species of ocypodid crab occurring in different proportion. *Ilyoplax frater* varied from 13-280 individuals 0.25 m^2 throughout the study period. *Manningis arabicum* had an average of 3 - 14 individuals 0.25 m^2, and

N. dotilliformis an average of 8-29 individuals 0.25 m^2, while *E. orientalis* was present at 5-8 individuals 0.25 m^2 during summer and autumn but was absent during winter months. In the lower intertidal *M. depressus* and *M. indica* occurred, the former with 13-24 0.25 m^2 during summer, while *M. indica* occurred at 4-6 individuals 0.25 m^2, both species were absent or reduced during winter months.

Al-Dhakhira N4

This site was sampled 4 times /year, and the survey showed that the dominant species along the transect were *S. crabricauda*, *I. frater*, *M. depressus* and *M. indica*. Station 1 contained *S. crabricauda*, which also appeared at station 2 during January 1994. *I. frater* was at station 2, but disappeared from this station during January. Stations 3-5 contained only *M. depressus* and *M. indica* and these species were absent from stations 4-5 during January 1994 (Fig. 28).

Al-Dhakhira N5

Five stations located along the transect at this site were sampled once during June 1994 (Fig. 29). At station 1, 3 species of ocypodid crab occurred in different proportions. *S. crabricauda* dominated with 10-11 individuals 0.25 m^2, while *E. orientalis* and *N. dotilliformis* were represented by 3-5 and 3-4 individuals 0.25 m^2 respectively. *Manningis arabicum* dominated at station 2 (20-22 individuals 0.25 m^2), while *E. orientalis* was represented by 2-4 individuals 0.25 m and *N. dotilliformis* by 2 individuals 0.25 m^2. At station 3 only 2 species were present *S. crabricauda* (14-16 individuals 0.25 m^2) and *E. orientalis* (2-3 individuals 0.25 m^2). There were 4 species at station 4 with *I. frater* reaching 8-9 individuals 0.25 m^2. The second species of importance was *M. depressus* with 3-4 individuals 0.25 m^2, while *E. orientalis* and *M. indica* formed only 1 and 1-2 individuals 0.25 m^2 respectively. The lower station (station 5) contained *M. depressus* and *M. indica* with 3-4 and only 1 individual 0.25 m^2 respectively.

Umm Al-Hul P1

The most dominant species at this site are *S. crabricauda, E. orientalis* and *M. depressus* (Fig. 30). The percentage occurrence differs from station to station throughout the period of study. In the upper intertidal level *S. crabricauda* occurred at 12-20 individuals 0.25 m^2, *M. depressus* with average of 6-31 individuals 0.25 m^2, both reduced abundance during winter months. *Eurycarcinus orientalis* averaged 4-6 individuals 0.25 m^2 during summer months, but was absent during winter. In the mid intertidal, *S. crabricauda* occurred at 5-20 individuals 0.25 m^2 during summer, but was absent during winter. *Macrophthalmus depressus* occurred at 6-31 crabs 0.25 m^2 throughout the study period, but on the lower intertidal abundance reached 7-39 individuals 0.25 m^2.

Al-Wakrah P2

This site was sampled 4 times / year, and the dominant species along the transect were *S. crabricauda* and *M. depressus* (Fig. 31). During January 1994 no crabs were observed at station 1 while stations 2-3 were occupied by *S. crabricauda* (2-4 individuals 0.25 m^2) and *M. depressus* only at station 2 (1-2 individuals 0.25 m^2). During March 1994 *S. crabricauda* was present at all stations with between 9 - 32 individuals 0.25 m^2, while *M. depressus* was present at stations 2-3 with 2-5 individuals 0.25 m^2. In April 1994 and June 1994 both species spread over all stations with *S. crabricauda* dominating, except at station 3 in June 1994, when *M. depressus* reach its highest abundance (82.89%).

Fuwairit P3

This site was sampled 4 times / year, and revealed *S. crabricauda*, *E. orientalis*, *M. arabicum* and *M. depressus* (Fig. 32). *M. arabicum* was only found during November 1993 at stations 1 and 5 (3-4 individuals 0.25 m^2). *E. orientalis* occurred at station 1 during November 1993, and station 2 during January and April 1994, but appeared at stations 1-3 during June 1994. The average maximum abundance of this crab was rarely above 4 individuals 0.25 m^2. *M. depressus* spread over stations 1-3 and extended to station 5 during June 1994. The average abundance of this species was 2-23 individuals 0.25 m^2. *S. arabicum* was found at most stations during April 1994 and ranged from 5-48 individuals 0.25 m^2.

Al-Mafjar P4

This site was sampled 3 times / year, revealing *S. arabicum* and *M. depressus* (Fig. 33). The former species abundance differed between stations and overall maximum density reached 12 individuals 0.25 m^2, while overall maximum abundance of the latter reached 5 individuals 0.25 m^2.

Zekrit P5

This site located on the west coast was sampled once during April 1994 (Fig. 34). The only species found on the transect was *S. crabricauda* with an average maximum abundance of only 1 individual 0.25 m^2.

Doha S

This saltmarsh was sampled for 7 months from December 1993-June 1994 (Fig.35). The dominant species in the upper intertidal were *S. crabricauda* and *N. dotilliformis*. The former reached 16-41 individuals 0.25 m^2, while the latter 3-25 individuals 0.25 m^2. The mid intertidal revealed 5 species of ocypodid crabs occurring in different proportions. *Scopimera crabricauda* extended to the mid intertidal at 16-41 individuals 0.25 m^2, *M. arabicum* was present at 13-43 individuals 0.25 m^2, *M. depressus* 9-30 individuals 0.25 m^2, *N. dotilliformis* at 3-25 individuals 0.25 m^2, and *E. orientalis* at 1-14 individuals 0.25 m^2 during study period. All species showed a reduction in abundance during winter at both levels of intertidal zone.

In summary, it appears that upper to lower intertidal species show a similar seasonality of abundance at all levels on all sites (Figs. 25, 26, 27, 30 and 35).

In general, abundance was extremely high during summer, followed by decline to lowest values in winter months.

Population Abundance

Burrows have been expressed as numbers 0.25 m^2 to give an estimation of population abundance. Unfortunately these counts cannot be used as indicators of specific species total population size, although as many as possible were excavated to ascertain total numbers per quadrate, Juvenilesand deep burrows forms may be vissal. However, burrows counts at different sites at least indicate the relative population abundances for different zones within the ecosystem. The population abundance for *M. messor* could not be measured as it does not form burrows. Crab species such as *E. orientalis, N. dotilliformis, M. depressus* spend minimal time on the surface or remain partially buried even when the tide is out. Data at all stations located along the transects of N1, N2, N3, P1 and S sites has been pooled to calculate monthly average population abundance for each site separately (Figs. 36 to 40).

The mean abundance of *S. crabricauda* (Figs. 36a, 37a, 39a, and 40a) shows a drop during winter at all sites. *Nasima dotilliformis* fluctuated throughout the study period (Figs. 36b, 37,b, 38a and 40b) with high abundance during March at all sites, but in July at Al-Dhakhira (N3). *Eurycarcinus orientalis* occurred in comparatively low number along the transect at different sites with low activity between December -March and high activity in spring (Figs. 36c, 38d and 40c). The mean abundance of *I. frater* was high during November and March (Fig. 38b). The Mean abundance of *M. arabicum* dropped in winter and peaked in spring (Figs. 38c and 40d). The mean abundance of *M. depressus* was also highest in warmer months at all sites (Figs. 36d, 38e, 39b and 40e). *Metaplax indica* followed a similar pattern and was only active during spring and summer (Figs. 36e and 38f).

Molluscan and Mud skipper Population Abundances

The most common gastropods associated with mangrove areas in Qatar are *Planaxis sulcatus*, *Cerithidea cingulata*, *Trochus erythraeus* and *Littorina glabrata*. Barnacles, *Balanus amphitrite* and gastropod *Littorina glabrata* are the only marine species which have invaded the branches and leaves of mangrove trees and the former extended to colonized pneumatophores, while *Planaxis sulcatus*, occurr in small numbers on the lower trunks and pneumatophores of trees. Mud skippers are perhaps the most conspicuous spending considerable periods out of water. *Boleophthalmus boddarti* is the common species found only on the natural mangrove and salt marsh. However, *Planaxis* were collected during different periods from natural mangrove, planted mangrove and salt marsh areas at a density of 0.5 m^2, while mud skipper abundance reached 10 m^{-2} (Tab. 14).

Hand net fishing results

It is obvious from the first fishing experiment (see appendix 2: Tab. I) that natural mangrove sites (N1 & N2) have a high number of species (7-8 species). Both numbers of species and individuals are significantly higher at these sites. Although 7 species were found at site P1 (planted mangrove), the individual numbers were lower. Site P5 situated on the west coast shows the lowest number of species caught (4 species), and lowest total numbers of individuals, 5 species were caught at site S (salt marsh). Crabs such as *P. pelagicus* were found in catches with fish at these sites. A Tukey - HDS test for ANOVA (SPSS ver. 6) indicates that there are significant differences between the mean of fish species caught at N1 and N2 compared with those caught at the salt marsh and planted mangrove areas. Sites N1 and N2 yielded 8-7 fish species and both sites have the highest number of individuals. Site P1 also yielded 7 species, but with a low number of individuals, while the lowest value of species (4) and individuals was recorded at site P1 on the west coast.

The result of the second experiment (see appendix 2: Tab.II) which was carried out at N1, P1 and SS (sandy beach) during August 1995 shows that N1 contained 10 species and the highest number of individuals. Site P1 contained 8 fish species, while site SS only 7 species and lowest number of individuals. A Tukey - HSD test indicates that significant differences are present between N1 and site SS, and significant differences occur between P1 compared with sites N1 and SS. Overall, hand net fishing results indicate that the mangrove area, specially pneumatophores of the mangroves trees, form a special habitat for small fish, most of which are commercial species.

Gill- net and seine net

Tab. 15 shows a total of 28 species caught by seine net and gill net representing 18 families collected from different habitats. At N1 and N3 14 species from seine nets and 17 species from gill nets were collected. A total catch of 2-9 and 6-5 individual species respectively were collected from planted mangrove areas (P3, P4) by using both nets. Although the fish caught are lower in numbers than in natural mangrove, the planted mangrove area is higher in fish species than the sandy area. Fishing at the sandy site resulted in 2 species caught by seine net and 6 species caught by gill net. It was observed that both abundance and species are higher in natural mangrove than planted mangrove and most catches at all sites consisted of commercial fish species.

Analysis of macrobenthic fauna

Similarity between the macrobenthic faunal communities (Tab. 8) of planted mangrove, natural mangrove and salt marsh sites has been analysed using cluster analysis, results are shown in Fig. 41. It is apparent from this figure that sites N1 and N3 (natural mangroves) show the closest faunal association with a percentage similarity of 84.75%. The next highest level of similarity (69.5%) occurs between the fauna inhabiting planted mangrove sites P1 and P2. Sites P3 and P4 also have a close faunal association and are linked at

62.65%. However, as all natural and planted mangrove sites link at the 61% level they can be regarded as essentially similar communities.

Analysis of fish fauna

A cluster analysis based on fish species caught at planted mangrove, natural mangrove and salt marsh habitats (Tab. 9) is given in Fig. 42. It is apparent from this figure that the highest similarity (68.38%) occurs between fish species inhabiting sites N1 and N3, both natural mangrove areas. Equal similarity (68.38%) exists between fish species inhabiting sites P3 and P4, and P2 is linked with these sites at 65.36%. Site S (salt marsh) links with sites P2 and P4 at 53.10% similarity. While P1 links with both natural mangrove sites at 51.01% similarity, there is less than 50% similarity between most planted sites / salt marsh and natural mangroves.

Table 1 : Location and the main features of the sampled stations on the study sites.

Site No.	Site Name	Location	Coordinates	No. of samples stations	Main features
1	Umm Al-Hul (P1)	Southeast	25° 04' 44N 051° 37' 05E	5	Planted mangrove
2	Al-Wakrah (P2)	Southeast	25° 10' 16N 051° 36' 49E	3	Planted mangrove
3	Doha (S)	Central East	25° 21' 59N 051° 31' 22E	6	Salt - marsh
4	Al-Khor (N1)	Northeast	25° 41' 55N 051° 33' 04E	6	Natural mangrove
5	Al-Khor (N2)	Northeast	25° 41' 46N 051° 33' 32E	4	Natural mangrove
6	Al-Dhakhira (N3)	Northeast	25° 44' 49N 051° 32' 13E	6	Natural mangrove
7	Al-Dhakhira (N4)	Northeast	25° 45' 17N 051° 33' 40E	5	Natural mangrove
8	Fuwairit (P3)	Northeast	26° 02' 03N 051° 22' 06E	5	Planted mangrove
9	Al-Mafjar (P4)	N -Northeast	26° 08' 27N 051° 16' 56E	5	Planted mangrove
10	Zekrit (P5)	Central West	26° 02' N 051° 22' E	3	Planted mangrove
				Total = 48	

Table 2: Grain size distribution and statistical parameters of sediment samples collected from mangrove and salt marsh sites at the different stations (M_z mean grain size (mm), σ_I sorting (standard deviation), sK_i skewness and K_G kurtosis).

Area	Station No.	Percentiles of grain size in Phi							Statistical parameters			
		φ5	φ16	φ 25	φ 50	φ 75	φ 84	φ 95	Mz	σI	sKi	KG
Al-Khor	1	0.5	1.47	2.02	2.76	3.56	3.86	4.73	0.15	1.24	-0.07	1.12
(N1)	2	1.53	2.29	2.62	3.37	4.03	4.41	4.88	0.09	1.04	-0.06	0.97
	3	0.70	1.79	2.25	2.14	3.85	4.22	4.87	0.12	1.24	-0.14	1.06
	4	0.52	1.91	2.24	3.00	3.73	3.99	4.84	0.13	1.18	-0.10	1.20
	5	1.05	2.06	2.33	3.07	3.72	3.95	4.73	0.12	1.03	-0.08	1.08
	6	0.77	1.87	2.19	2.84	3.55	3.81	4.59	0.14	1.06	-0.05	1.16
Al-Khor	1	0.24	1.07	1.50	2.47	3.32	3.67	4.39	0.19	1.28	-0.07	0.94
(N2l)	2	0.00	1.31	1.98	2.66	3.48	3.82	4.83	0.17	1.36	-0.09	1.32
	3	3.19	3.61	3.95	7.55	9.10	9.42	9.82	0.01	2.46	-0.34	0.53
	4	3.18	3.59	3.92	7.24	9.04	9.39	9.81	0.01	2.45	-0.24	0.53
Al-Dhakhira	1	3.51	4.50	5.58	8.22	9.22	9.50	9.84	0.01	2.21	-0.49	0.71
(N3)	2	3.28	3.91	4.39	5.95	9.07	9.40	9.81	0.01	2.36	0.22	0.57
	3	3.18	3.59	3.92	4.83	7.59	9.09	9.72	0.02	2.37	0.52	0.73
	4	3.29	3.91	4.26	5.96	9.19	9.48	9.84	0.01	2.39	0.23	0.54
	5	3.40	4.18	4.64	5.95	7.33	7.87	8.82	0.02	1.74	0.05	0.82
	6	3.56	4.30	4.70	8.20	9.27	9.53	9.85	0.01	2.26	-0.48	0.57
Al-Dhakhira	1	0.00	0.87	1.32	2.43	3.40	3.67	3.99	0.18	1.31	-0.17	0.78
(N4)	2	0.00	1.10	2.02	3.32	3.91	4.28	4.87	0.15	1.53	-0.38	1.06
	3	0.00	0.99	1.78	3.08	3.74	3.98	4.81	0.14	1.48	-0.34	1.01
	4	0.09	1.28	2.00	2.86	3.66	3.95	4.92	0.15	1.40	-0.17	1.19
	5	0.32	1.79	2.27	3.15	3.83	4.18	4.95	0.28	1.30	-0.18	1.22
Umm Al-Hul	1	0.00	0.56	1.09	1.92	2.71	3.00	4.46	0.28	1.29	0.01	1.13
(P1)	2	0.50	1.27	1.61	2.40	3.37	4.24	4.90	0.16	1.42	0.19	1.03
	3	0.13	1.19	1.72	2.92	4.36	4.67	5.23	0.13	1.64	-0.05	0.79
	4	0.00	0.78	1.32	2.48	4.11	4.5	4.98	0.17	1.69	0.05	0.73
	5	0.27	1.43	2.06	3.21	4.09	4.45	4.90	0.12	1.46	-0.22	0.93
Al-Wakrah	1	0.18	1.10	1.34	2.01	2.59	2.8	3.57	0.26	0.94	-0.08	1.12
(P2)	2	0.80	1.32	1.61	2.24	2.69	2.85	3.73	0.23	0.83	-0.09	1.12
	3	1.04	1.47	1.83	2.33	2.73	2.87	3.7	0.21	0.75	-0.1	1.21

Table 2 continued

Table 2: Grain size distribution and statistical parameters of sediment samples collected from mangrove and salt marsh sites at the different stations (M_z mean grain size (mm), σ_I sorting (standard deviation), sK_i skewness and K_G kurtosis).

Area	Station No.	Percentiles of grain size in Phi							Statistical parameters			
		ϕ 5	ϕ 16	ϕ 25	ϕ 50	ϕ 75	ϕ 84	ϕ 95	Mz	σI	sKi	KG
Fuwairit	1	0.00	0.49	1.17	2.52	3.45	3.77	4.58	0.21	1.52	-0.17	0.82
(P3)	2	0.29	1.28	1.82	2.58	3.36	3.71	4.83	0.17	1.30	-0.40	1.21
	3	0.35	1.72	2.12	2.67	3.39	3.76	5.02	0.15	1.22	0.04	1.5
	4	0.92	2.02	2.22	2.79	3.50	3.78	4.72	0.14	1.02	0.07	1.22
	5	0.78	1.77	2.14	2.71	3.40	3.7	4.55	0.15	1.05	0.00	1.22
Al-Mafjar	1	0.00	1.03	1.41	2.55	3.54	3.85	4.65	0.18	1.41	-0.09	0.89
(P4)	2	1.07	1.62	2.04	2.79	3.53	3.79	4.49	0.15	1.06	-0.05	0.94
	3	0.56	1.38	1.78	2.86	3.84	4.28	4.89	0.14	1.38	-0.04	0.86
	4	0.05	1.13	1.51	2.74	3.83	4.29	4.93	0.15	1.53	-0.06	0.86
	5	0.11	0.79	1.17	1.96	6.65	4.28	4.99	0.28	1.61	0.28	0.81
Zekrit	1	0.00	0.35	1.10	3.08	3.92	4.30	4.80	0.17	1.71	-0.34	0.7
(P5)	2	0.00	0.00	0.75	3.33	4.32	4.59	4.92	0.16	1.89	-0.4	0.57
	3	0.12	1.40	2.16	3.26	3.9	4.27	4.88	0.13	1.44	-0.31	1.12
Doha	1	3.58	4.18	4.41	5.08	6.84	7.69	9.53	0.02	1.78	0.49	1.01
(S)	2	3.61	4.28	4.60	5.68	7.00	7.59	8.69	0.02	1.60	0.17	0.87
	3	0.00	0.00	0.00	0.96	1.88	2.47	3.75	0.45	1.19	0.35	0.82
	4	3.42	4.17	4.53	5.61	6.99	8.13	9.65	0.02	1.93	0.28	1.04
	5	3.24	3.76	4.18	5.34	6.68	7.38	9.35	0.02	1.83	0.22	1.00
	6	0.00	0.52	1.12	2.68	3.51	3.74	4.13	0.02	1.43	-0.32	0.71

Table 3: Tidal ranges along the east coast of Qatar (figures in metres and the tidal levels referred to chart datum).

Location	MHHW	MLHW	MHLW	MLLW	MSL
Al-Wakrah	1.68	0.73	1.01	0.28	0.91
Doha	1.75	0.76	0.89	0.20	0.90
Al-Khor	1.76	0.85	0.92	0.27	0.95
Fuwairit	1.73	1.03	0.72	0.27	0.94
Zekrit	0.63	0.41	0.32	0.05	0.35

Table 4: Sediment characteristics at different sites at the different stations.

Site	Station No.	Sand %	Silt %	Clay %	Organic matter %	Mean grain size (mm)	Moisture content (g)	Soil pH
Al-Khor (N1)	1	88.17	11.83	-	2.11	0.15	14.80	7.12
	2	74.33	25.67	-	2.50	0.09	20.60	7.70
	3	80.19	19.81	-	2.80	0.12	22.00	7.55
	4	84.30	15.70	-	3.00	0.13	23.32	7.61
	5	85.79	14.21	-	3.13	0.12	23.74	7.62
	6	90.76	9.24	-	2.75	0.14	23.56	7.16
Al-Khor (N2)	1	92.36	7.64	-	2.20	0.19	16.51	NR
	2	88.59	11.41	-	2.75	0.17	17.17	NR
	3	26.34	27.58	46.09	3.00	0.01	29.88	NR
	4	27.12	29.45	43.43	4.25	0.01	26.93	NR
Al-Dhakhira (N3)	1	9.82	35.19	54.99	2.88	0.01	23.65	7.08
	2	17.66	41.91	40.44	3.00	0.01	27.25	7.60
	3	27.20	49.45	23.35	3.20	0.02	23.09	7.45
	4	17.50	37.36	45.14	3.71	0.01	25.89	7.30
	5	12.37	73.87	13.76	3.44	0.02	26.02	7.72
	6	9.00	37.00	54.00	3.67	0.01	34.47	NR
Al-Dhakhira (N4)	1	95.24	4.76	-	1.86	0.18	6.65	NR
	2	78.81	21.19	-	3.2	0.15	20.77	NR
	3	84.74	15.26	-	3.67	0.14	24.28	NR
	4	85.66	14.34	-	2.5	0.15	30.56	NR
	5	81.38	18.62	-	2.25	0.28	22.98	NR
Umm Al-Hul (P1)	1	91.95	8.05	-	1.75	0.28	8.50	7.80
	2	80.29	19.71	-	2.17	0.16	20.37	7.90
	3	64.46	35.54	-	3.67	0.13	21.11	7.54
	4	72.45	27.55	-	2.60	0.17	20.82	7.26
	5	72.81	27.19	-	1.33	0.12	19.00	7.13
Al-Wakrah (P2)	1	96.67	3.33	-	1.88	0.26	18.27	NR
	2	96.08	3.92	-	2.14	0.23	19.50	NR
	3	96.29	3.71	-	2.00	0.21	20.99	NR
Fuwairit (P3)	1	90.30	9.70	-	2.00	0.21	17.63	7.85
	2	91.38	8.62	-	2.60	0.17	19.83	7.27
	3	89.86	10.14	-	2.63	0.15	20.81	7.04
	4	91.20	8.80	-	2.89	0.14	20.87	7.37
	5	93.08	6.92	-	2.43	0.15	20.77	7.38
Al-Mafjar (P4)	1	88.58	11.42	-	2.00	0.18	12.45	NR
	2	91.29	8.71	-	2.43	0.15	19.20	NR
	3	79.08	20.92	-	2.89	0.14	23.29	NR
	4	79.06	20.94	-	2.63	0.15	23.30	NR
	5	79.58	20.42	-	2.60	0.28	20.86	NR
Zekrit (P5)	1	77.55	22.45	-	2.50	0.17	17.15	NR
	2	64.55	35.45	-	3.29	0.16	25.57	NR
	3	79.03	20.97	-	2.80	0.13	18.87	NR
Doha (S)	1	8.66	78.45	12.89	5.00	0.02	28.08	7.23
	2	8.15	82.03	9.82	3.86	0.02	29.60	7.70
	3	96.59	3.41	-	2.13	0.45	16.63	7.50
	4	11.93	71.80	16.27	3.17	0.02	25.17	7.84
	5	21.19	69.20	9.61	3.54	0.02	27.19	7.90
	6	94.28	5.72	-	2.50	0.02	7.81	7.00

(NR: not recorded)

Table 5: Over all mean of organic matter (%) and mean grain size (mm) of the sediment samples collected from natural, planted mangroves and salt marsh.

Site	Mean organic matter % ± SE	Mean grain size (mm) ± SE	Mean moisture content (g) ± SE	Mean Soil pH
Al-Khor (N1)	2.70 ± 0.15	0.13 ± 0.01	21.34 ± 1.40	7.46 ± 0.10
Al-Khor (N2)	3.05 ± 0.43	0.10 ± 0.05	22.62 ± 1.47	NR
Al-Dhakhira (N3)	3.32 ± 0.14	0.01 ± 0.00	26.73 ± 1.67	7.11 ± 0.11
Al-Dhakhira (N4)	2.71 ± 0.33	0.18 ± 0.03	21.05 ± 3.95	NR
Umm Al-Hul (P1)	2.30 ± 0.40	0.17 ± 0.03	17.96 ± 2.39	7.53 ± 0.15
Al-Wakrah (P2)	2.01 ± 0.08	0.23 ± 0.01	19.59 ± 0.79	NR
Fuwairit (P3)	2.51 ± 0.15	0.16 ± 0.01	19.98 ± 0.62	7.38 ± 0.13
Al-Mafjar (P4)	2.51 ± 0.15	0.18 ± 0.03	19.82 ± 0.56	NR
Zekrit (P5)	2.86 ± 0.23	0.15 ± 0.01	20.53 ± 2.57	7.73 ± 0.27
Doha (S)	3.03 ± 0.26	0.09 ± 0.07	20.75 ± 4.32	7.53 ± 0.15
Over all mean of (N)	2.95 ± 0.14	0.11 ± 0.04	22.94 ± 1.31	7.21 ± 0.17
Over all mean of (P)	2.44 ± 0.15	0.18 ± 0.01	19.58 ± 0.43	7.55 ± 0.10
Over all mean of (S)	3.03	0.09	20.75	7.53

(NR: not recorded)

Table 6: Soil water oxygen concentration at different sites. (from Weiss 1970, 100% O_2 saturation at 35°C and 49 ‰ is equivalent 3.81 ml l^{-1}).

Site / Station	O_2 ml l^{-1} concentration	O_2 % saturation
Sea Water	3.81	100
Al-Khor N1		
1	1.32	34.74
2	1.01	26.40
3	0.74	19.47
4 M	0.37	9.72
5 M	0.27	7.09
6 M	0.32	8.34
Al-Khor N2		
1	1.01	26.40
2	0.95	25.02
3	0.53	13.89
4	0.37	9.72
Al-Dhakhira N3		
1	1.27	33.36
2	1.27	33.36
3	0.58	15.30
4 M	0.48	12.51
5 M	0.37	9.72
6 M	0.37	9.72
Al-Dhakhira N4		
1	1.27	33.36
2	1.06	27.81
3 M	0.58	15.30
4 M	0.53	13.89
5 M	0.69	18.06
Umm Al-Hul P1		
1	0.39	24.31
2 M	0.45	11.80
3 M	0.45	11.80
4 M	0.48	12.51
5 M	0.48	12.51
Al-Wakrah P2		
1	1.27	33.36
2 M	0.48	12.51
3 M	0.37	9.72
Fuwairit P3		
1	1.19	31.28
2 M	0.74	19.47
3 M	0.45	11.80
4 M	0.41	10.43
5 M	0.53	13.89
Al-Mafjar P4		
1	1.06	27.81
2	0.42	11.13
3 M	0.45	11.80
4 M	0.66	17.39
5 M	0.66	17.39
Zekrit P5		
1	0.69	18.06
2 M	0.42	11.13
3 M	0.48	12.51
Doha S		
1	0.32	8.34
2	0.48	12.51
3	0.58	15.30
4	0.64	16.68
5	0.58	15.30
6	1.27	33.36

(M : mangrove)

Table 7: Air temperature and burrow temperatures at 3 main sites.

(a) Umm Al-Hul (P1)

Date	Time	Air temp. C°	Burrow temp. C°	
			S. crabricauda	*M. depressus*
17 June - 93	01:20 PM	-	-	-
24 July	02:48 PM	-	-	-
10 August	03:40 PM	-	-	-
7 September	02:50 PM	37.5	34	32
4 October	02:25 PM	43	36	28
25 November	08:58 AM	28	25	23
10 December	09:10 AM	22	18	18
7 January - 94	07:30 AM	14	14	13
5 February	09:00 AM	17	14	13
9 March	12:30 PM	23	21	21
2 April	02:35 PM	25	24	24
17 May	02:30 PM	35	31	30
2 June	04:00PM	36	33	32

(b) Al-Khor (N1)

Date	Time	Air temp. C°	Burrow temp. C°				
			S. crabricauda	*E. orientalis*	*N. dotilliformis*	*M. indica*	*M. depressus*
28 June -93	10:00 AM	41	-	-	-	-	-
25 July	03:15 PM	37.5	-	-	-	-	-
16 August	09:40 AM	40	-	-	-	-	-
15 September	09:15 AM	35	30	29	29	28	28
20 October	03:20 PM	33	28	-	28	28	29
26 November	08:50 AM	28	20	-	20	-	22
4 December	03:20 PM	21	19	-	19	-	20
25 January - 94	01:15 PM	21	18	-	17	-	18
February	09:15 PM	18.5	15	14	14	-	14
March	01:45 PM	25	21	20	20	-	20
April	02:20 PM	37	32	31	28	28	28
May	01:45 PM	34	30	29	30	28	28
June	09:18 AM	40	36	36	33	34	34

(c) Al-Dhakhira (N3)

Date	Time	Air temp. C°	Burrow temp. C°				
			N. dotilliformis	*M. arabicum*	*I. frater*	*E. orientalis*	*M. depressus & M. indica*
18 June -93	09:10 AM	42	-	-	-	-	-
26 July	03:40 PM	39.5	-	-	-	-	-
23 August	02:42 PM	41.5	-	-	-	-	-
9 September	02:42 PM	41.5	34	34	-	32	30
7 October	03:15 PM	37	32	32	-	-	30
3 November	03:30 PM	34	30	28	-	-	-
2 December	02:30 PM	37	28	28	-	-	-
24 January - 94	02:00 PM	26	22	21	-	-	-
8 February	12:08 AM	22	16	15	-	-	-
3 March	11:11 AM	21	18	16	-	-	-
19 April	03:15 PM	21	20	20	19	-	19
4 May	02:35 PM	25	23	23	23	23	23
6 June	04:00PM	30	29	29	29	29	28

Table 8: Crustacea, mollusca and associated with salt - marsh and mangrove areas on the east coast of Qatar (**S** :salt marsh, **N** :natural mangrove and **P** :planted mangrove).

Species	(N1)	(N3)	(P1)	(P2)	(P3)	(P4)	(S)
Phylum : Arthropoda							
Class: Crustacea							
Chthamalus malayensis	*	*	*	*	*	*	*
Balanus amphitrite	*	*	*	*	*	*	*
Penaeus semisulcatus	*	*	*	*	*	*	*
Ocypode rotundata	¤	¤	*		*	*	¤
Nasima dotilliformis	*	*			*	¤	*
Manningis arabicum	*	*	*	*	*	¤	*
Serenella leachii	¤	¤	*	*	¤	¤	*
Macrophthalmus depressus	*	*	*	*	*	*	*
Macrophthalmus grandidieri			*	*		*	
Ilyoplax frater	*	*		*	*	¤	*
Scopimera crabricauda	*	*	*	*	*	*	*
Metopograpsus messor	*	*	*	*	*	*	*
Metaplax indica	*	*	*	*	*	*	
Portunus pelagicus	*	*	*	*	*	*	*
Epixanthus frontalis	¤	¤	*	*	*		*
Eurycarcinus orientalis	*	*	*	*	*	*	*
Petrolisthes rufescens	*	*	*	*	*	*	*
Phylum : Mollusca							
Class : Gastropoda							
Clypeomorus caeruleum	¤	¤	¤	¤	*	¤	¤
Cerithidea cingulata	*	*	*	*	*	*	*
Cerithium scabridum	*	*	*	*	*	*	*
Euchelus asper	¤	*	¤	¤	¤	*	¤
Clypeomorus bifasciata	*	*	*	*	*	*	
Pirinella conica	*	*	*	*	*	*	*
Planaxis sulcatus	*	*	*	*	*	*	*
Trochus sp.	¤	*	¤		¤	¤	¤
Thais savignyi	*	*	*	*	¤	¤	¤
Trocus erythraeus	*	*	¤		*	¤	¤
Nodilittorina subnodsa	*	*	*	*	*	*	*
Littorina glabrata	*	*	*	*	*	*	
Class : Bivalvia							
Brachidontes emarginatus	*	*	*	*	*	¤	¤
Clypeomorus bifasciata	*	*			*		
Marcia optima	*	*	¤	¤	¤	¤	¤
Monodonta vermiculata	¤	¤	¤	¤	*	*	¤
Barbatia helbingii					*	*	
Isognomon dentifera	*	*	¤	*	¤	*	¤
Gari roseus	*	*	*	*	*	*	
Phylum : Annelida							
Class : Polychaeta							
Eunice sp.	*	*	*	*	*	*	*
Nereis sp.	*	*	*	*	*	*	*
Nephtys sp.	*	*	*	*	*	*	
Perinereis sp.	*	*	*	*	*	*	
Sp. 1	*	*	*	*			*
Sp. 2	*	*	*				*
Sp. 3							*
Total	33	34	32	31	33	27	24

(¤) no habitat, (*) Present

Table 9: Fish species associated with salt - marshes and mangroves area on the east coast of Qatar (**S** :salt marsh, **N** :natural mangrove and **P** :planted mangrove).

Species	(N1)	(N3)	(P1)	(P2)	(P3)	(P4)	(S)
Phylum : Chordata							
Superclass: Pisces							
Allanetta forskali	*	*		*	*	*	*
Ablennes hians	*	*	*	*	*	*	*
Tylosurus leiurus	*	*	*	*	*	*	*
Pseudorhombus arsius	*		*		*	*	
Scomberoides commersonianus	*	*		*	*	*	*
Nematalosa nasus	*	*	*			*	
Gerres filamentosus	*	*	*	*	*	*	*
Gerres oyena	*	*	*	*	*	*	*
Hemiramphus marginatus	*	*	*	*	*	*	*
Lethrinus nebulosus	*	*	*	*	*	*	*
Lutjanus fulviflamma	*	*	*		*	*	
Liza macrolepis	*	*	*				
Liza subviridis	*	*					
Platycephalus maculipinna	*	*	*				
Platycephalus indicus	*	*		*	*	*	*
Scolopsis vosmeri	*	*	*		*	*	
Scomberomorus commersoni	*	*				*	
Siganus canaliculatus	*	*				*	
Mylio bifasciatus	*	*	*				
Mylio latus	*	*			*	*	
Rhabdosargus sarba	*	*			*	*	
Pelates quadrilineatus	*	*	*	*	*	*	*
Therapon jarbua	*	*	*			*	*
Chelonodon patoca	*	*	*	*	*	*	*
Parachirus marmoratus	*						
Sillago sihama	*		*				*
Rhinobatos granulatus	*						
Boleophthalmus boddarti	*	*					*
Cryptocentrus luthrus	*	*	*	*	*	*	*
Aphanius dispar	*	*	*	*	*	*	*
Total	30	26	19	13	18	22	16

Table 10: Zonation pattern of intertidal Brachyura on different transects at several sites in Qatar.

Zone	Species	N1	N2	N 3	N4	N5	P1	P2	P3	P4	P5	S
Upper intertidal	*Scopimera crabricauda*	*	*	*	*	*	*	*	*	*	*	*
	Metopograpsus messor	*	*	*	*	*	*	*	*	*	*	*
	Nasima dotilliformis	*	*	*		*	¤	¤	¤	¤	¤	*
	Eurycarcinus orientalis	*		*	*	*			*			*
Mid intertidal	*Scopimera crabricauda*	*	*	*	*	*	*	*	*	*		*
	Eurycarcinus orientalis	*		*	*		*		*	*		*
	Serenella leachii	¤	¤	¤	¤	¤	*	*	¤	¤	¤	*
	Ilyoplax frater	*	*	*	*	*	¤	*	*	¤	¤	*
	Manningis arabicum	*	*	*	*	*		*	*	¤	¤	*
	Nasima dotilliformis	*	*	*	*	*	¤	¤	¤	¤	¤	*
	Macrophthalmus depressus	*	*	*	*	*	*	*	*	*	¤	*
Lower intertidal	*Macrophthalmus depressus*	*	*	*	*	*	*	*	*	*	¤	
	Metaplax indica	*	*	*	*	*			*	*	¤	
	Macrophthalmus grandidieri	*		*			*	*		*		
	Ebalia sp.	*										
Sub-littoral fringe	*Portunus pelagicus*	*	*	*	*	*	*	*	*	*	*	*

(¤) no habitat

Key to area:

N1- Al-Khor (natural mangrove).

N2- Al-Khor (natural mangrove).

N3- Al-Dhakhira (natural mangrove).

N4- Al-Dhakhira (natural mangrove).

N5- Al-Dhakhira (natural mangrove).

P1- Umm AL-Hul (planted mangrove).

P2- Al-Wakrah (planted mangrove).

P3- Fuwairit (planted mangrove).

P4- Al-Mafjar (planted mangrove).

P5- Zekrit (planted mangrove).

S - Doha (salt marsh)

Table 11: Brachyura present on transects in natural mangrove areas (N), planted mangrove areas (P), a salt marsh area (S), sandy-muddy shore (SM) and sandy-rocky shore (SR).

Species	N1	N3	N4	N5	P1	P2	P3	P4	P5	S	SM **	SR **
Ocypodidae:												
Ocypode rotundata												*
Scopimera crabricauda	*		*	*	*	*	*	*	*	*	*	¤
Nasima dotilliformis	*	*	*	*	¤	¤	¤	¤	¤	*	¤	¤
Serenella leachii				*	*							¤
Manningis arabicum	*	*	*	*		*	*	*		*		¤
Ilyoplax frater	*	*	*	*	¤	*	*	¤	¤	*	*	¤
Macrophthlamus depressus	*	*	*	*	*	*	*	*		*	*	¤
Macrophthalmus grandidieri												¤
Grapsidae:												
Metopograpsus messor	*	*	*	*	*	*	*	*	*	*	*	*
Metaplax indica	*	*	*	*							*	¤
Portunidae												
Portunus pelagicus	*	*	*	*	*	*	*	*	*	*	*	*
Charybdis natator												*
Xanthidae:												
Eurycarcinus orientalis	*	*	*	*	*	*	*	*		*	*	¤
Epixanthus frontalis	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	*
Xantho sp.	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	*
Pilumnus sp.	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	*
Total	9	8	9	10	6	7	7	6	3	8	7	7

N.B. ** these data collected during August 1995.
SM: sandy muddy site.
SR: sandy rocky site.
(¤) no habitat.

Table 12: General zonation pattern of intertidal Brachyura as observed in Qatar compared with the Arabian Gulf.

Zone	Species	**Qatar	*Saudi	*Kuwait	*Bahrain	*Oman
Littoral fringe	*Ocypode rotundata*	x				
	Scopimera crabricauda	x	x	x	x	x
	Metopograpsus messor	x	x	x	x	x
	Eurycarcinus orientalis	x	x	x	x	
Upper intertidal	*Uca sindensis*			x		
	Scopimera crabricauda	x			x	x
	Manningis arabicum	x	x	x		
	Leptochryseus kuwaitense			x		
	Nasima dotilliformis	x	x	x	x	x
	Ilyoplax stevensi		x	x		
	Ilyoplax frater	x	x		x	
	Eurycarcinus orientalis	x	x	x		x
	Serenella leachii	x				x
	Metopograpsus messor	x	x		x	x
Mid intertidal	*Scopimera crabricauda*	x	x		x	
	Ilyoplax frater	x	x	x	x	
	M dilatatus sulcatus		x	x		
	Macrophthalmus depressus	x	x		x	x
	Metaplax indica		x	x	x	
	Tylodiplax indica			x		
Lower intertidal	*Macrophthalmus grandidieri*	x		x		x
	Macrophthalmus depressus	x	x	x	x	x
	Metaplax indica	x	x	x		
	Eurycarcinus integrifrons		x			
	Ebalia sp.	x	x			
	Macrophthalmus pectinipes			x		
Sub-littoral fringe	*Portunus pelagicus*	x	x	x	x	x
	Charybdis natator	x				

Sources(*) : modified from Jones (1983; 1986); Jones & Clayton (1983); Basson *et al.*,(1977); Vousden (1987); Davies (1994). (**) This is data collected in the present survey.

Table 13: Actual minimum and maximum densities of burrows / 0.25 m^2 on different sites.

Species / Site	Date of sample	Actual minimum recorded / $0.5m^{-2}$	Actual maximum recorded / $0.5m^{-2}$	Mean density / $0.5m^{-2}$
Al-Khor (N1)	Jun.'93 - Jun.'94			
Scopimera crabricauda		3	12	7
Nasima dotilliformis		1	5	3
Eurycarcinus orientalis		1	5	3
Metaplax indica		1	4	2
Macrophthalmus depressus		1	9	5
Al-Khor (N2)	Jul.'93 - Jun.'94			
Scopimera crabricauda		1	5	3
Nasima dotiliformis		2	14	8
Al-Dhakhira (N3)	Jun.'93 - Jun.'94			
Nasima dotilliformis		1	23	8
Manningis arabicum		3	13	7
Ilyoplax frater		22	200	72
Eurycarcinus orientalis		1	3	2
Metaplax indica		1	3	2
Macrophthalmus depressus		2	9	5
Al-Dhakhira (N4)	Jun.'93; Jan.'94; May '94; Jun.'94			
Scopimera crabricauda		1	32	18
Ilyoplax frater		6	21	10
Metaplax indica		1	2	1
Macrophthalmus depressus		1	10	4
Al-Dhakhira (N5)	Jun.'94			
Scopimera crabricauda		10	16	13
Nasima dotilliformis		2	4	3
Manningis arabicum		20	22	21
Ilyoplax frater		2	9	8
Eurycarcinus orientalis		1	5	2
Metaplax indica		1	1	1
Macrophthalmus depressus		3	5	4
Umm Al-Hul (P1)	Jun.'93 - Jun.'94			
Scopimera crabricauda		1	19	8
Macrophthalmus depressus		1	19	6
Eurycarcinus orientalis		2	4	3
Serenella leachii		NR	NR	NR
Al-Wakrah (P2)	Jan.'94; Mar.'94; Apr.'94; Jun.'94			
Scopimera crabricauda		4	43	4
Macrophthalmus depressus		2	21	6
Fuwairit (P3)	Nov.'93; Jan.'94; Apr.'94; Jun.'94			
Scopimera crabricauda		5	48	18
Manningis arabicum		2	17	9
Eurycarcinus orientalis		1	4	2
Macrophthalmus depressus		2	23	10
Al-Mafjar (P4)	Jan.'94; Apr.'94; Jun.'94			
Scopimera crabricauda		4	30	12
Macrophthalmus depressus		2	11	5
Zekrit (P5)	May '94			
Scopimera crabricauda		1	2	1
Doha (S)	Dec.'93 - Jun.'94			
Scopimera crabricauda		2	18	8
Nasima dotilliformis		1	21	7
Manningis arabicum		8	18	14
Eurycarcinus orientalis		1	7	2
Macrophthalmus depressus		2	12	5

N.B. NR : Not recorded

Table 14: Minimum, maximum and mean densities of gastropods / 0.25 m^2 and mud skipper /10 m^{-2} collected from 10 sites.

Species / area	Date of collection	Actual Minimum density recorded	Actual Maximum density recorded	Mean density
Al-Khor (N1)	Nov.'93,Jan.'94			
Planaxis sulcatus	&	8	56	23
Cerithidea cingulata	May'94-Jun.'94	212	322	286
Littorina glabrata		14	2	6
Boleophthalmus boddarti		24	8	15
Al-Dhakhira (N3)	Dec.93, &			
Cerithidea cingulata	Apr.'93-Jun.'94	424	512	458
Littorina glabrata		3	10	6
Trochus erythraeus		3	4	3
Al-Dhakhira (N4)	Jun.'94			
Planaxis sulcatus		4	103	50
Cerithidea cingulata		31	342	137
Littorina glabrata		2	14	24
Trochus erythraeus		1	4	3
Al-Dhakhira (N5)	Jun.'94			
Cerithidea cingulata		80	120	98
Littorina glabrata		9	23	14
Trochus erythraeus		1	2	1
Doha (S)	Jun.'93-Mar.'94			
Cerithidea cingulata		35	40	38
Boleophthalmus boddarti		8	18	12
Umm Al-Hul (P1)	Jan.'94-Mar.94			
Planaxis sulcatus	& May '94	20	150	45
Cerithidea cingulata		172	448	296
Littorina glabrata		3	22	11
Al-Wakrah (P2)	Jan.'94, Apr.'94			
Cerithidea cingulata	& Jun. 94	41	424	132
Littorina glabrata		2	3	2
Fuwairit (P3)	Nov.'93,Jan.'94			
Cerithidea cingulata	Apr.'94&Jun. 94	200	239	219
Littorina glabrata		2	18	9
Trochus erythraeus		1	3	2
Al-Mafjar (P4)	Jun.'93, Jan.94			
Planaxis sulcatus	& Apr.'94	35	60	44
Cerithidea cingulata		10	84	51
Littorina glabrata		2	14	5
Zekrit (P5)	May'94			
Cerithidea cingulata		288	400	360

N.B. *Littorina glabrata* : Individual numbers found on tree trunks.

Table 15: Species caught by using seine net (2.5 cm mesh size) (D) and gill net (7 cm mesh size) (G) in natural mangrove areas (N), planted mangrove areas (P) and sandy beach (SR) by fishing for 15 m with using seine net and 4 h with using gill net at each site.

Species	(N1)		(N3)		(P3)		(P4)		(SR)	
	D	G	D	G	D	G	D	G	D	G
Crustacea										
Family : PORTUNIDAE										
Portunus pelagicus	*	*	*	*	*	*	*	*		*
Family : PENAEIDAE										
Penaeus semisulcatus	*	*	*	*						
Pisces										
Family : ATHERINIDAE										
Allanetta forskali	*		*		*		*			
Family : Belonidae										
Ablennes hians		*		*		*				
Tylosurus leiurus		*		*				*		
Family : Bothidae										
Pseudorhombus arsius	*		*				*			
Family : CARANGIDAE										
Gnathanodon speciosus		*		*		*		*		
Scomberoides commersonianus		*		*		*		*		
Family : CLUPEIDAE										
Nematalosa nasus	*	*	*	*		*		*		
Family : GERREIDAE										
Gerres filamentosus	*	*	*	*						*
Gerres oyena	*	*	*	*		*	*	*	*	*
Family : HEMIRAMPHIDAE										
Hemiramphus marginatus	*	*	*	*						
Family : LETHRINIDAE										
Lethrinus nebulosus		*		*				*		
Lethrinus kallopterus										*
Family : LUTJANIDAE										
Lutjanus fulviflamma								*		
Family : MUGILIDAE										
Liza macrolepis	*	*	*	*						
Liza subviridis	*		*							
Family : PLATYCEPHALIDAE										
Platycephalus indicus	*		*				*			
Platycephalus macullplnna									*	
Family : POMADASYIDAE										
Scolopsis vosmeri	*	*	*	*			*			
Plectorhynchus sordidus										*
Family : SCOMBRIDAE										
Scomberomorus commerson								*		
Family : SIGANIDAE										
Siganus canaliculatus		*		*				*		
Family : SPARIDAE										
Mylio bifasciatus	*		*							
Mylio latus		*		*		*		*		
Rhabdosargus sarba	*	*	*	*		*		*		
Family : Serranidae										
Eplnephelus areolatus										*
Family : THERAPONIDAE										
Therapon jarbua		*		*		*		*		
Family : RHINOBATIDAE										
Rhynchobatus djiddensis								*		
Total	14	17	14	17	2	9	6	14	2	6

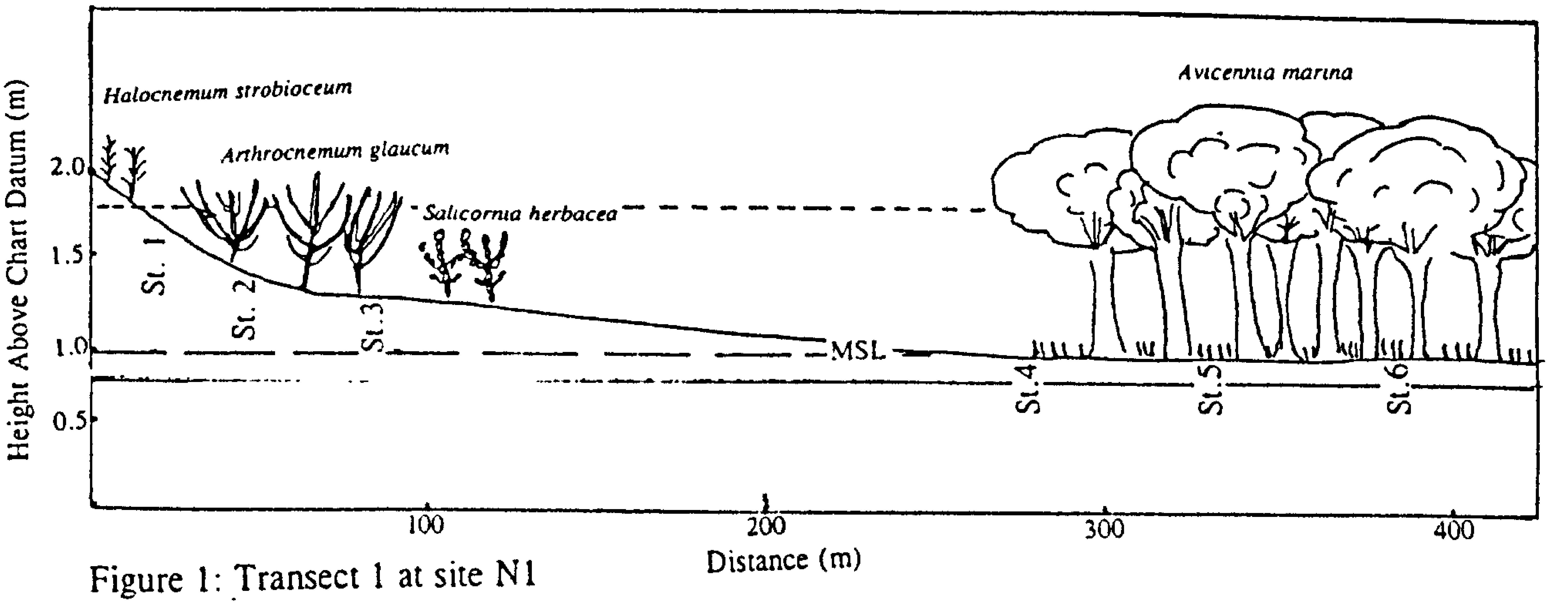


Figure 1: Transect 1 at site N1

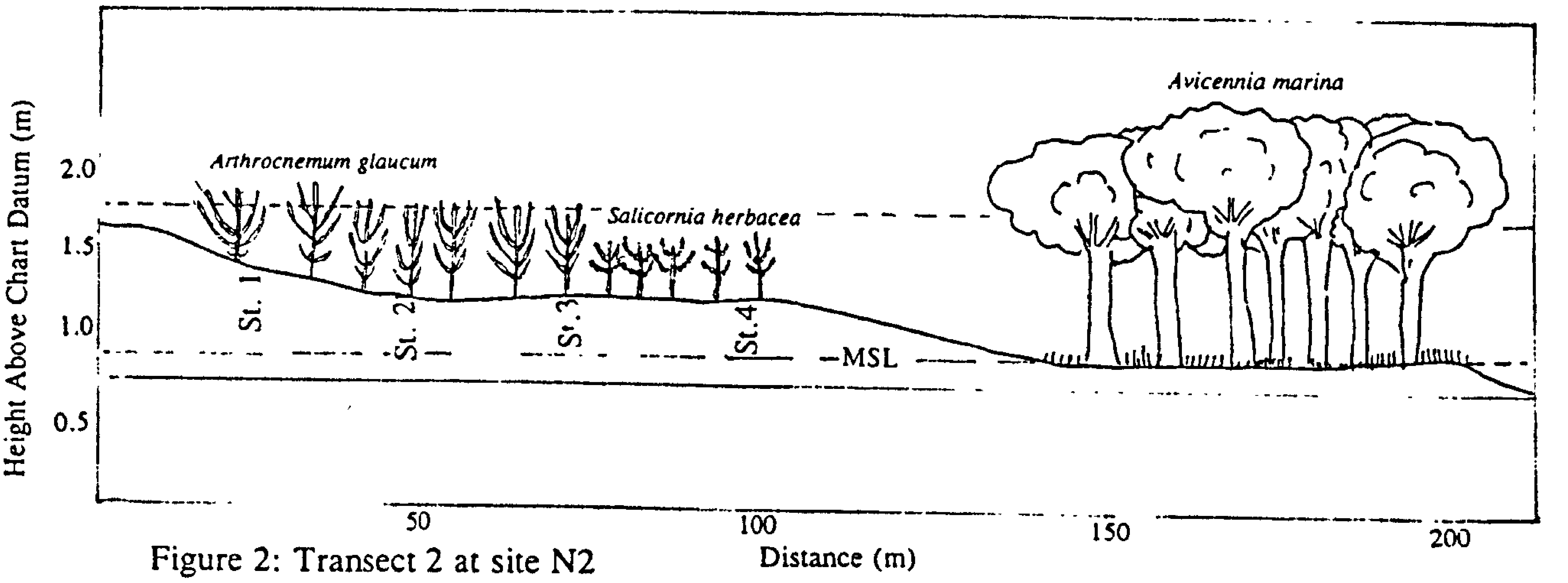


Figure 2: Transect 2 at site N2

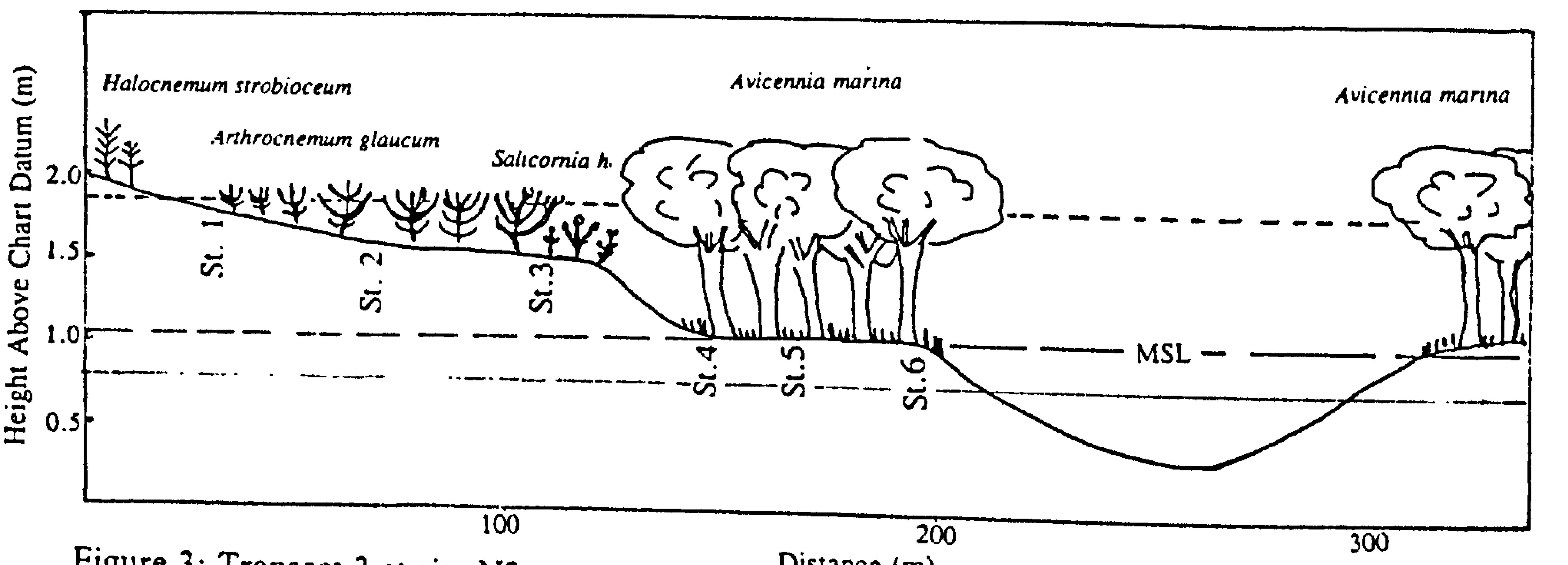


Figure 3: Transect 3 at site N3

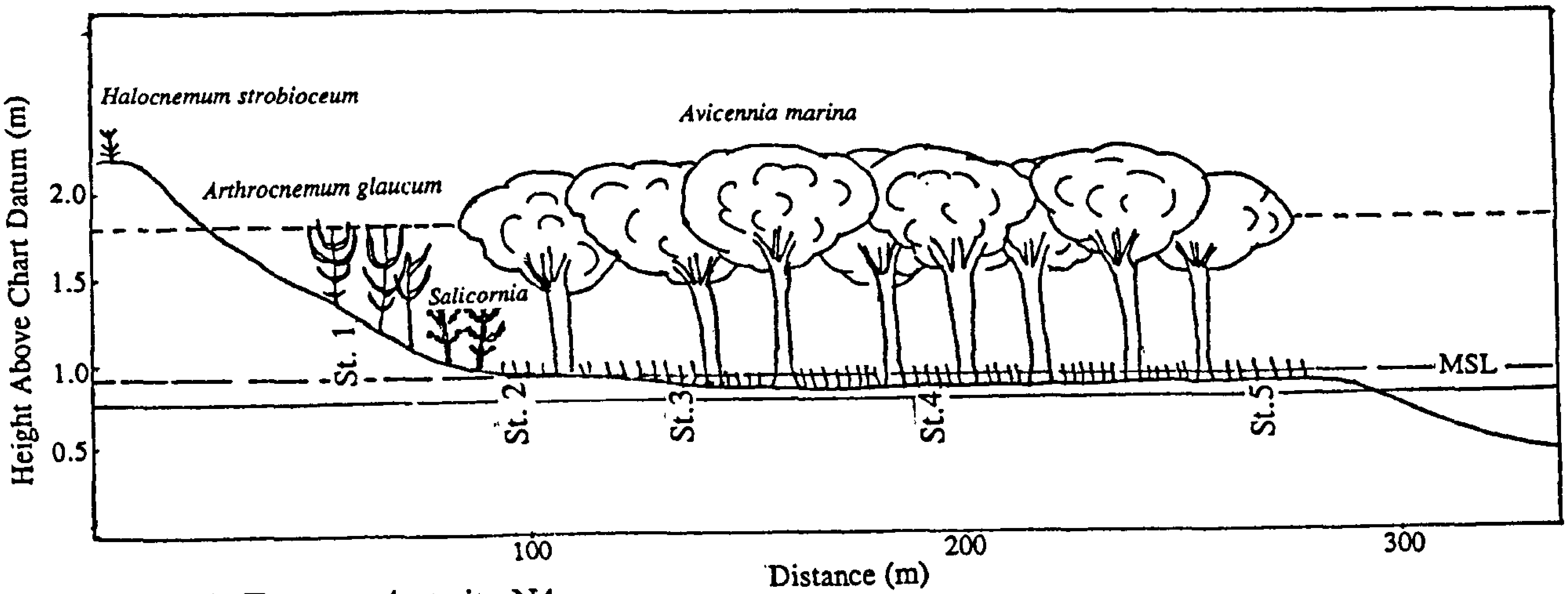


Figure 4: Transect 4 at site N4

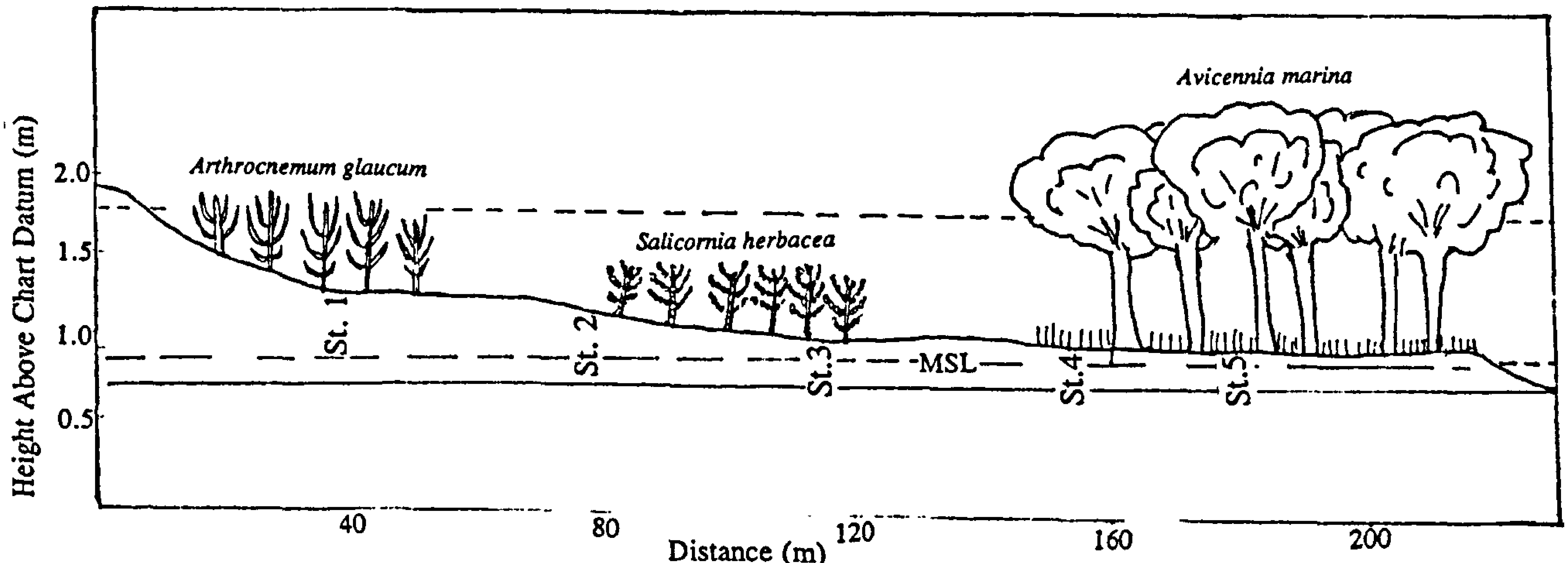


Figure 5: Transect 5 at site N5

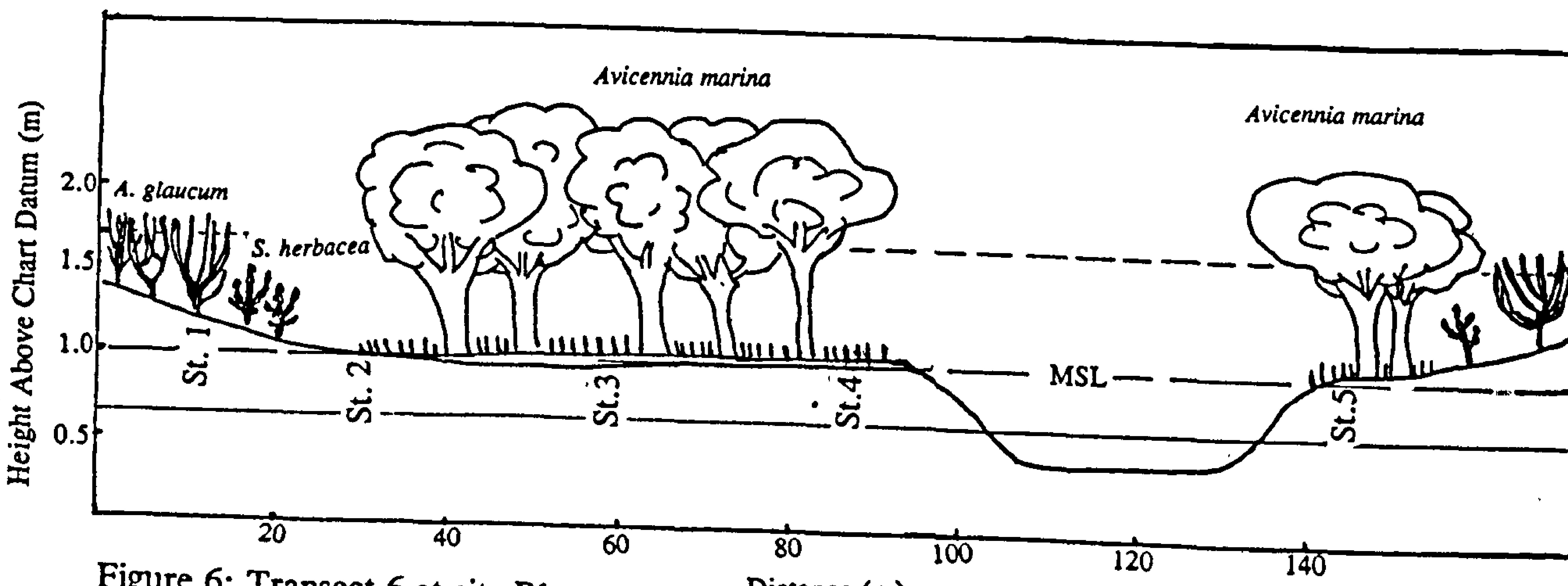


Figure 6: Transect 6 at site P1

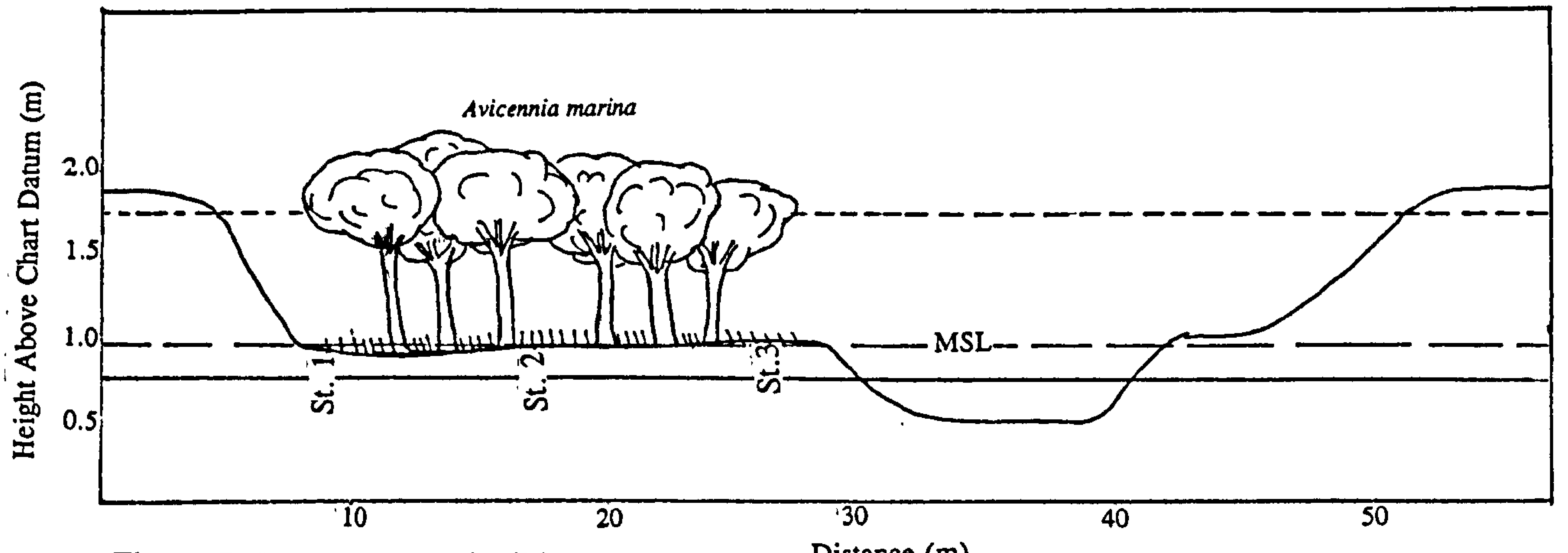


Figure 7: Transect 7 at site P2

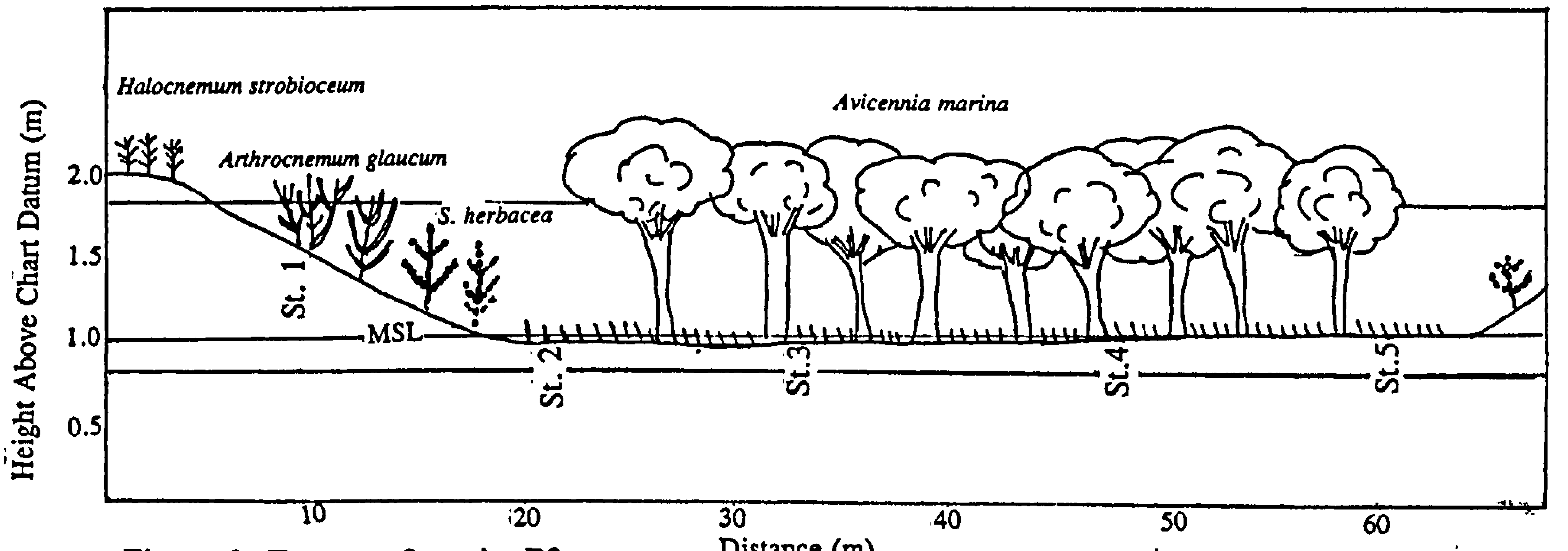


Figure 8: Transect 8 at site P3

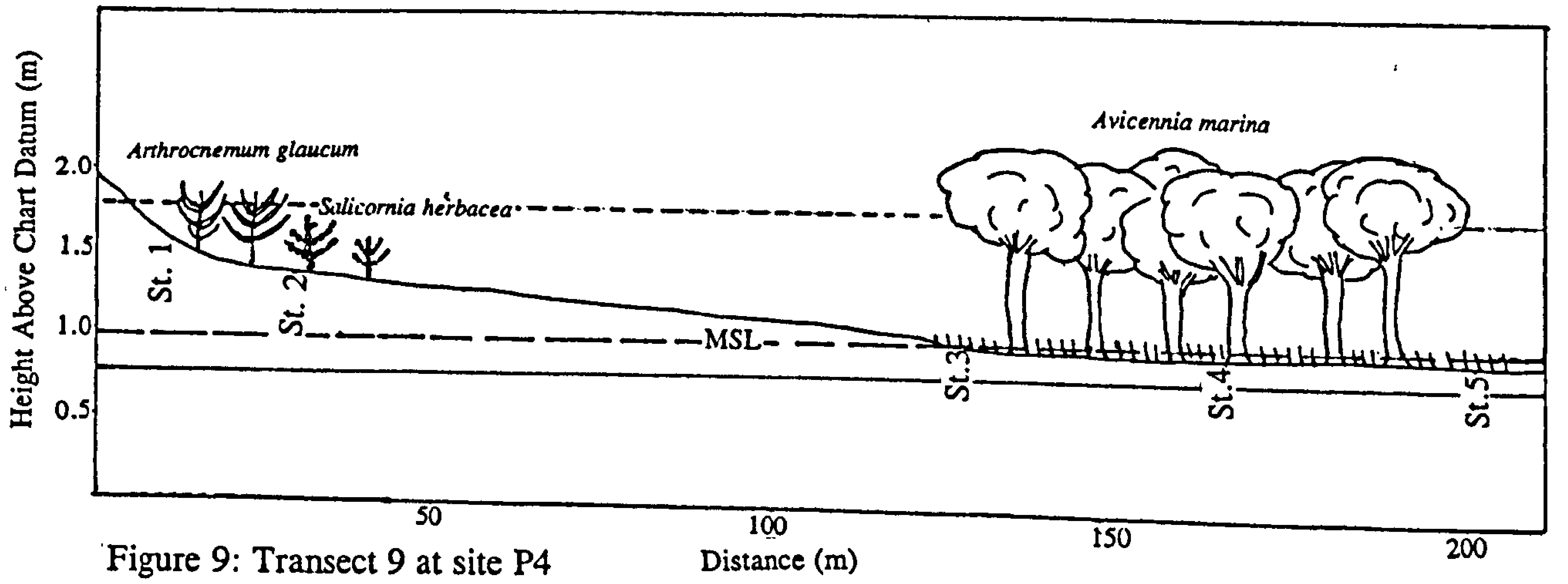


Figure 9: Transect 9 at site P4

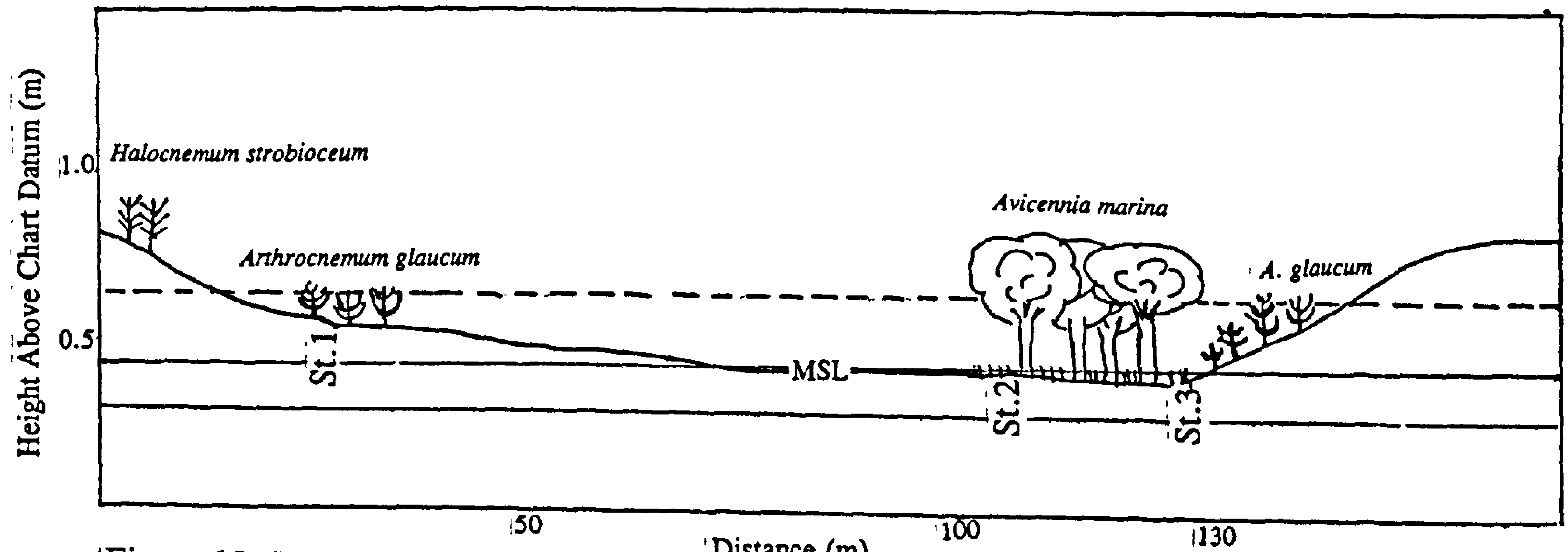


Figure 10: Transect 10 at site P5

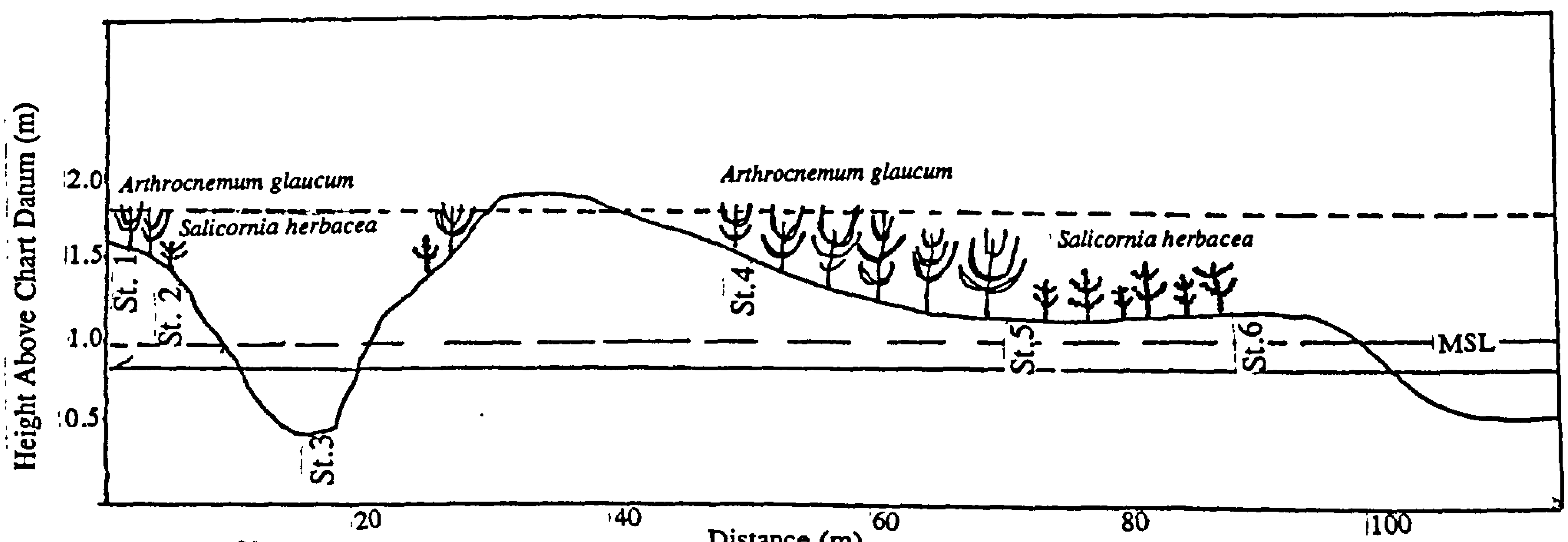


Figure 11: Transect 11 at site S

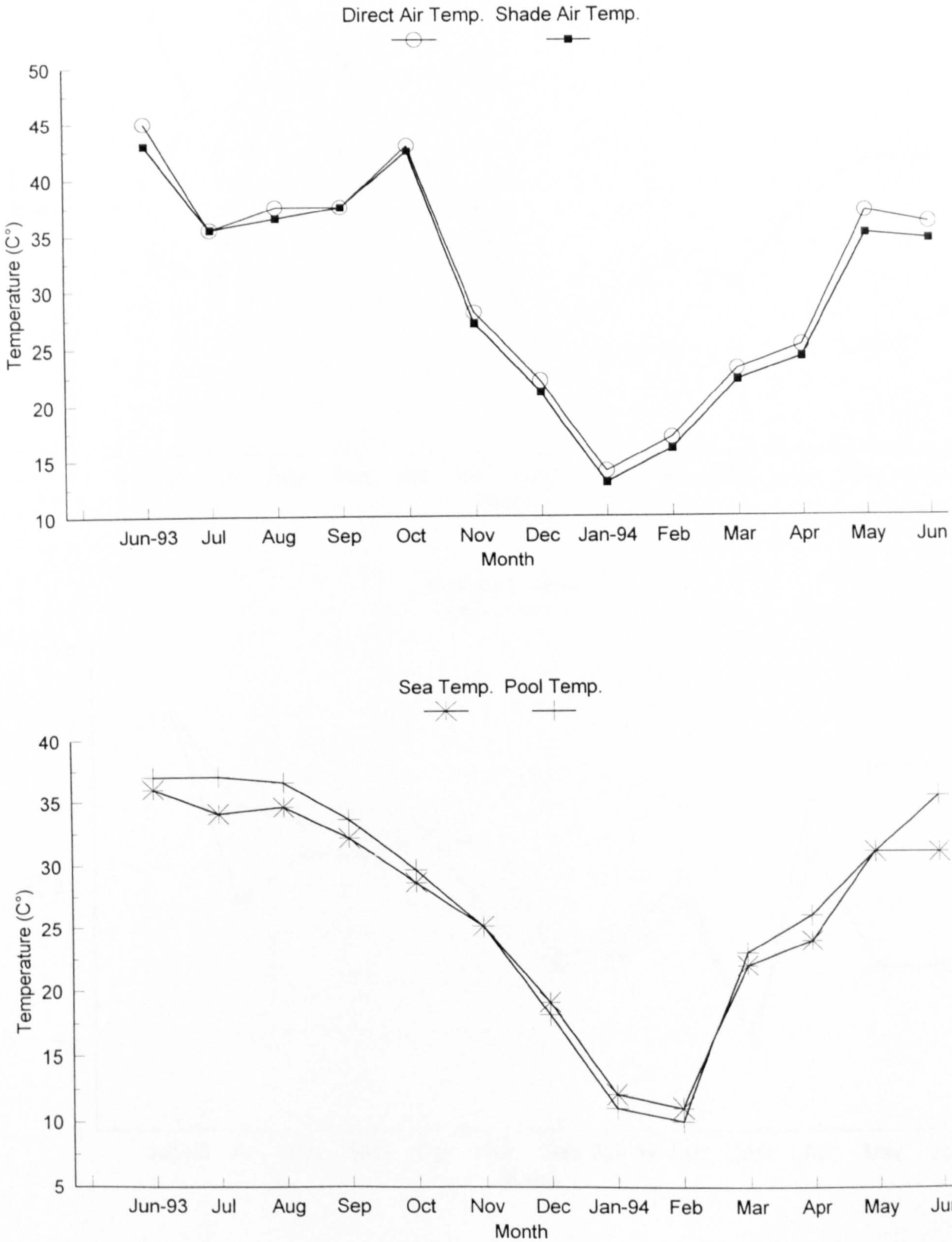
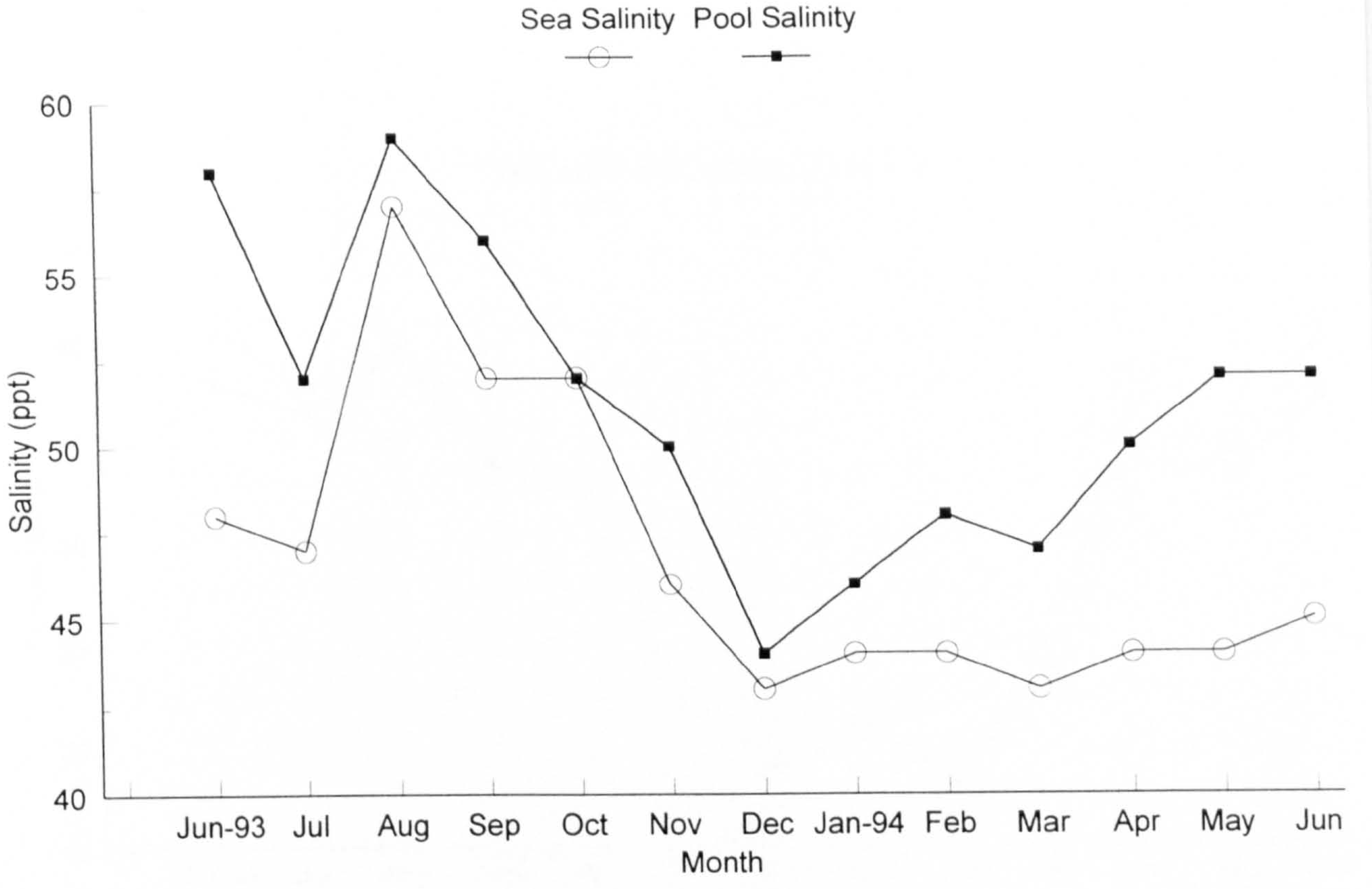


Figure 12: Temperature of the air, surface sea water and pool sea water in a planted mangrove at Umm Al - Hul, June 1993 - June 1994.



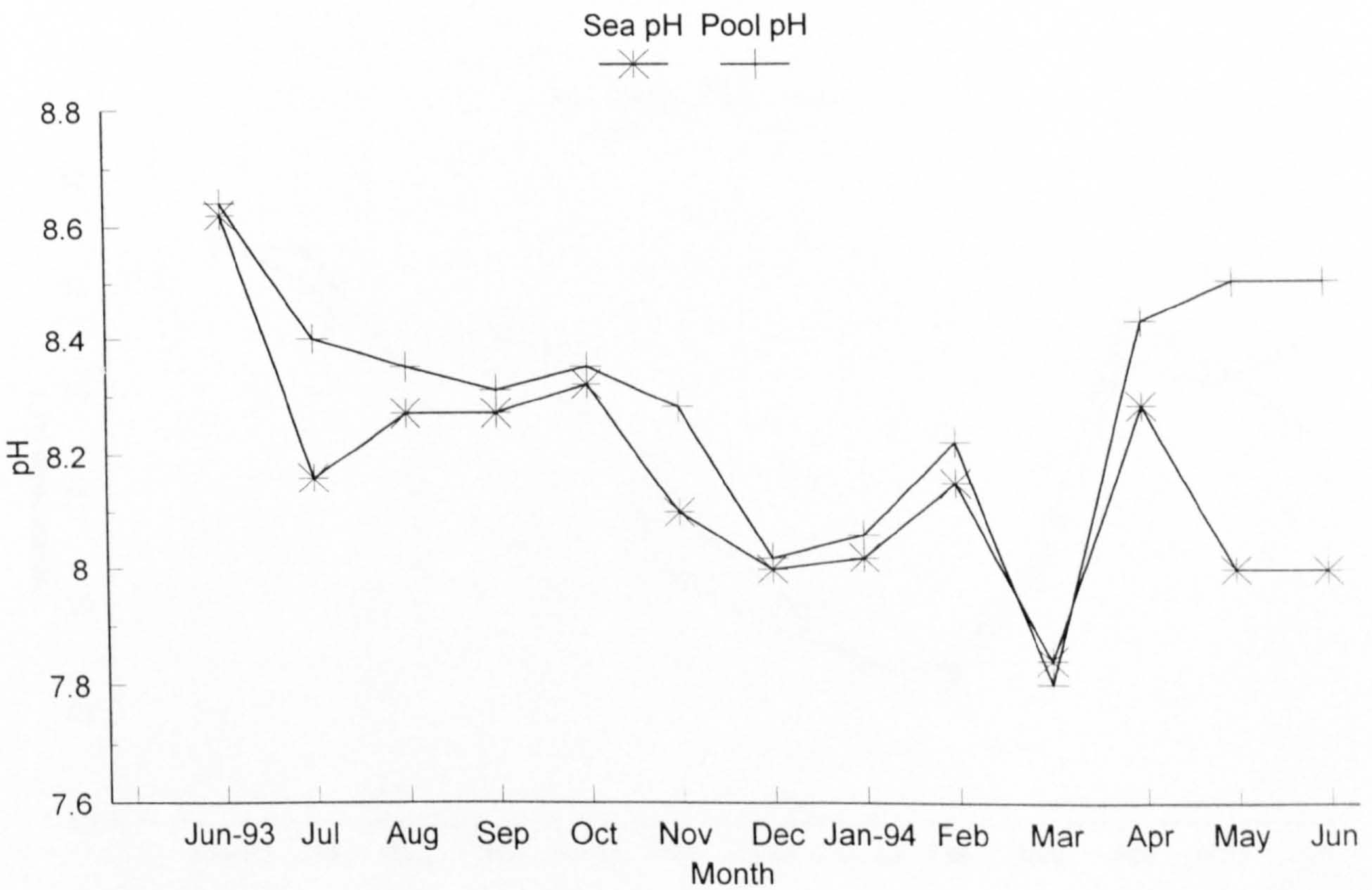
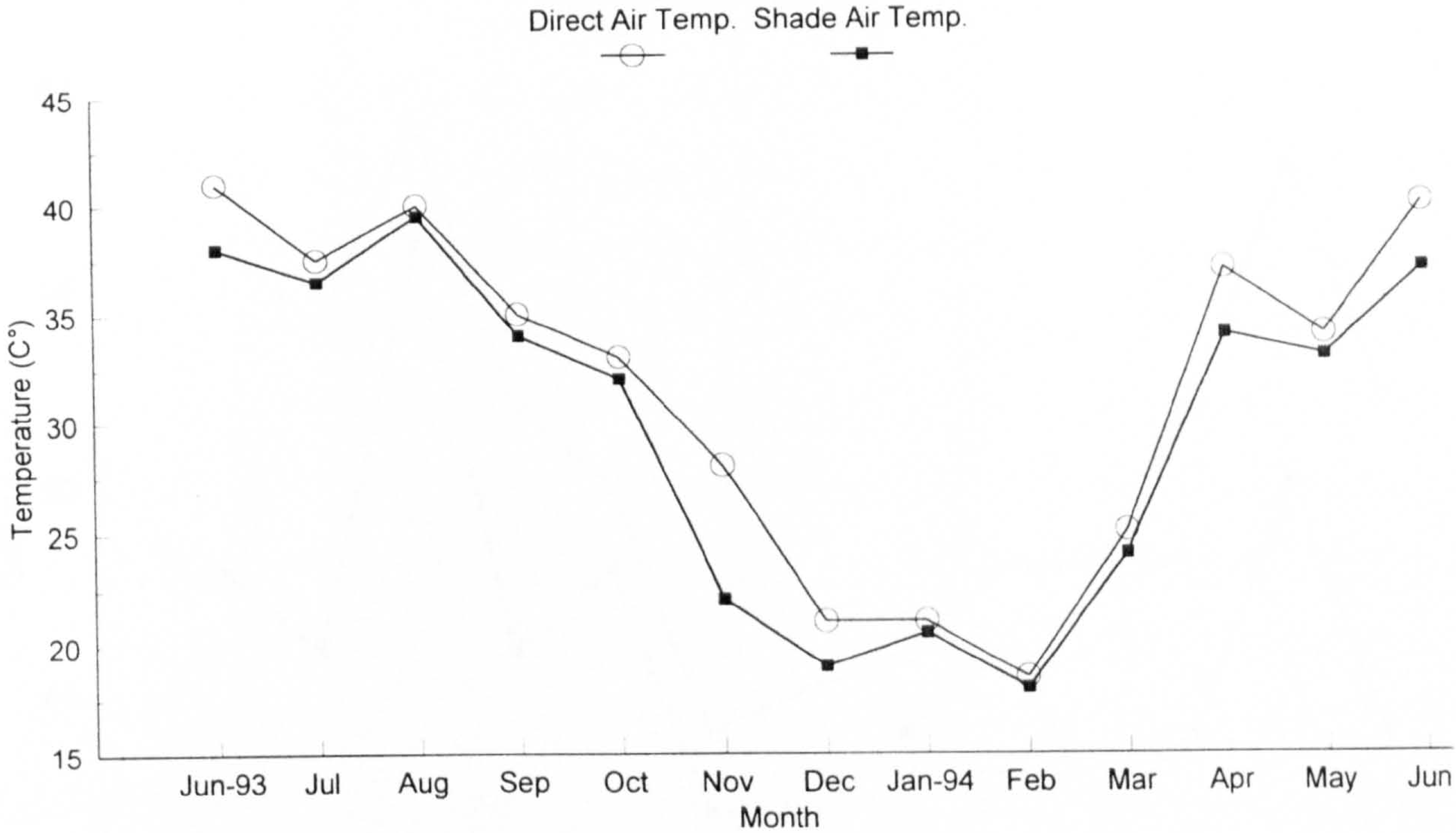


Figure 13: Salinity(ppt) and pH of sea water and pool sea water of planted mangrove at Umm Al - Hul, June 1993 - June 1994.



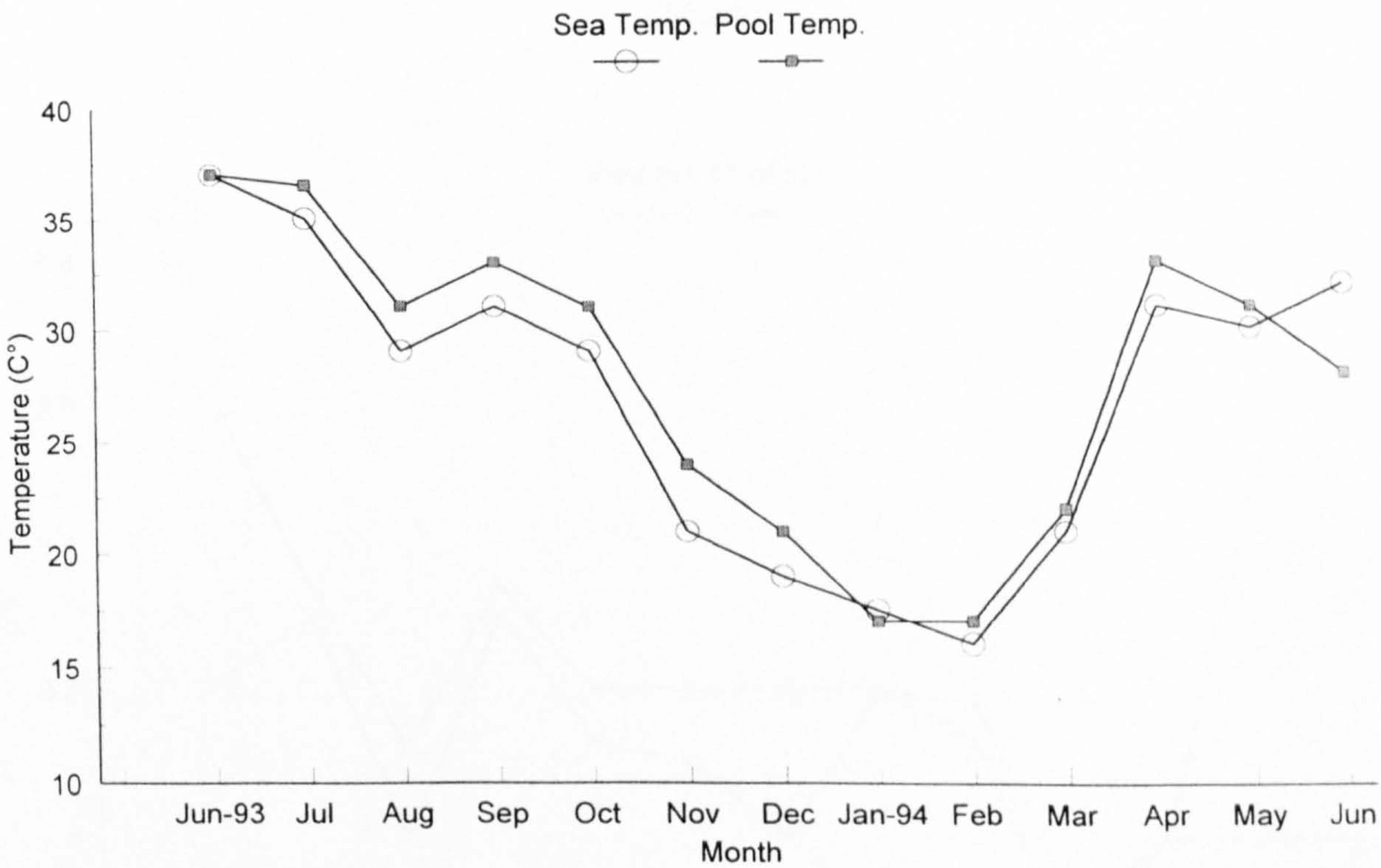
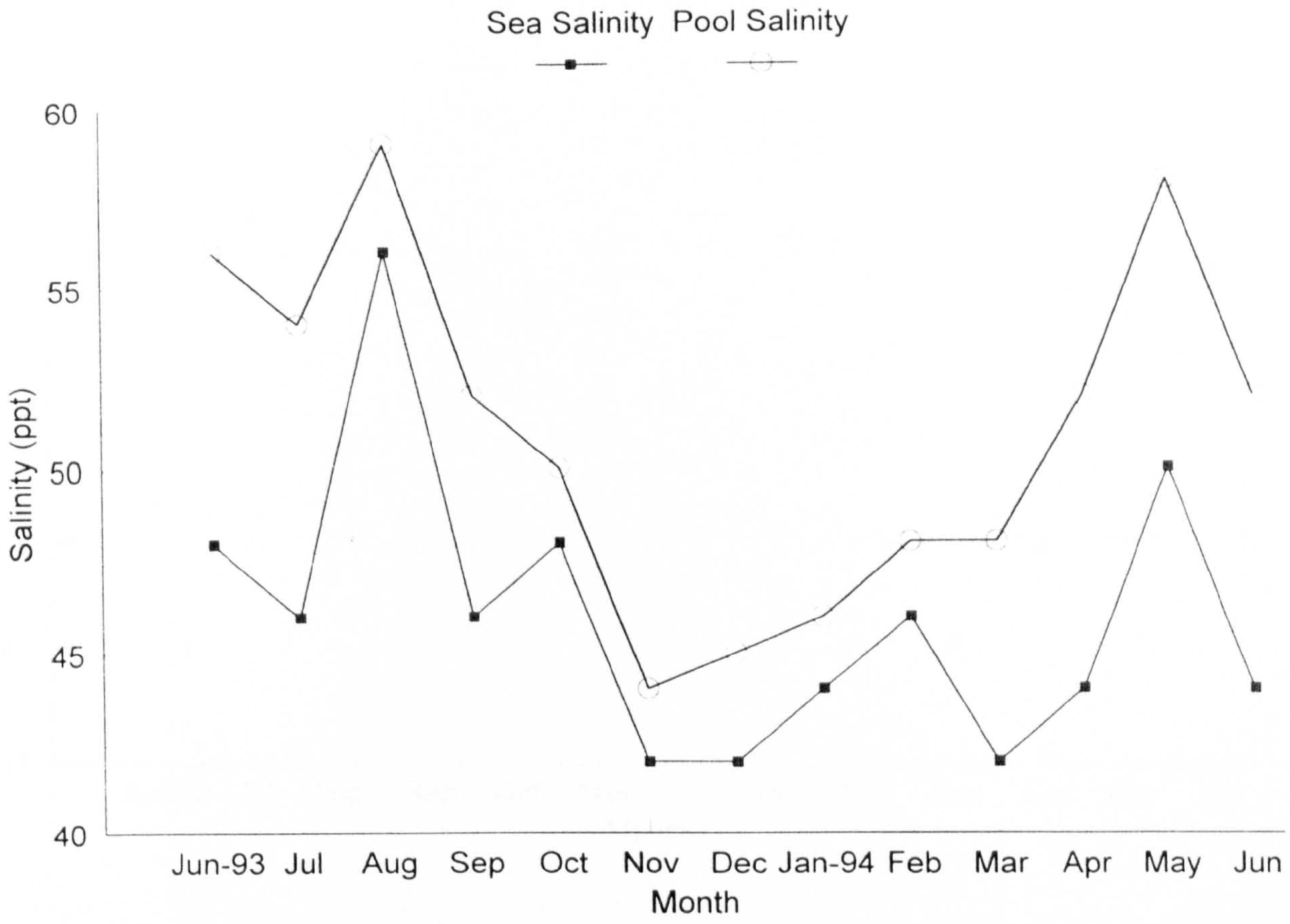


Figure 14 : Temperature of the air, surface sea water and pool sea water of natural mangrove at Al - Khor, June 1993 - June 1994.



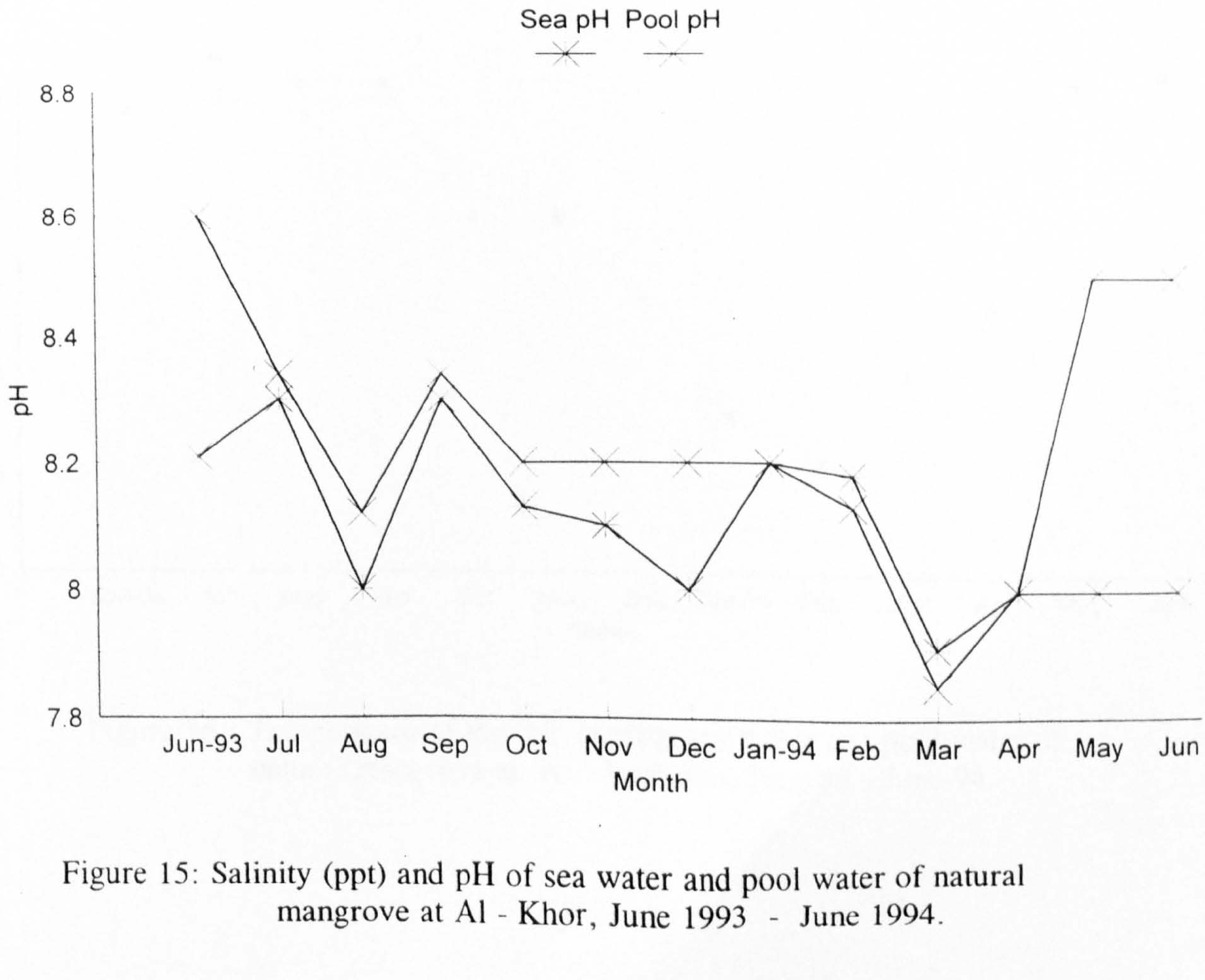
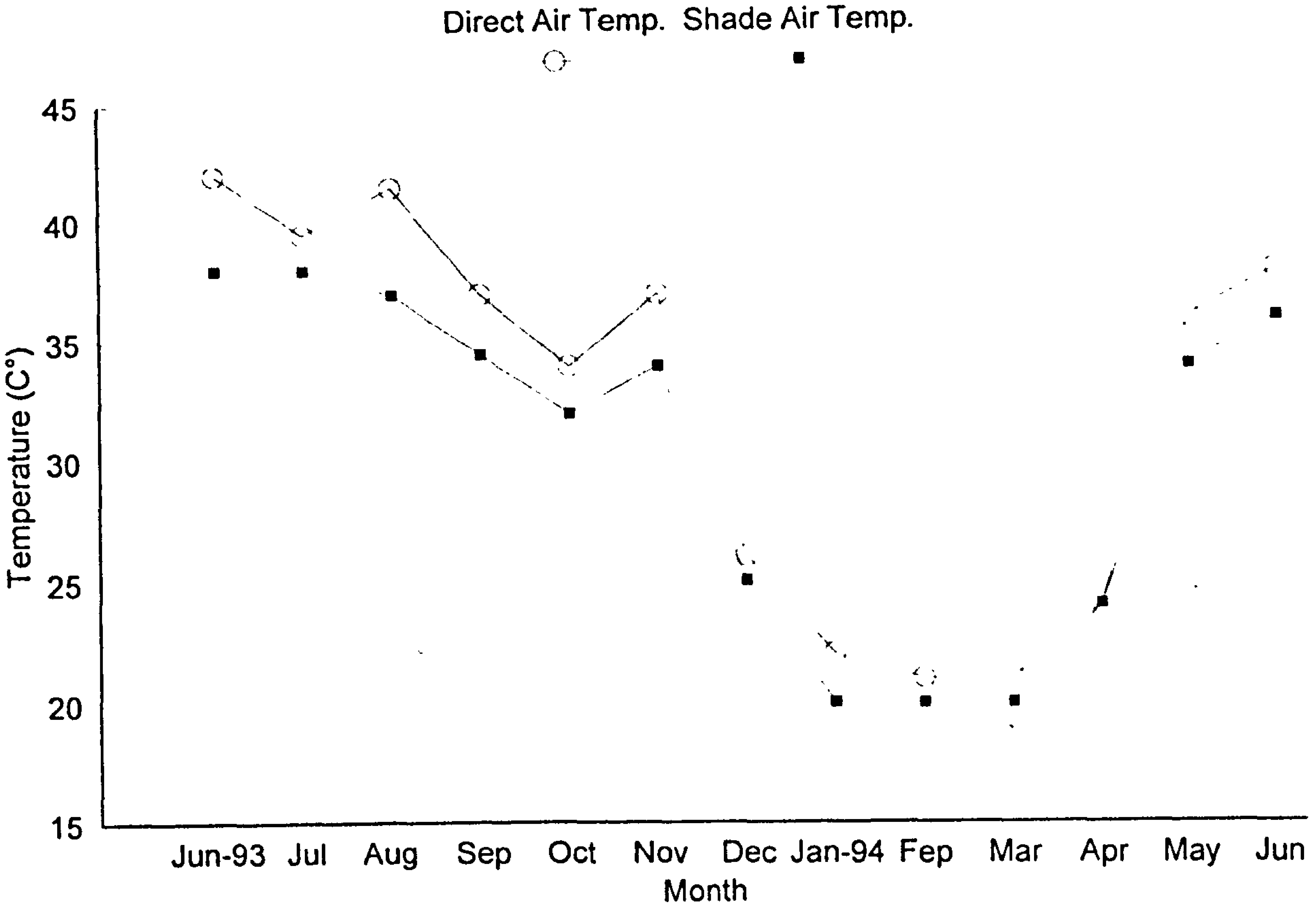


Figure 15: Salinity (ppt) and pH of sea water and pool water of natural mangrove at Al - Khor, June 1993 - June 1994.



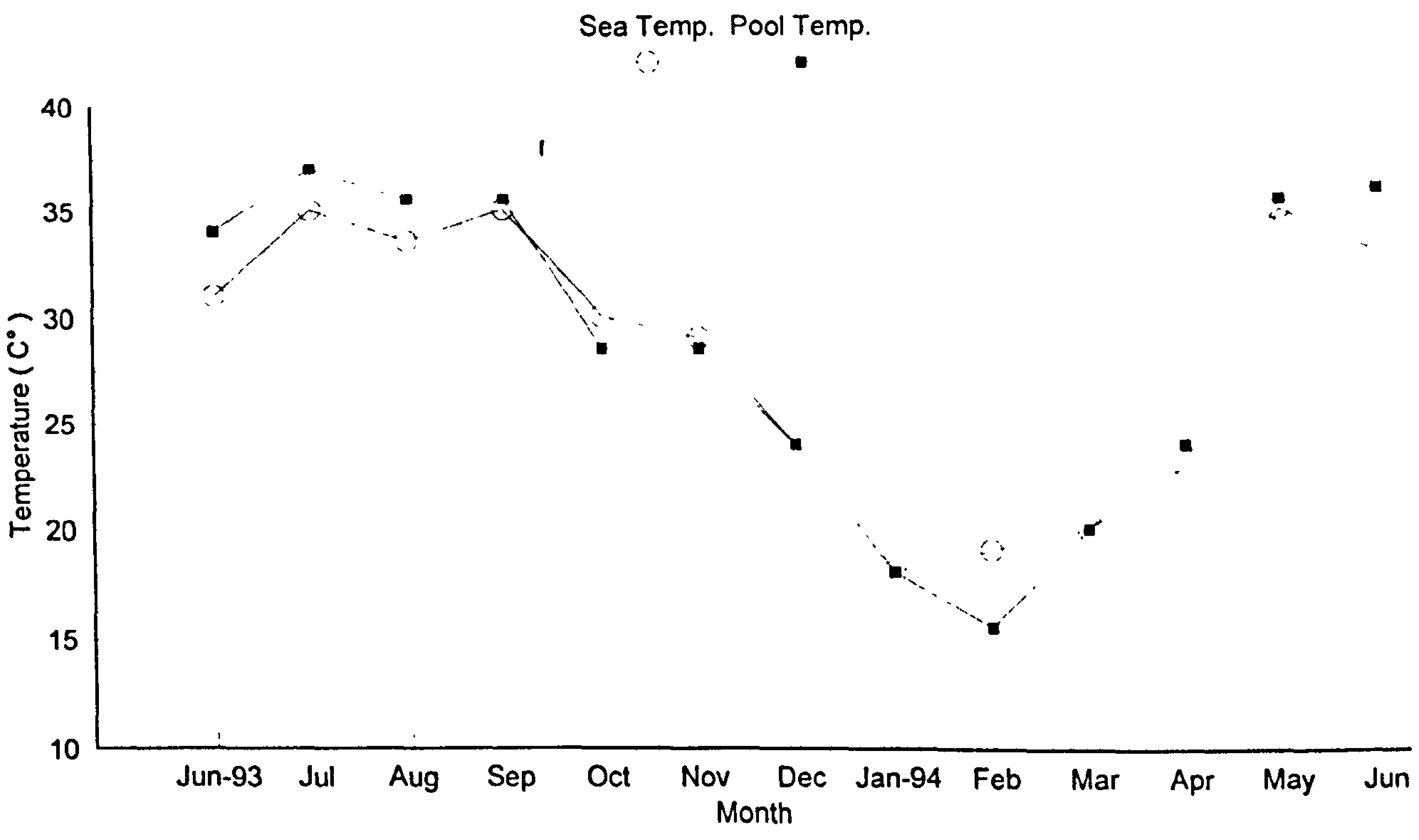
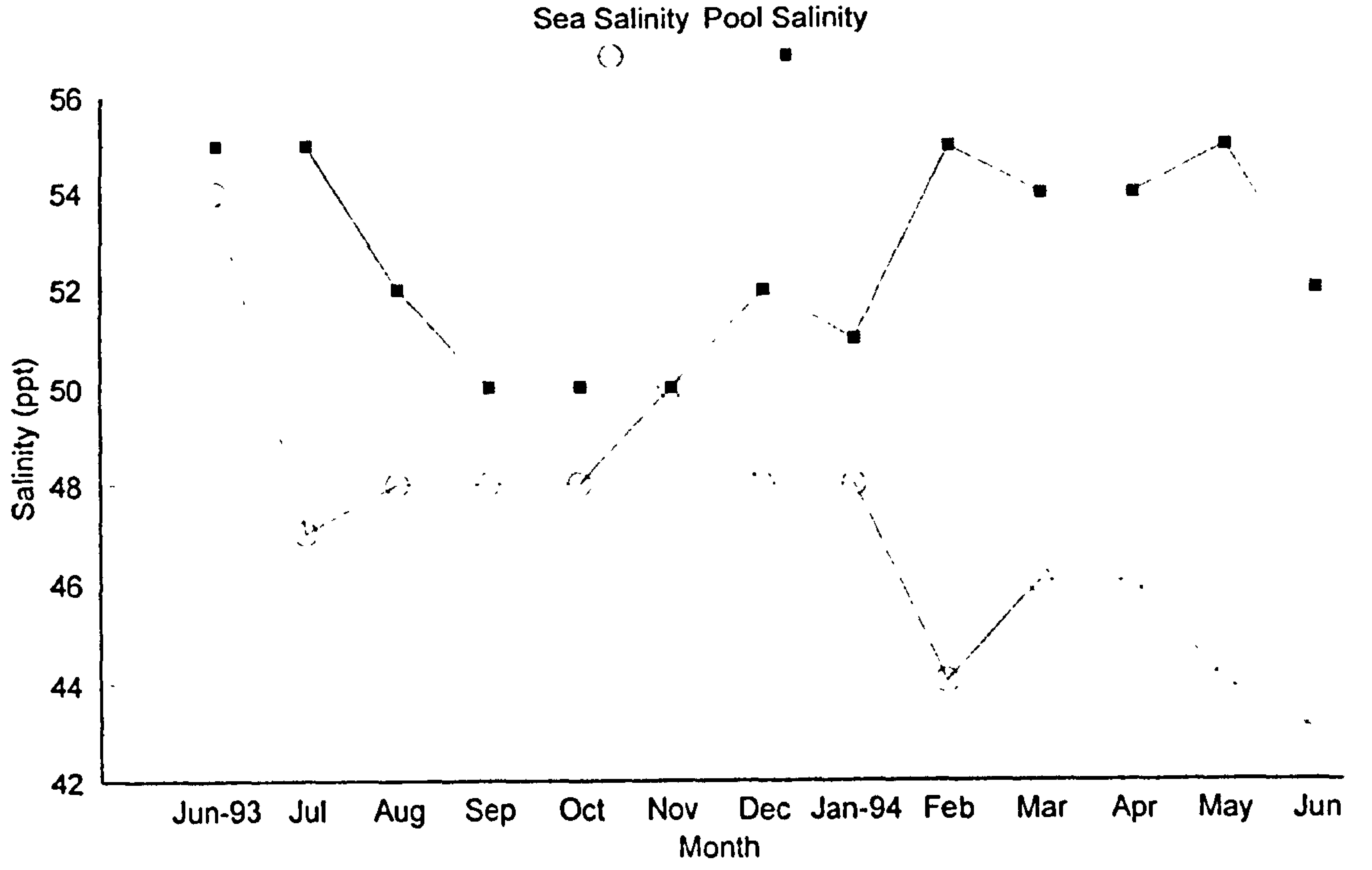


Figure 16 : Temperature of the air, surface sea water and pool water of natural mangrove at Al - Dhakhira, June 93 - June 94.



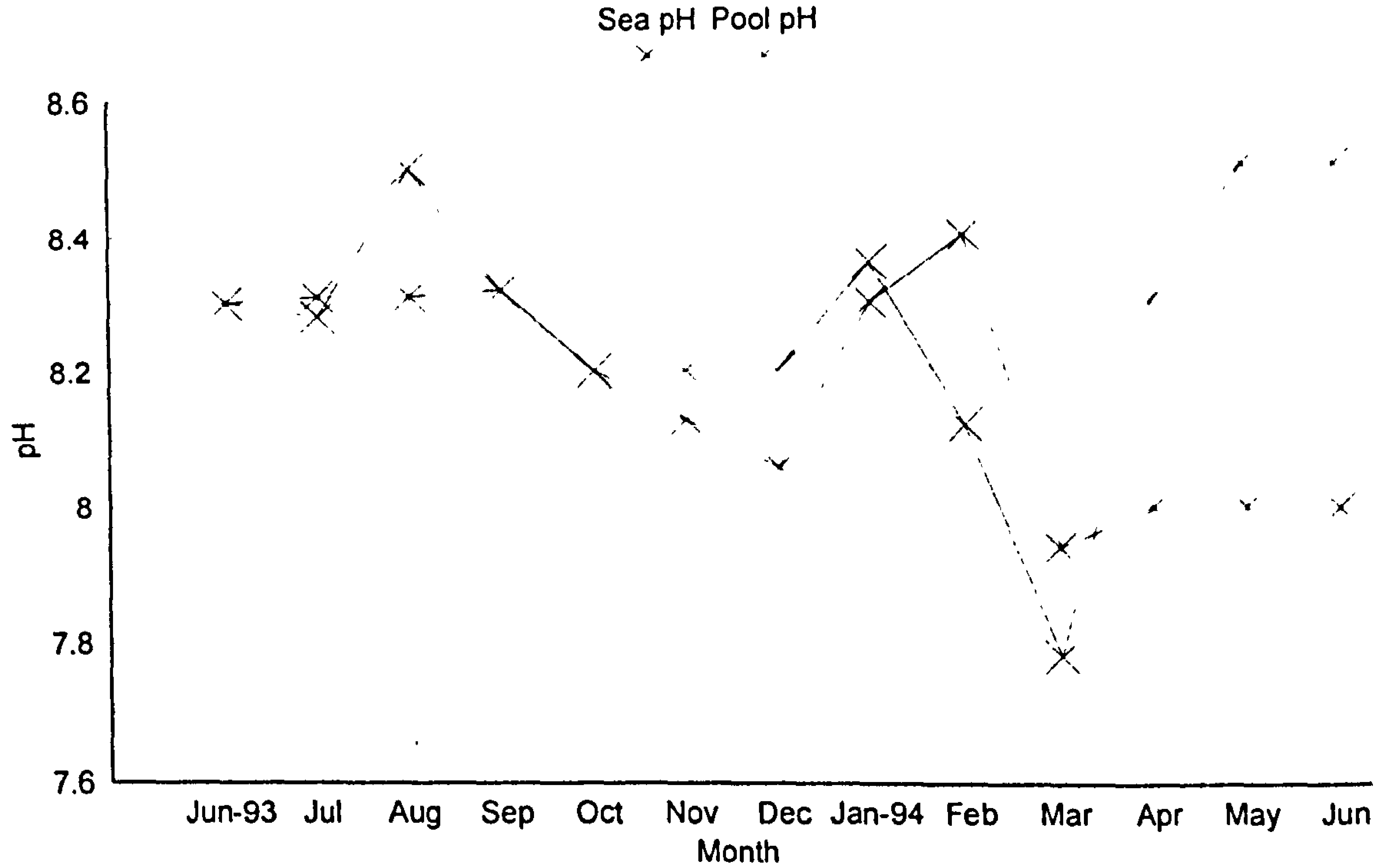


Figure 17 : Salinity (ppt) and pH of sea water and pool water of natural mangrove at Al - Dhakhira, June 1993 - June 1994.

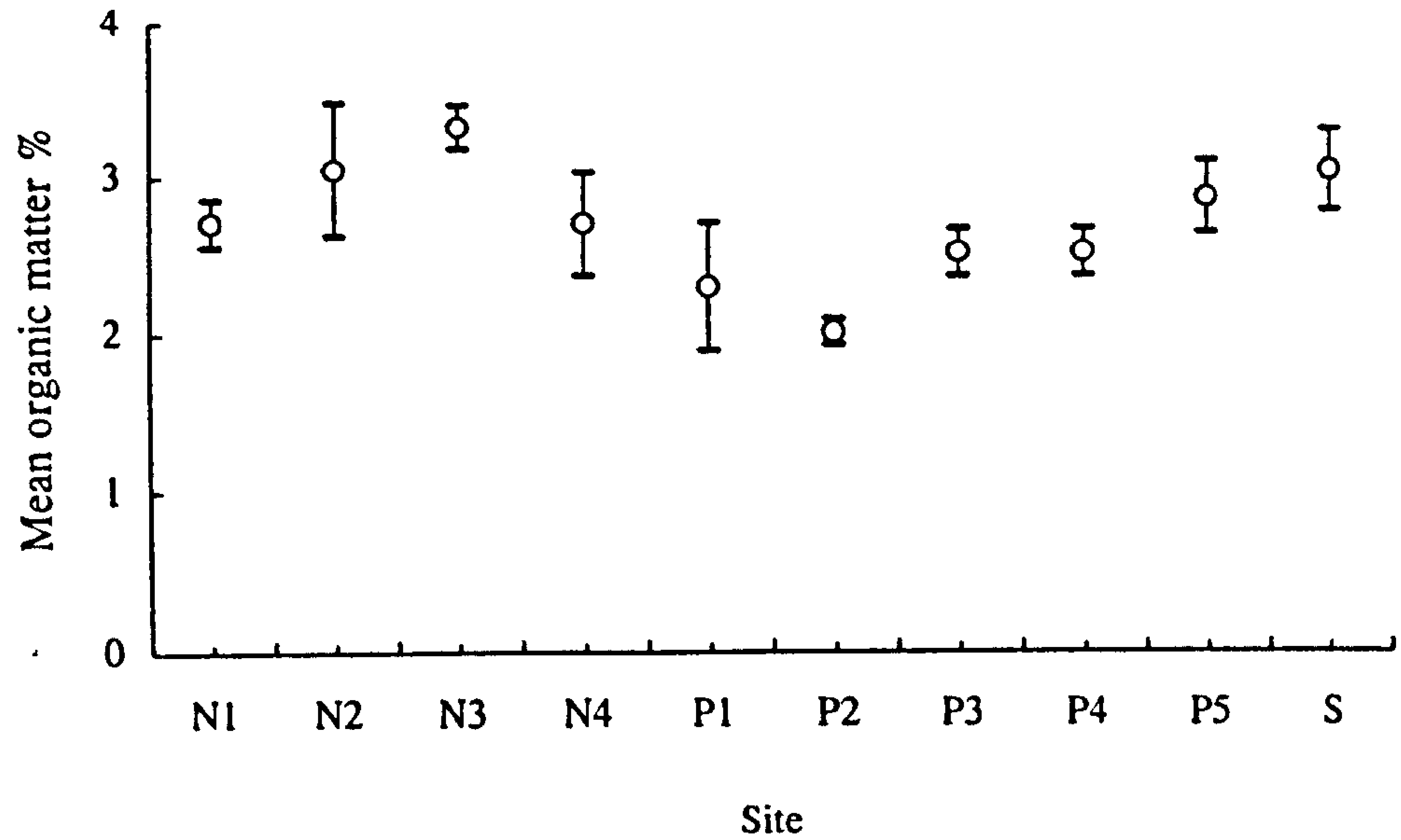


Figure 18: Means and standard errors of substrate organic matter at different sites.

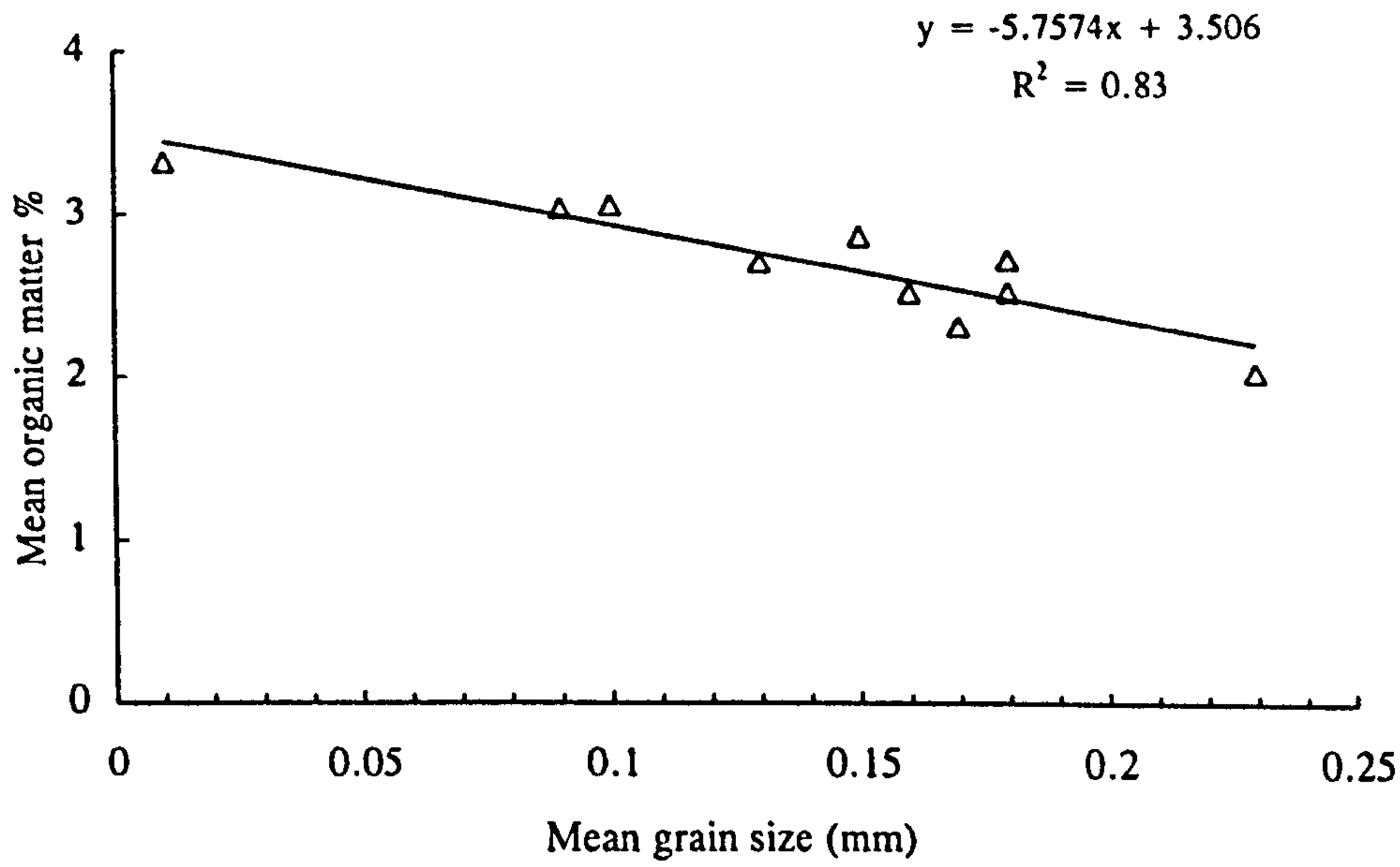


Figure 19: Non-linear regression equation for mean grain size - mean organic matter.

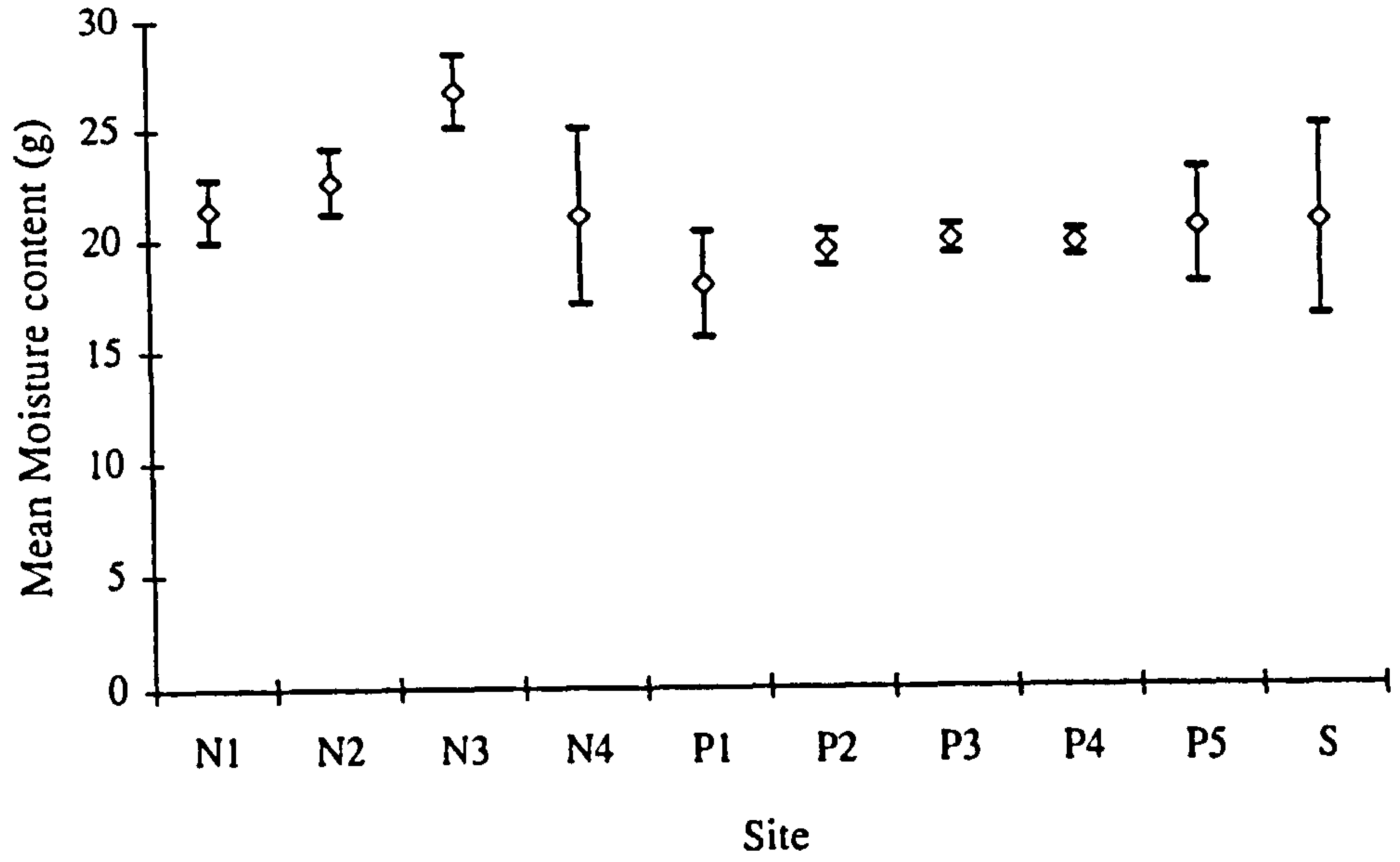


Figure 20: Means and standard error of substrate moisture content (g) at different sites.

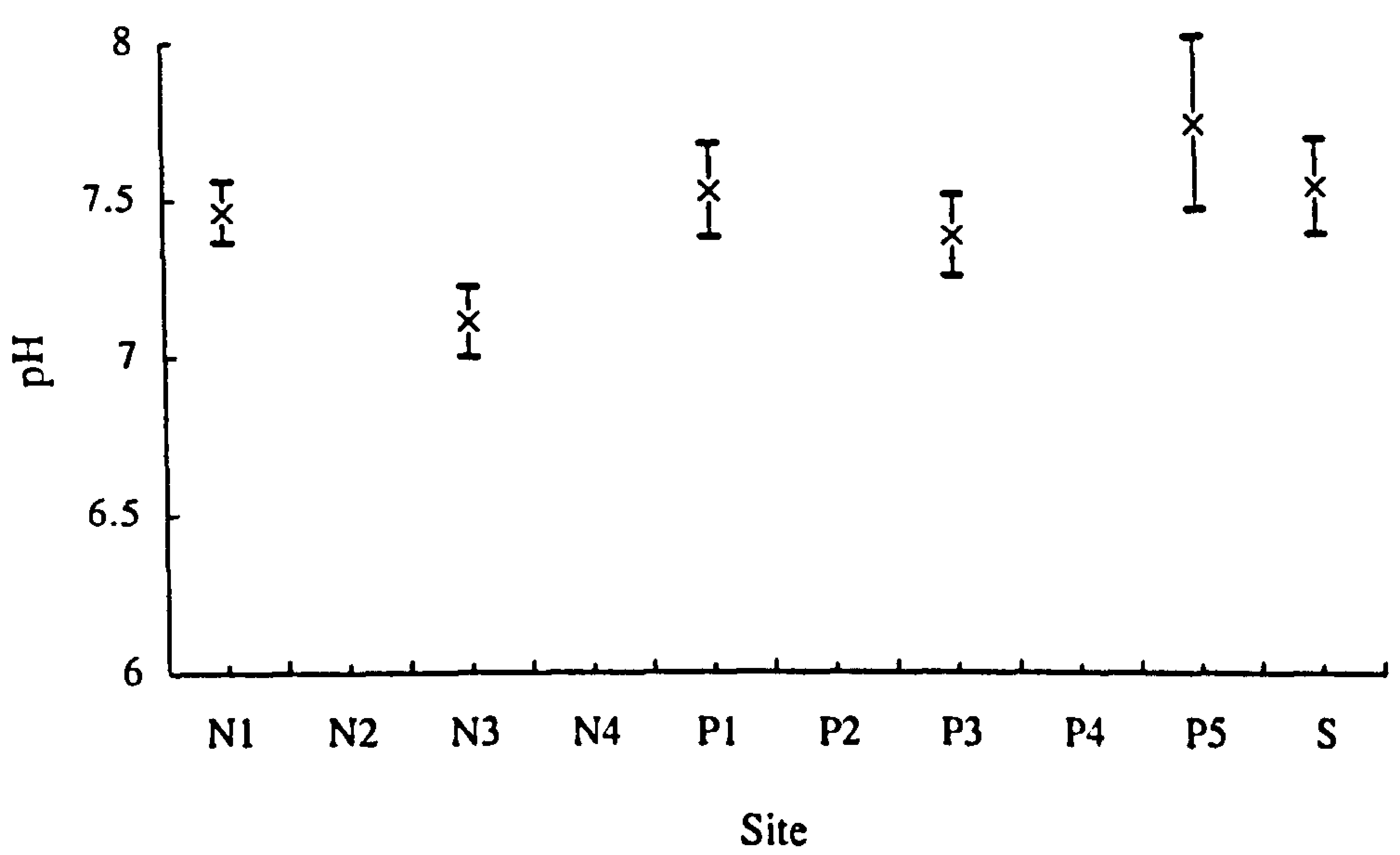


Figure 21: Mean and standard error of pH of ground water at different sites. (Sites N2, N4, P2, P4 pH value was not recorded).

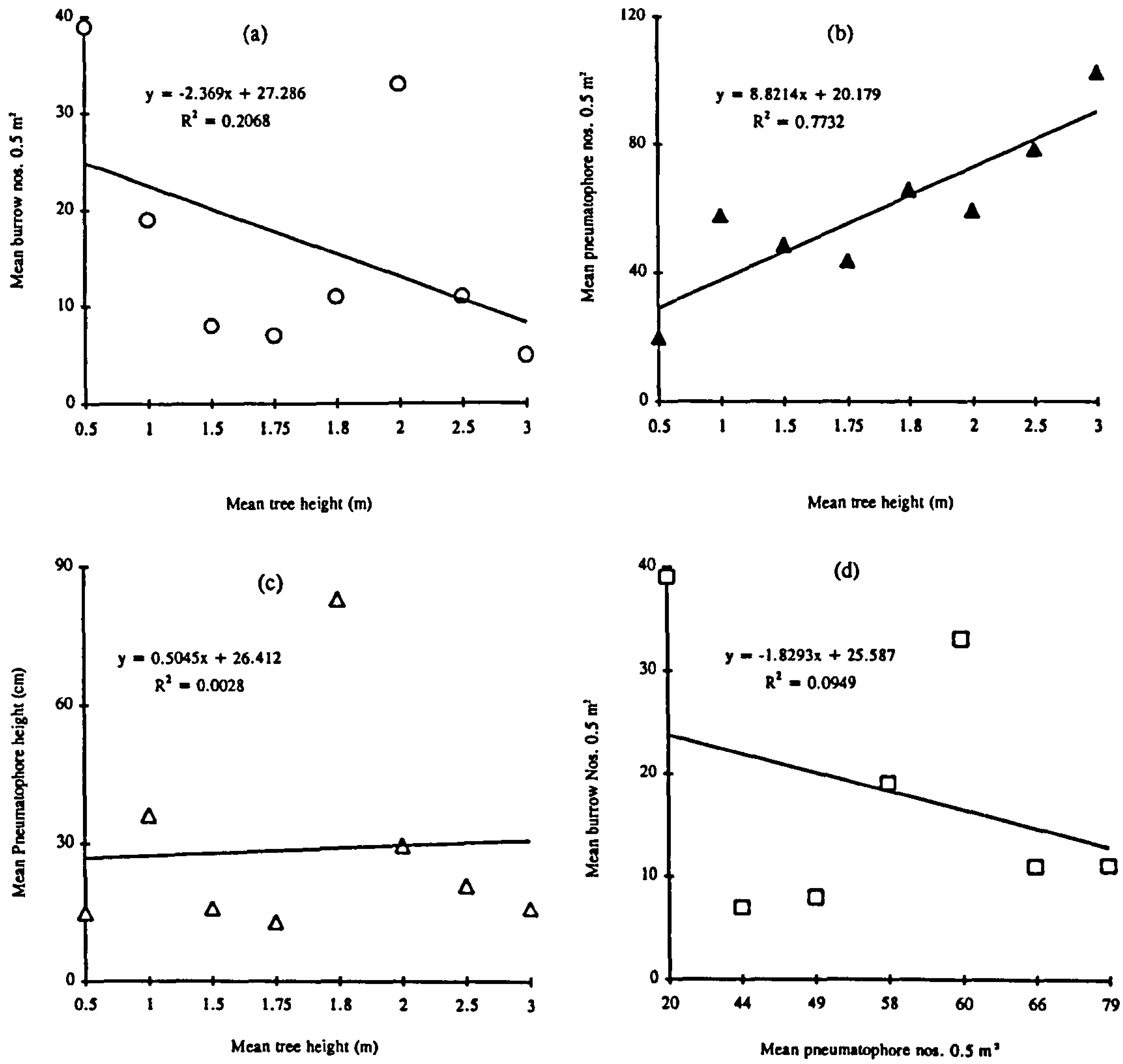


Figure 22: Four different relationships calculated for natural mangrove area.

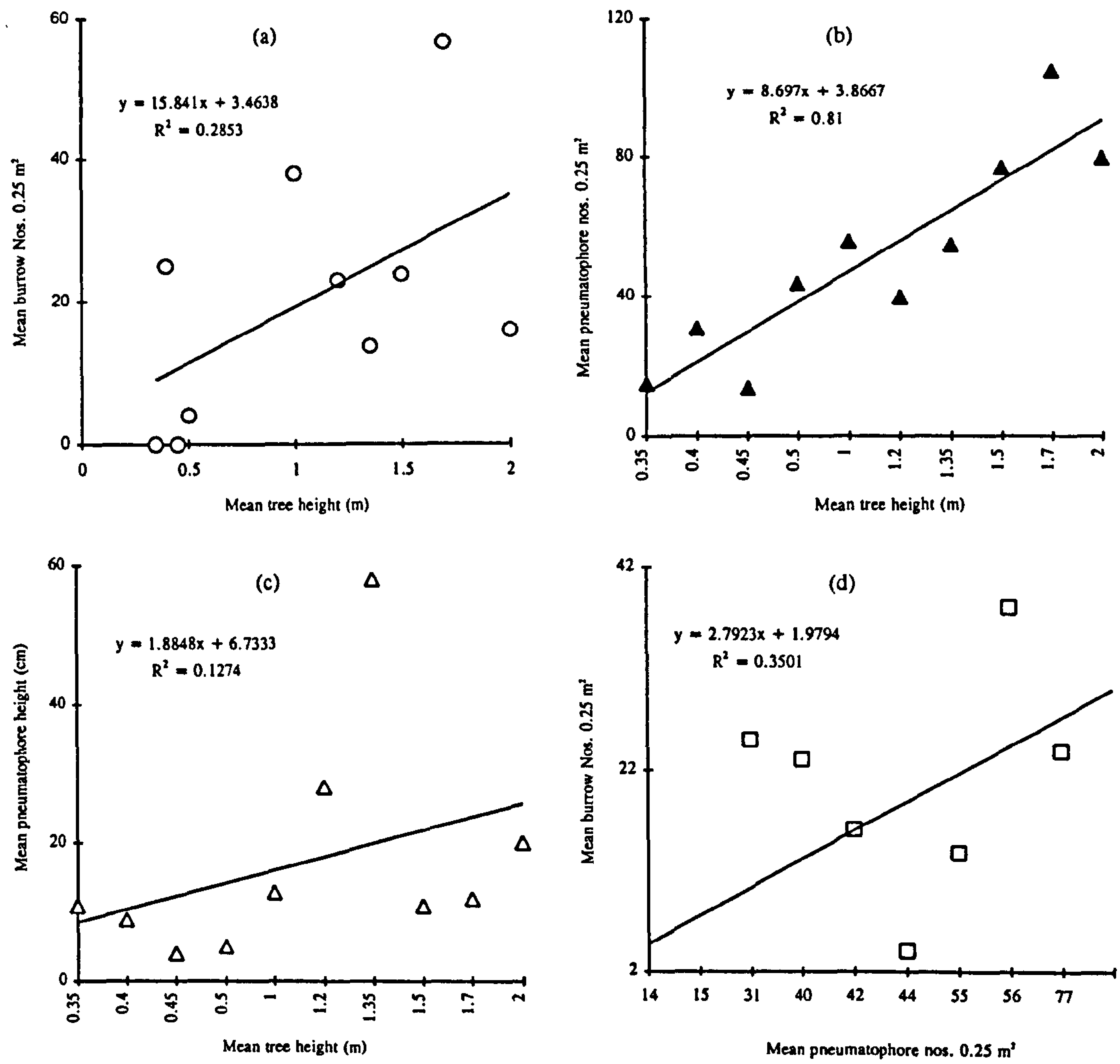


Figure 23: Four different relationship from a-d calculated for planted mangrove area.

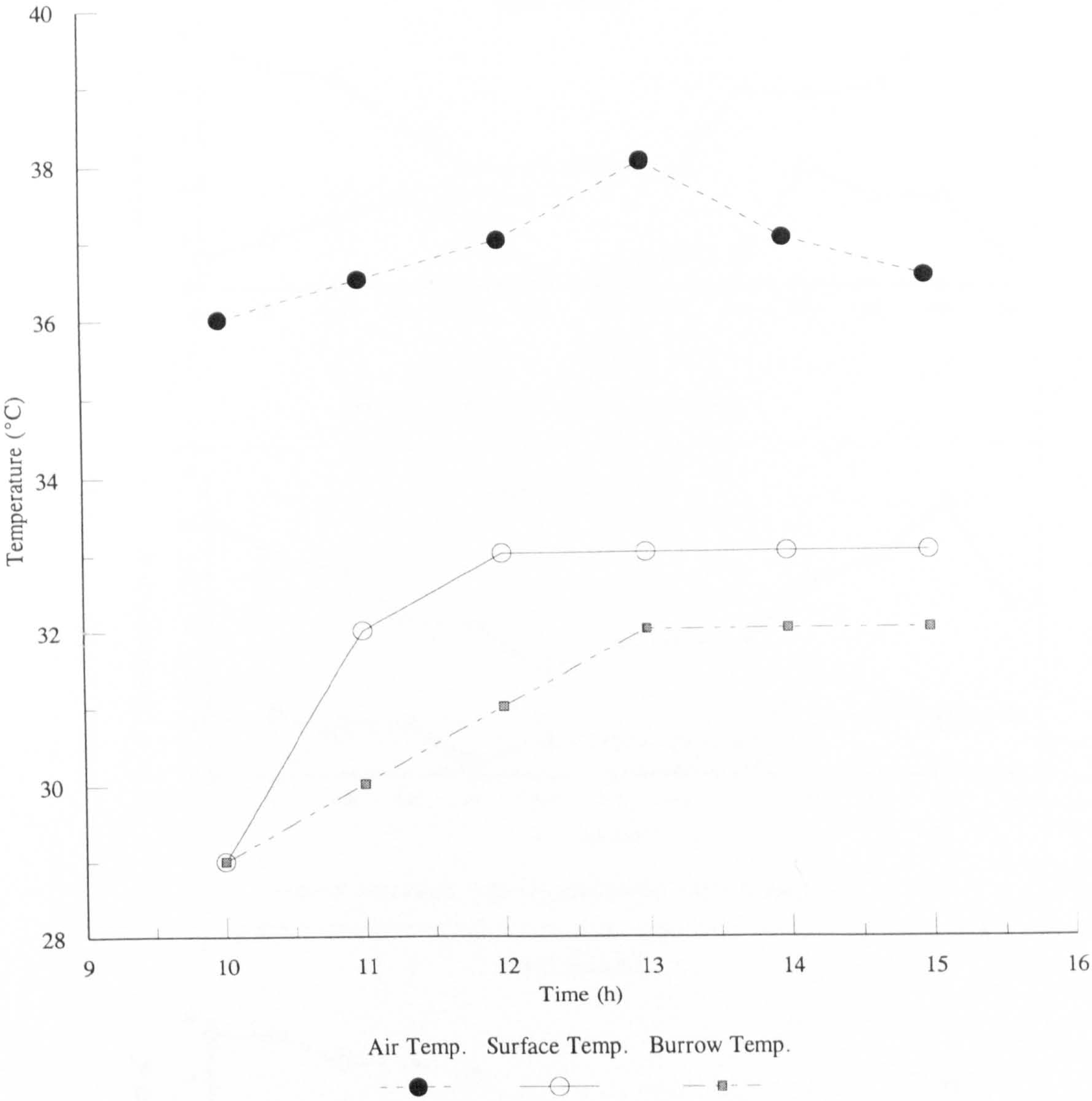


Figure 24: Temperature of the air,surface and burrow of crab (*N. dotilliformis*) at Al - Khor (August 1995).

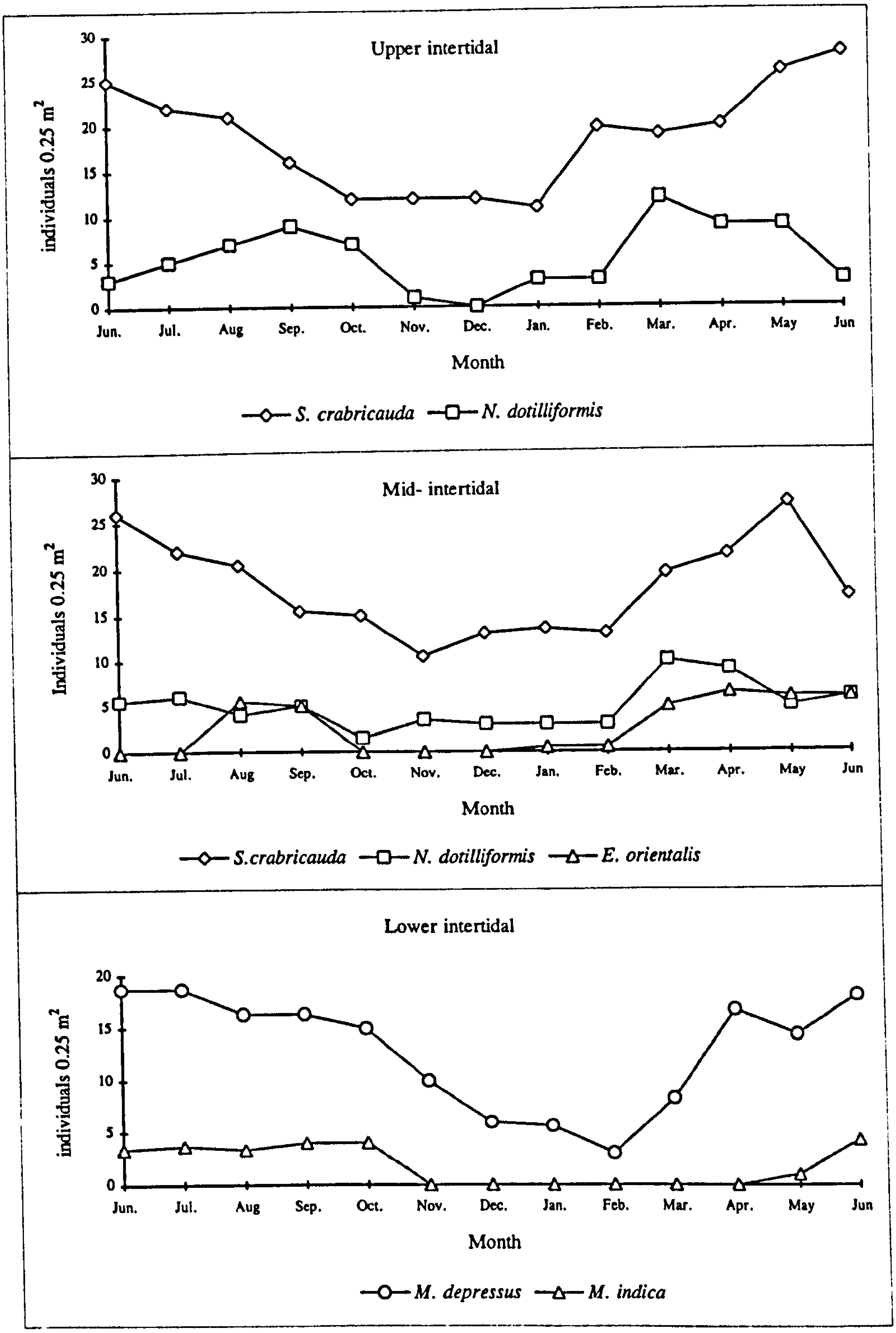


Figure 25: Over all mean abundance of crab species at the different levels at Al-Khor (N1).

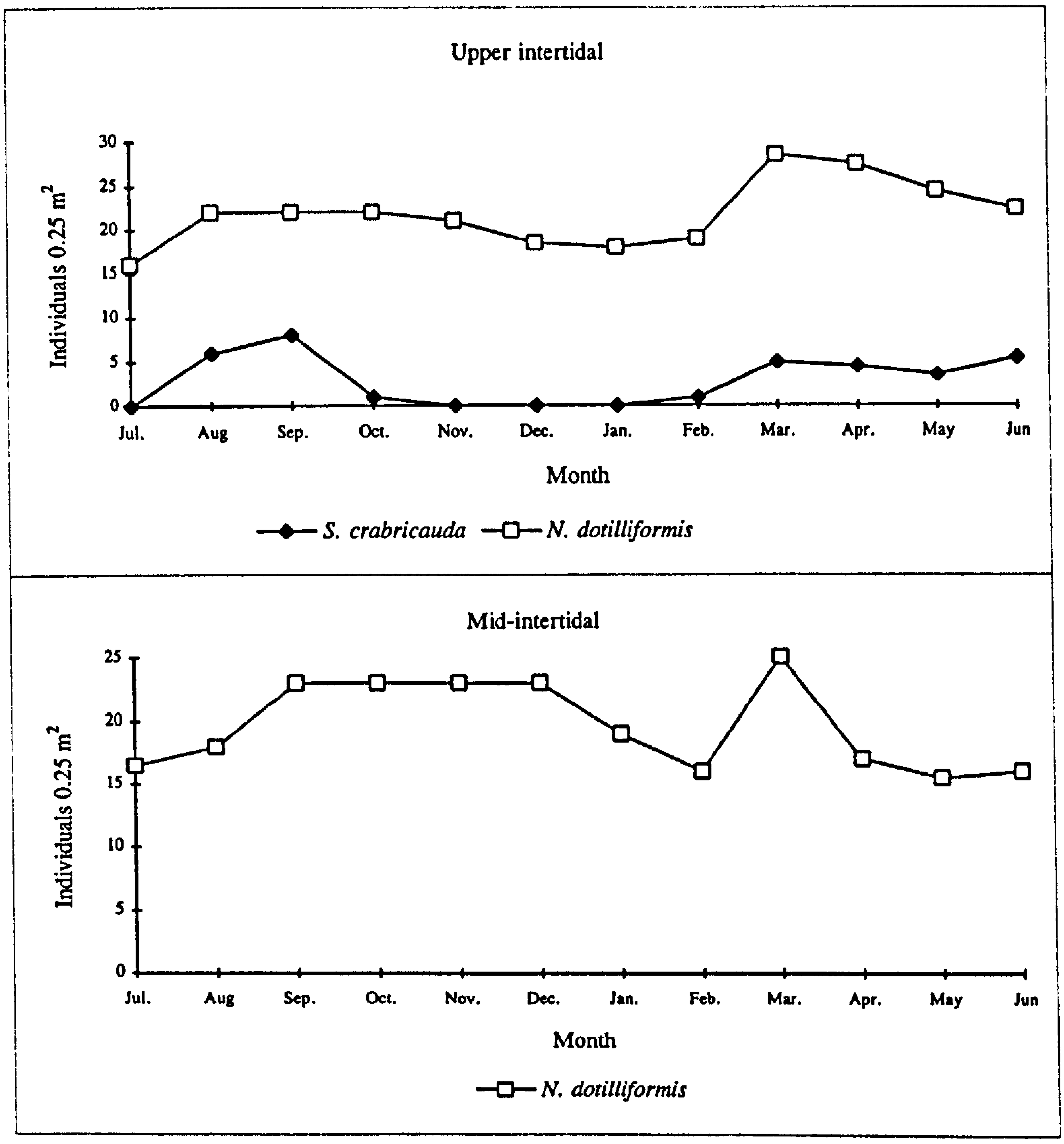


Figure 26: Over all abundance of crab species at the different levels at Al-Khor (N2).

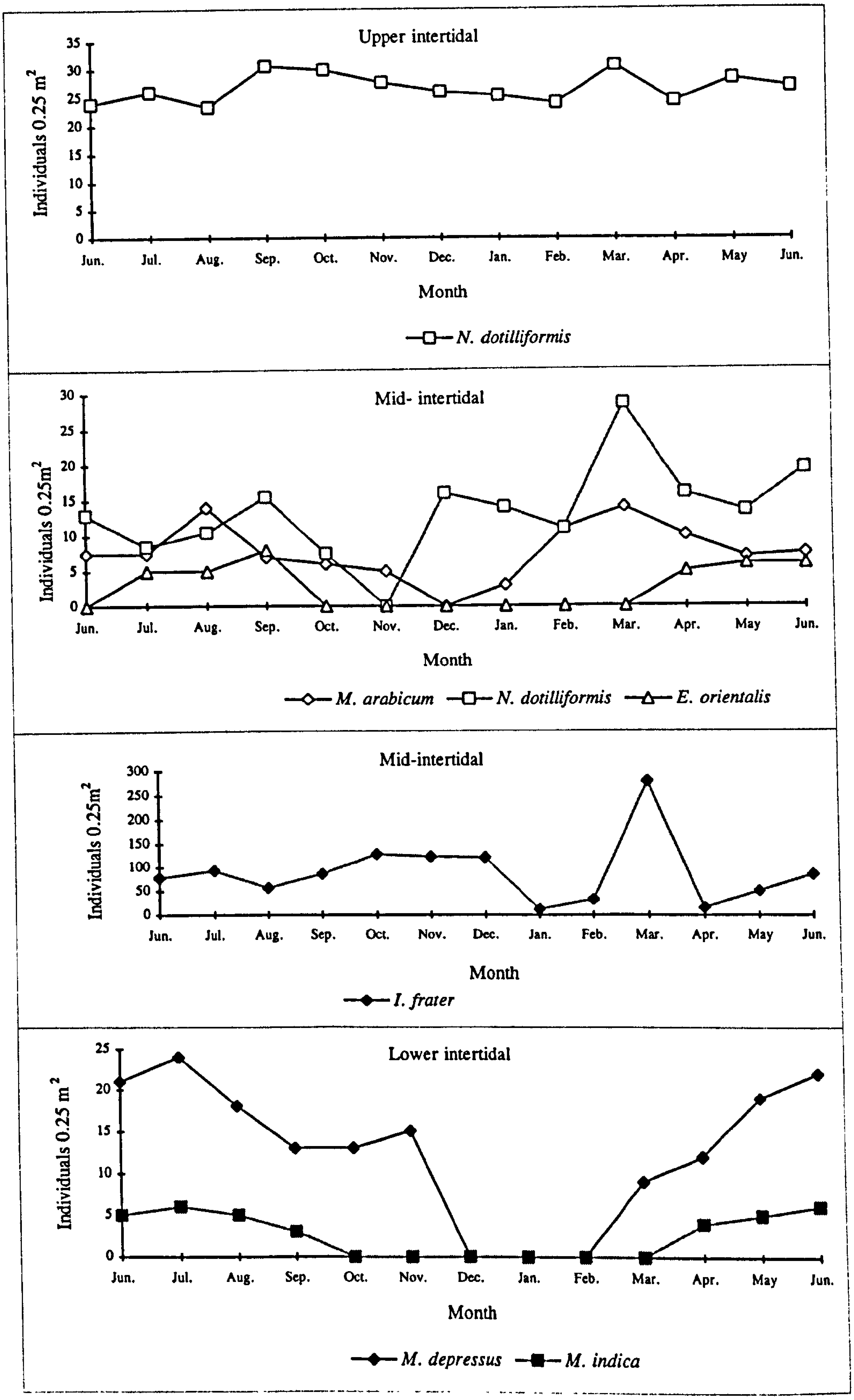


Figure 27: Over all mean abundance of crab species at the different levels at Al-Dhakhira (N3).

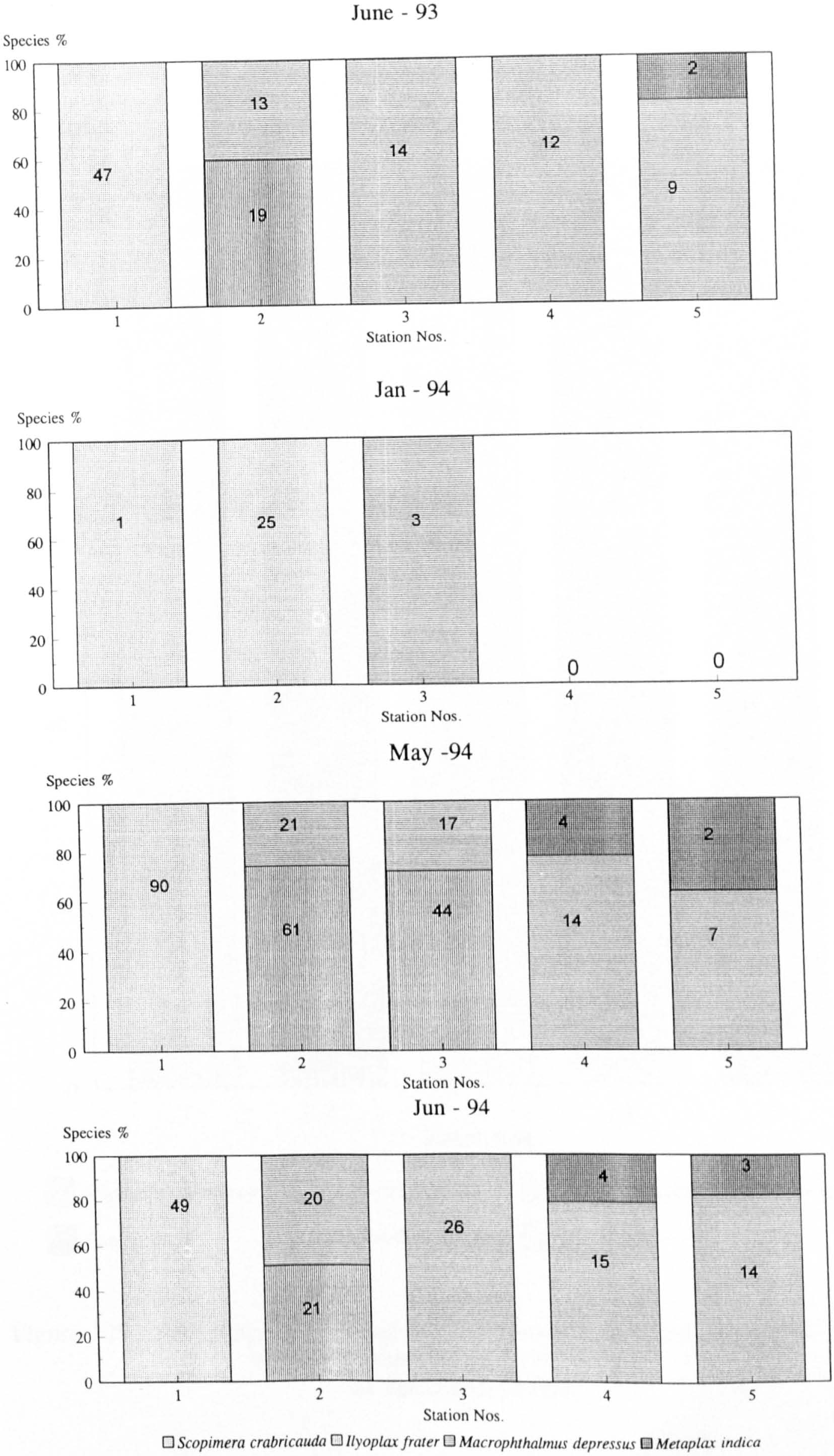


Figure 28: Percentage distribution of the different crab species collected along the transect line from Station 1- 5 at Al - Dhakhira (N4).

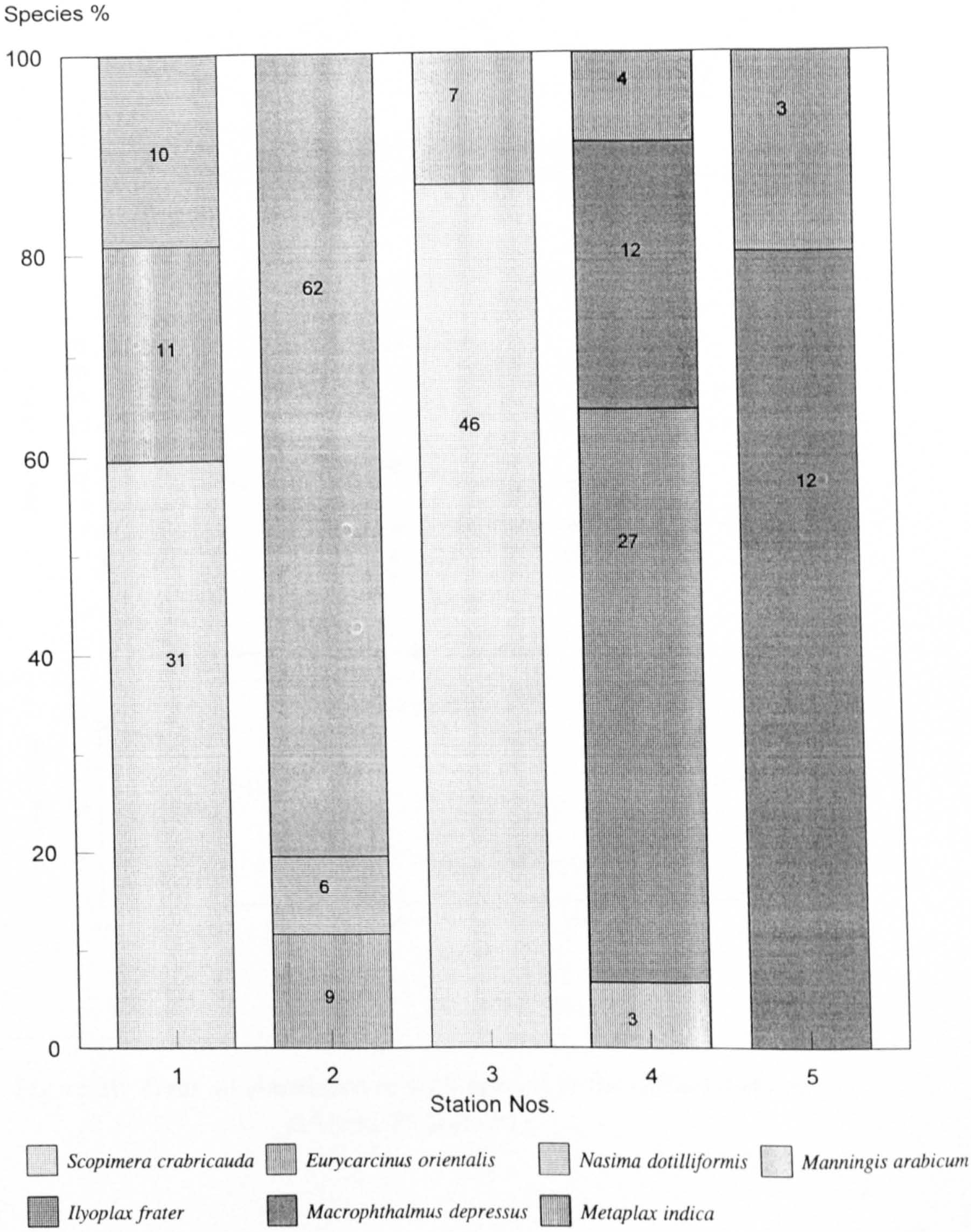


Figure 29 : Percentage distribution of the different crab species collected June 1994 along the transect line from station 1 - 5 at Al-Dhakhira (N5).

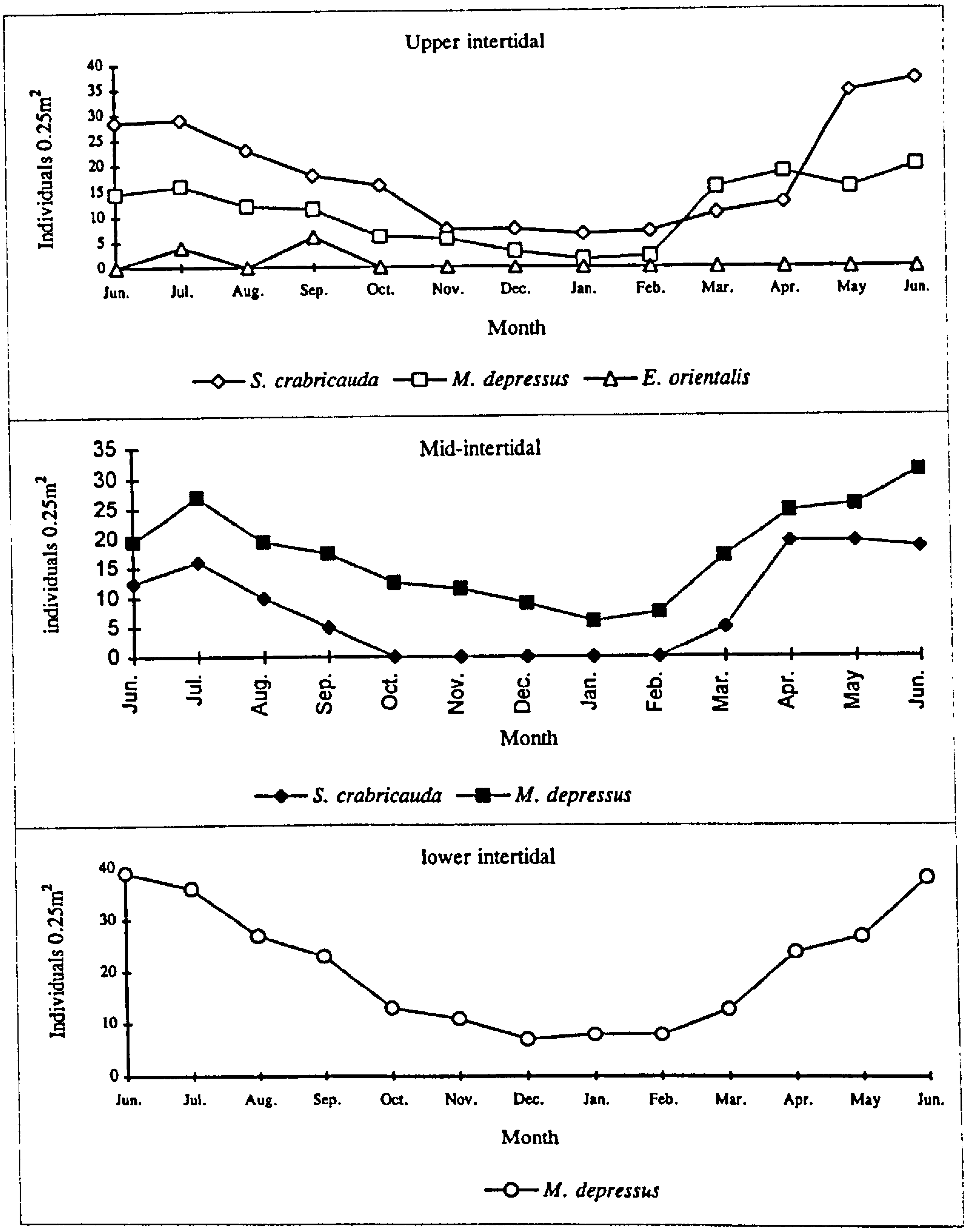


Figure 30: Over all abundance of crab species at the different levels at Umm Al-Hul (P1).

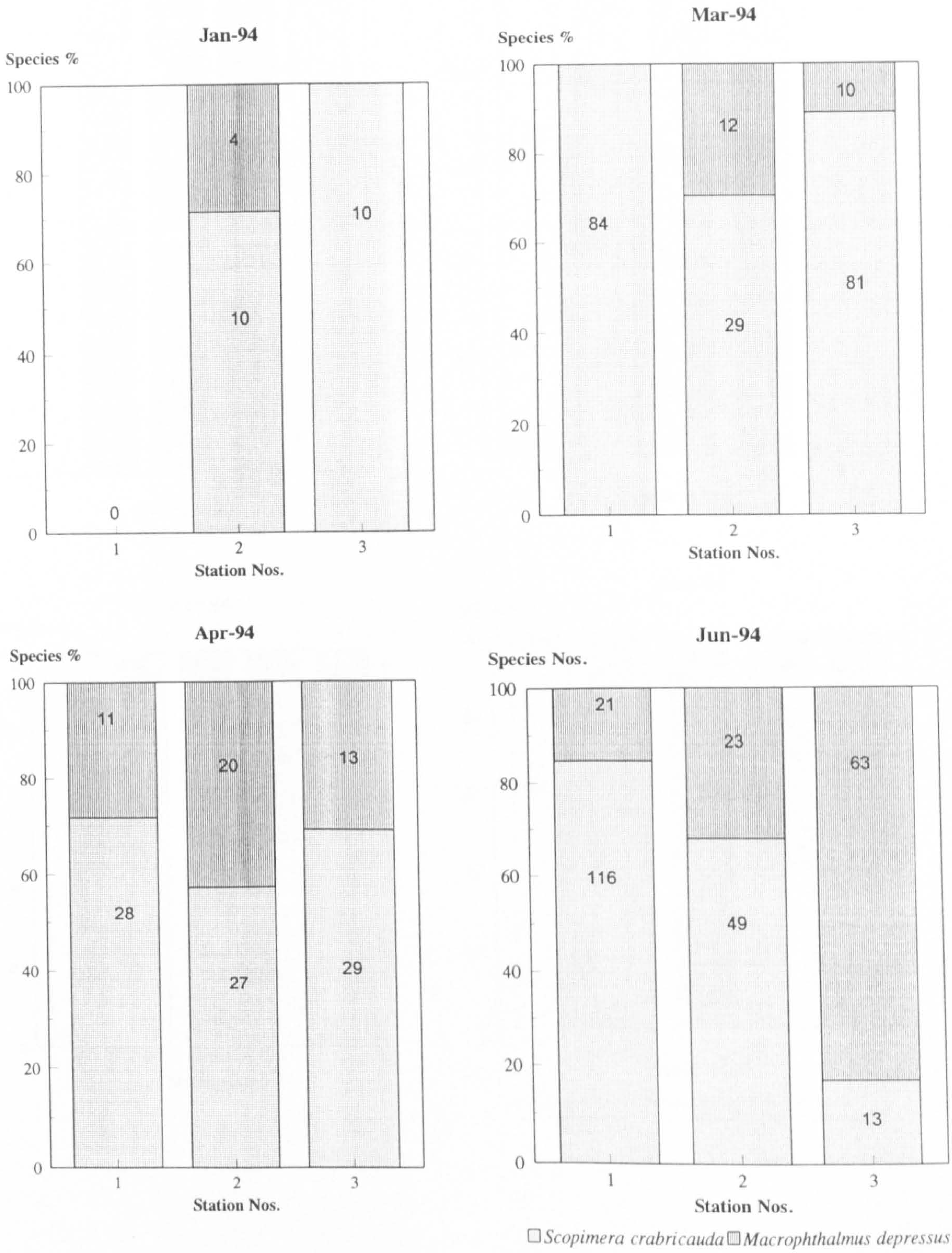


Figure 31: Percentage distribution of different crab species collected along the transect line from station 1 - 3 at Al-Wakrah (P2).

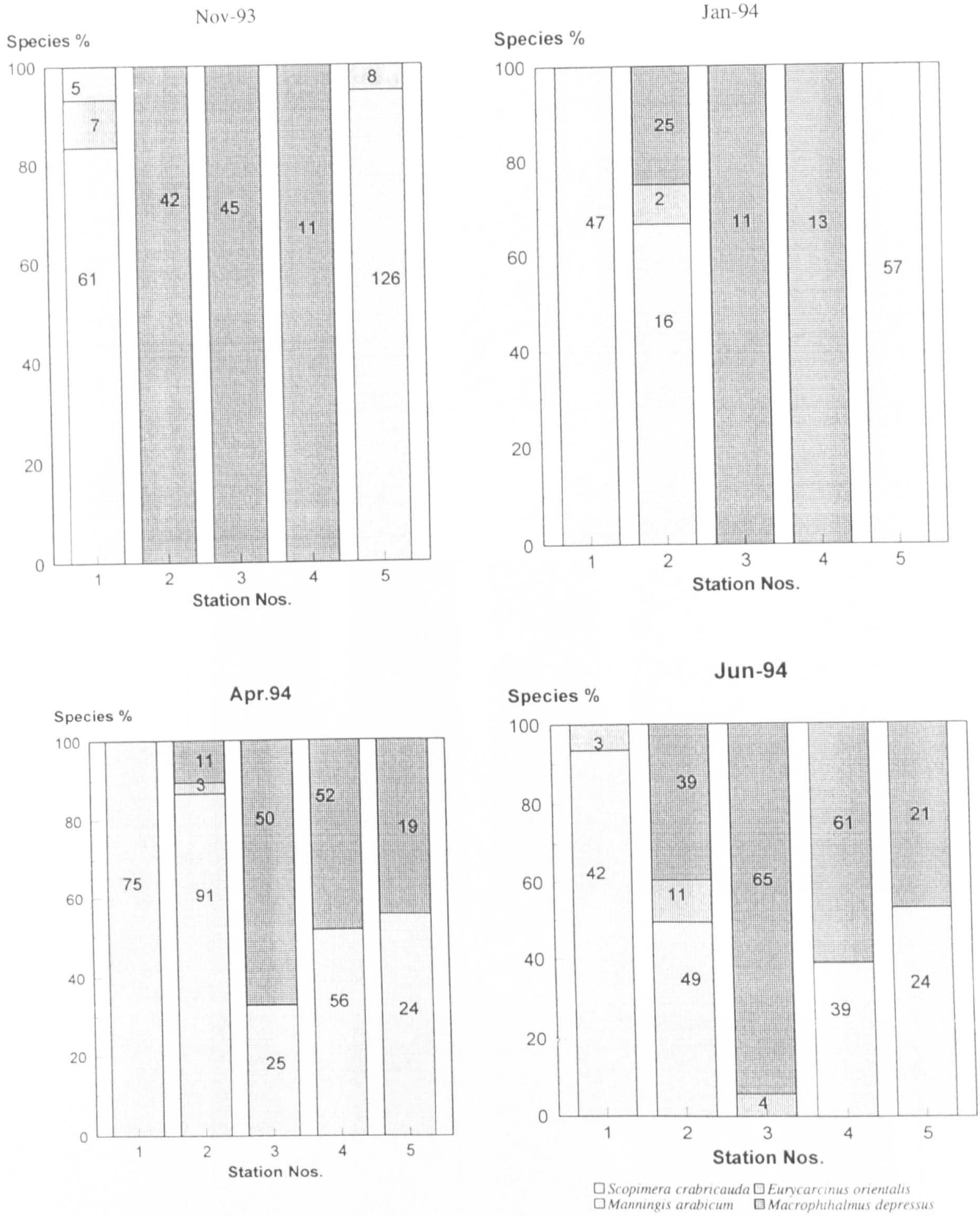


Figure 32: Percentage distribution of different crab species collected along the transect line from station 1 - 5 at Fuwairit (P3).

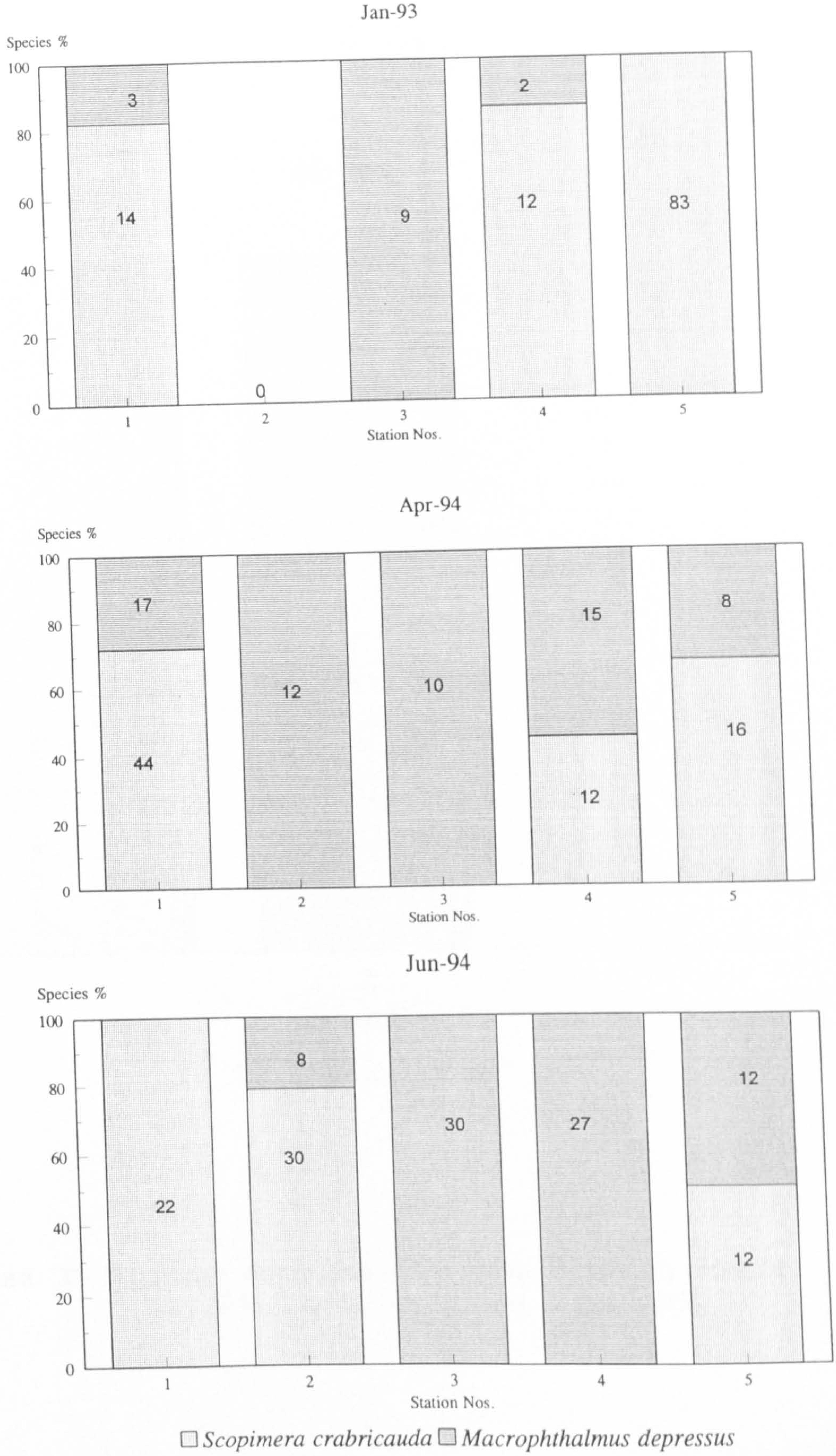


Figure 33: Percentage distribution of the different crab species collected along the transect line from station 1- 5 at Al-Mafjar (P4).

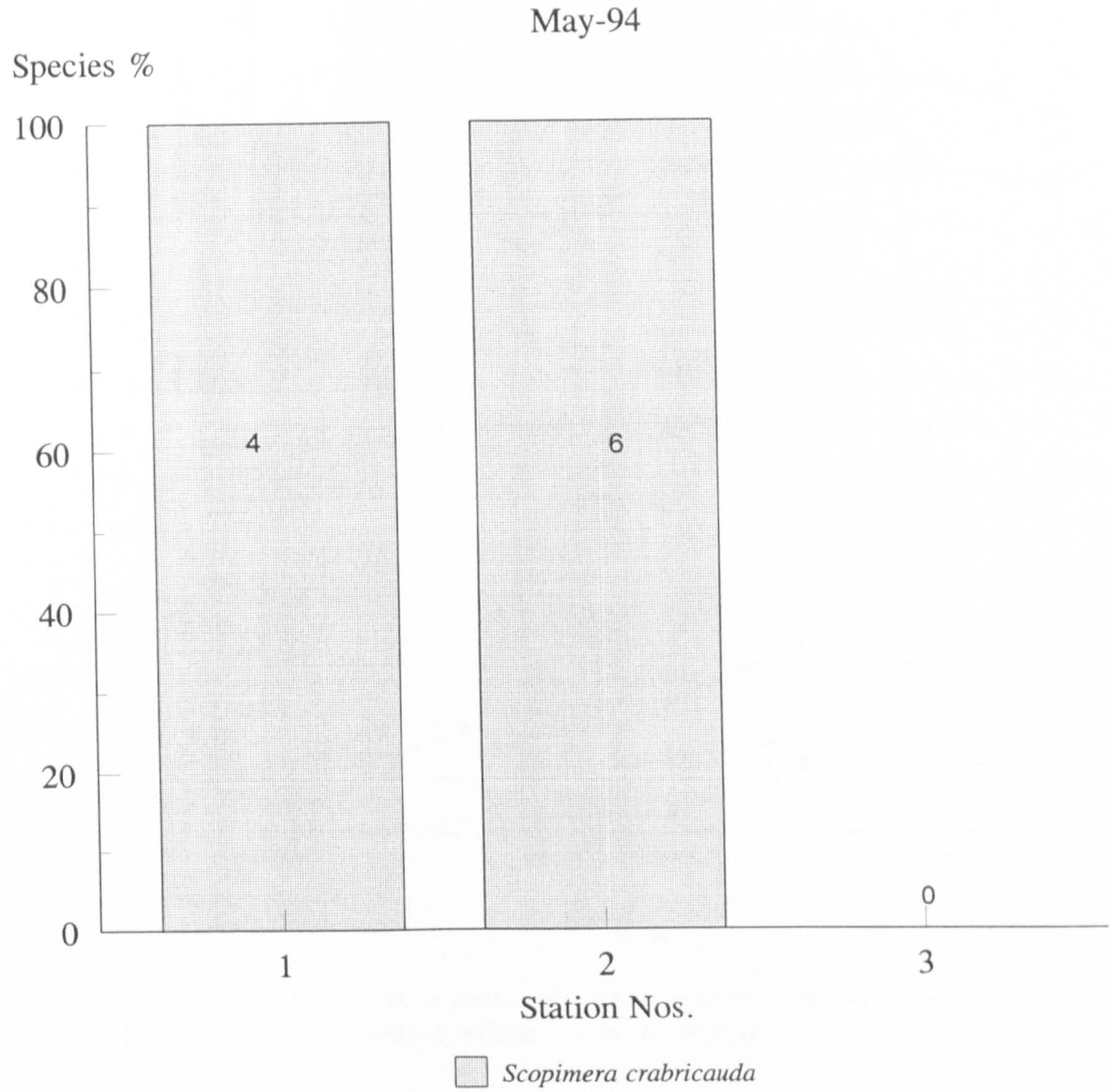


Figure 34: Percentage distribution of *Scopimera crabricauda* collected May 1994 along the transect line in Zekrit (P5).

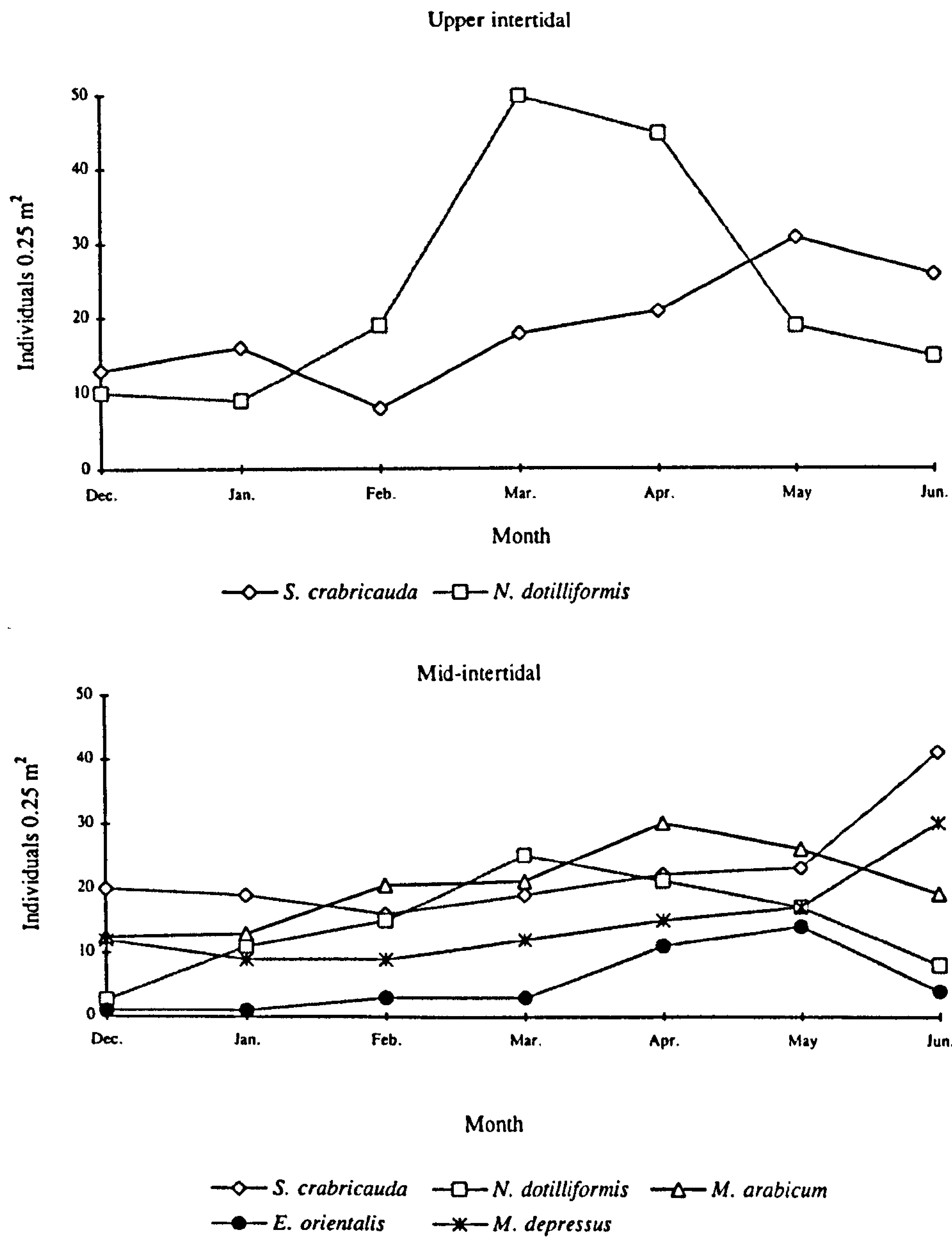


Figure 35: Over all mean abundance of crab species at the different levels at Doha (S).

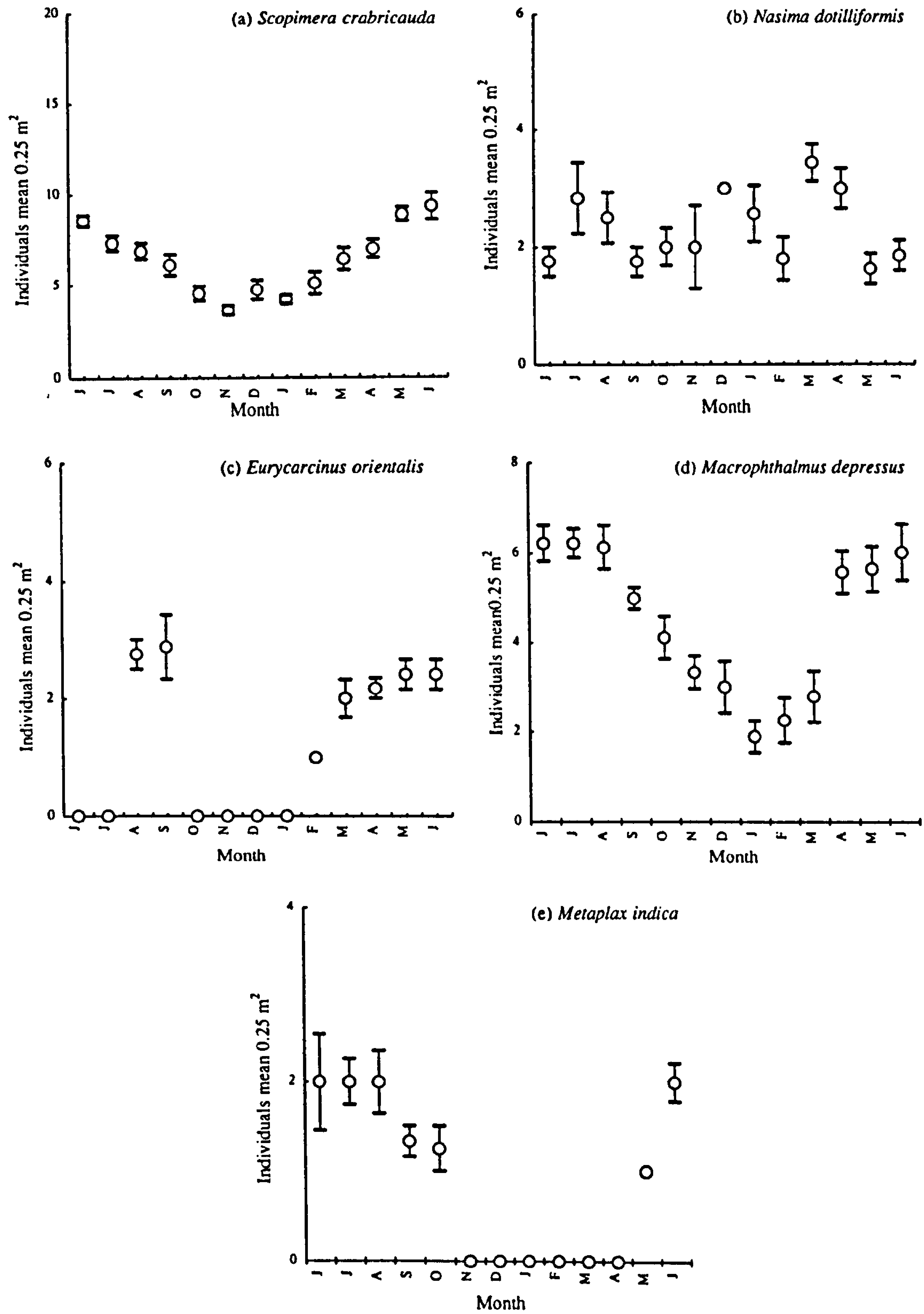


Figure 36: Monthly average of population abundance (0.25 m^2) for 5 crab species collected from Al-Khor (N1), June 1993 - June 1994. Vertical bars indicates standard error.

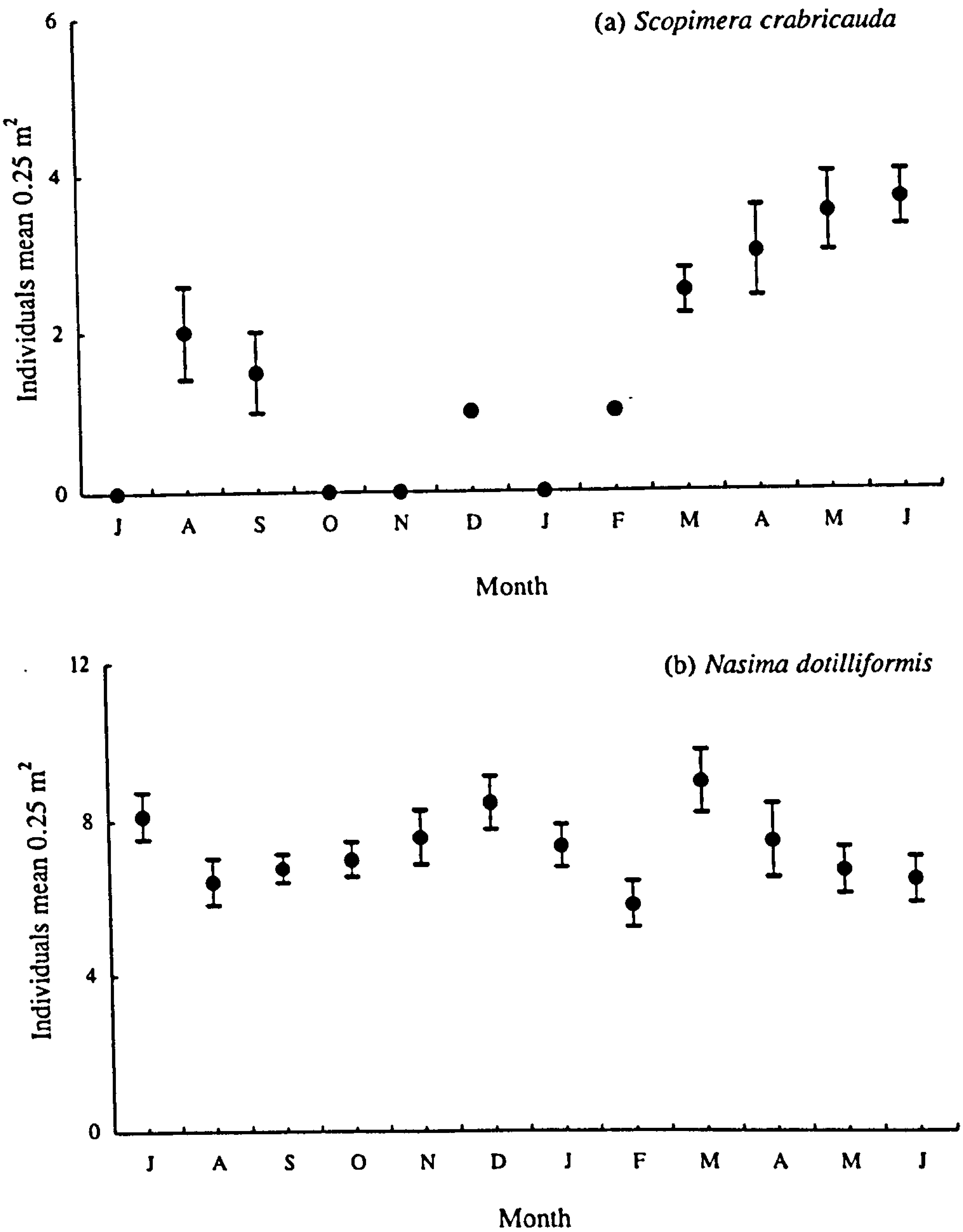


Figure 37: Monthly average population abundance (0.25 m^2) for 2 crab species collected from Al-Khor (N2), July 1993 - June 1994. Vertical bars indicates standard error.

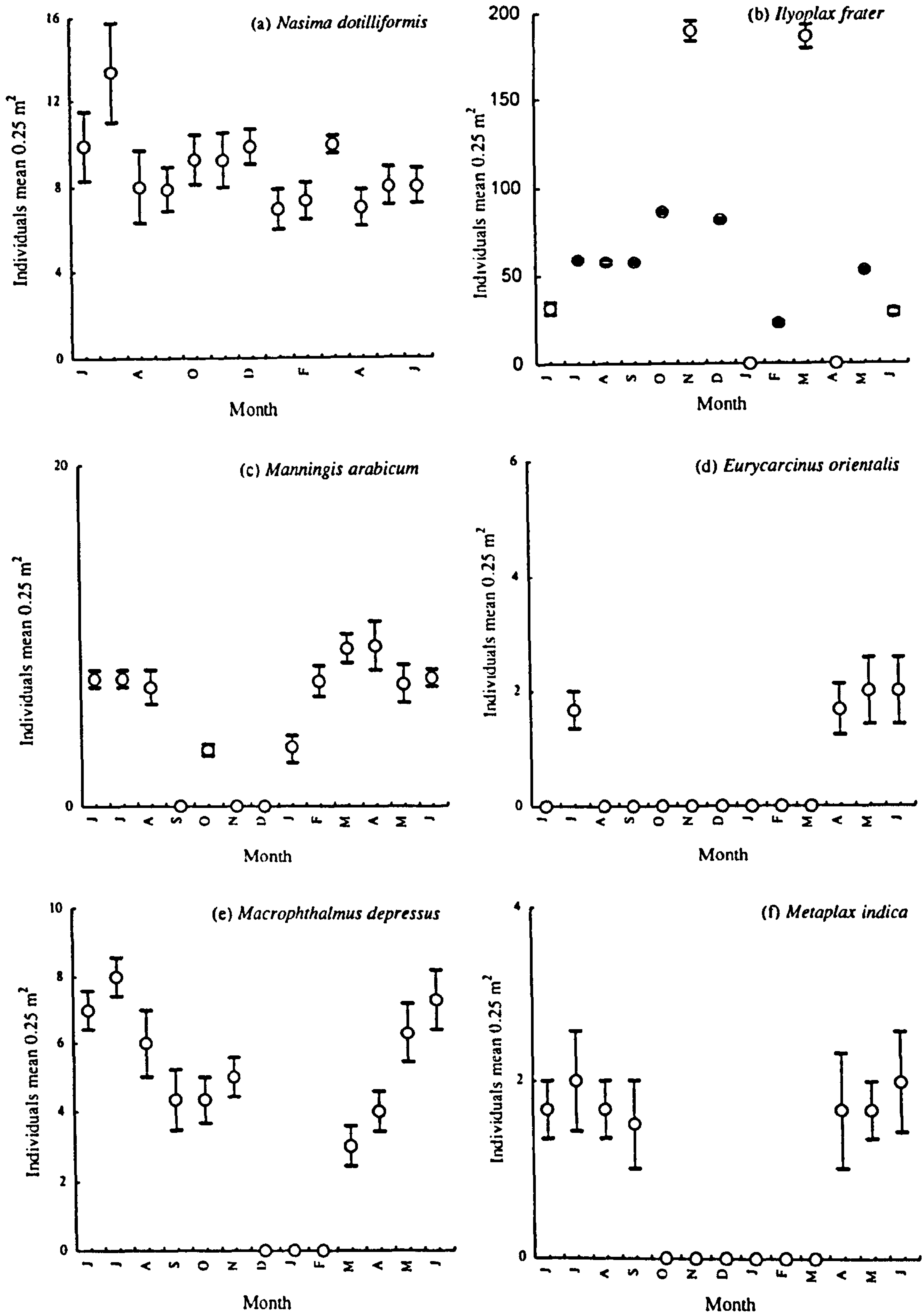


Figure 38: Monthly average population abundance (0.25 m^2) for 6 crab spec collected from Al-Dhakhira (N3), June 1993 - June 1994. Vertical bars indicates standard error.

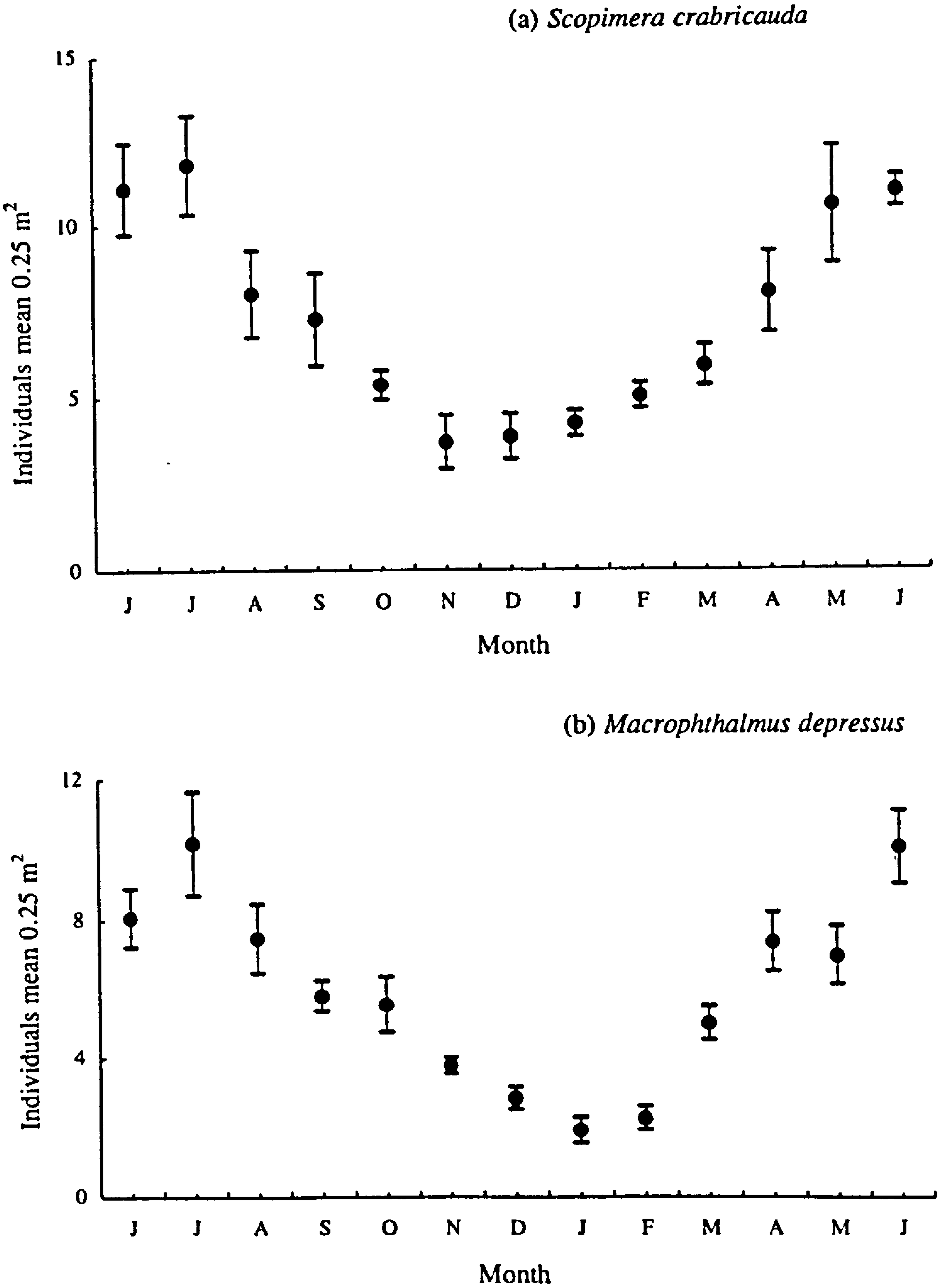


Figure 39: Monthly average of population abundance (0.25 m^2), for 2 species collected from Umm Al-Hul (P1), June 1993 - June1994. Vertical bars indicates standard error.

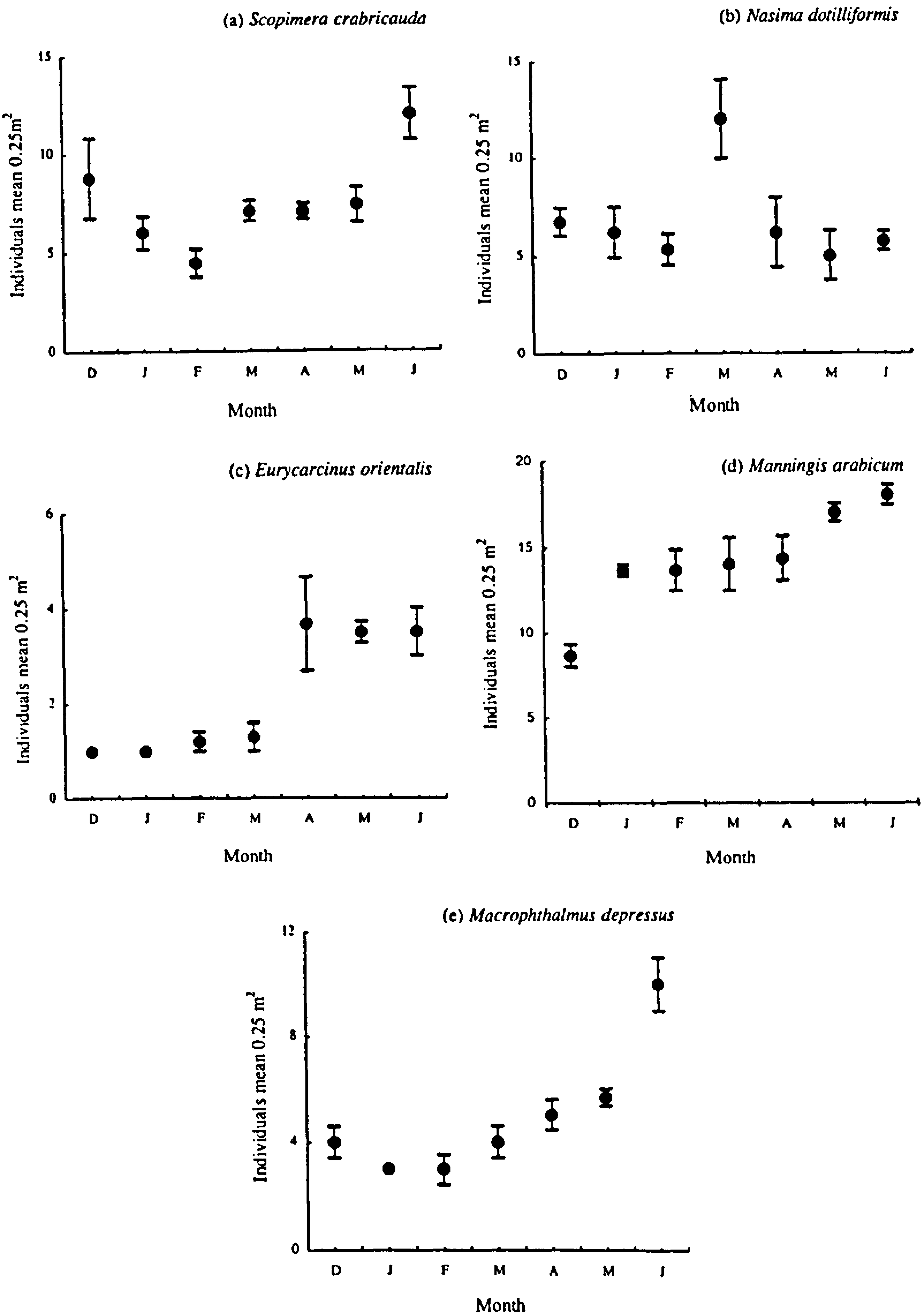


Figure 40: Monthly average of population abundance (0.25 m^2) for 5 crab species collected from Doha (S), Dec. '93 - Jun. '94. Vertical bars indicates standard error.

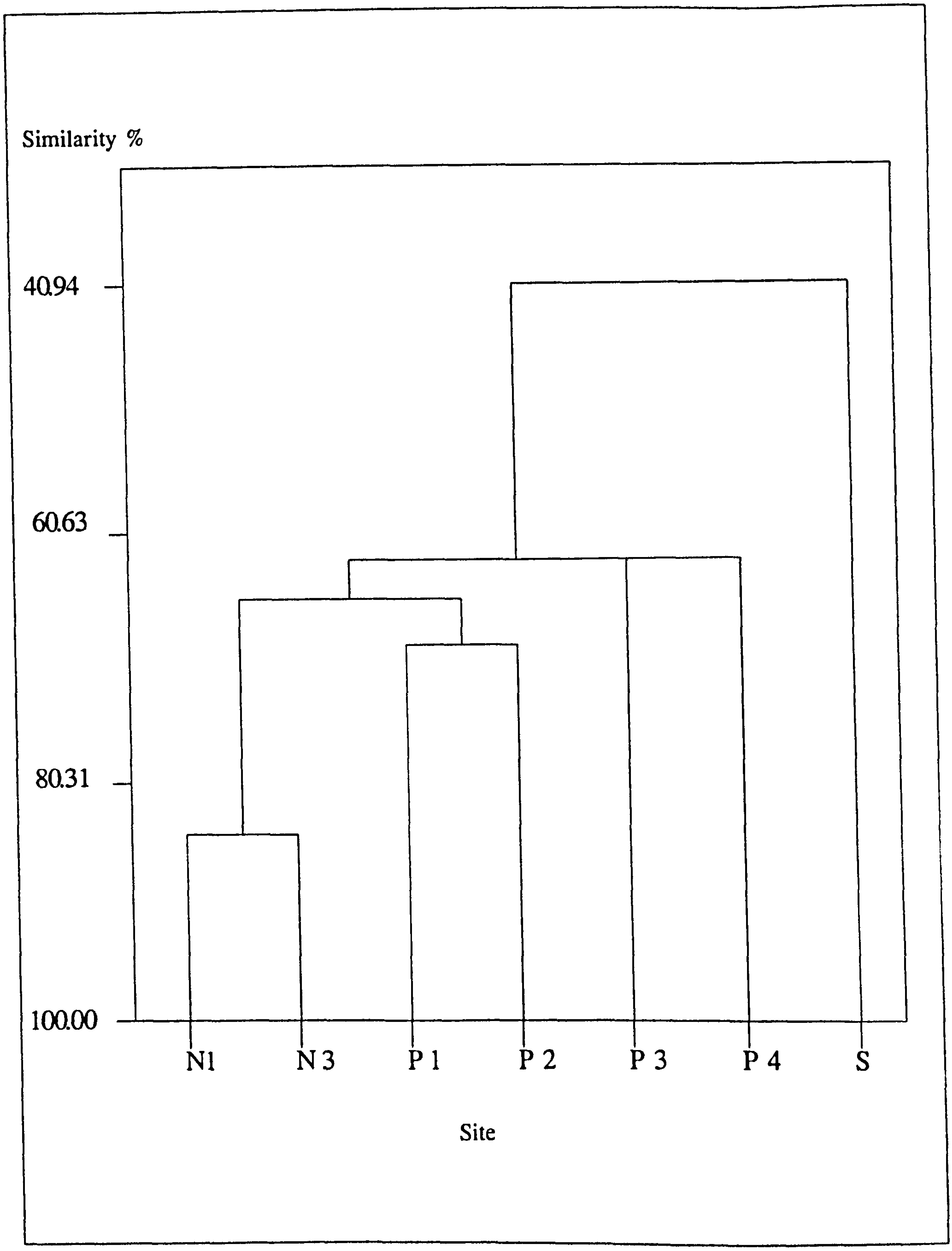


Figure 41: Cluster analysis based on macrobenthic fauna at different sites (N-natural mangrove; P- planted mangrove; S- salt marsh).

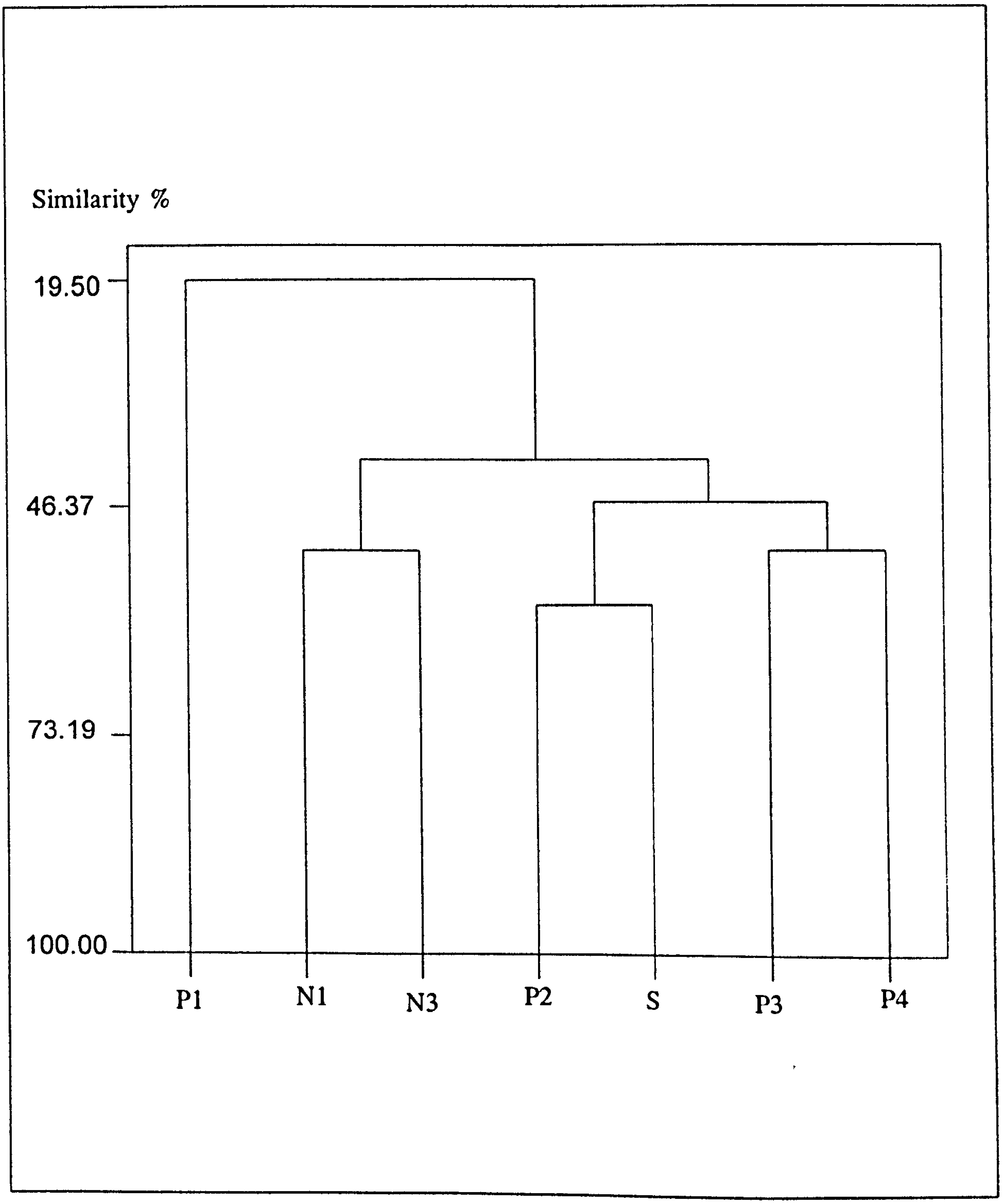


Figure 42: Cluster analysis based on fish species presence - absence at different sites (N- natural mangrove; P- planted mangeroves; S- salt marsh).

DISCUSSION

Mangroves and other salt-tolerant vegetation colonize sheltered shores and estuaries of the Gulf region. They occupy an area from above the high tide mark to just below the mid-tidal level. The only species of mangrove that occurs in the Gulf region is *Avicennia marina* and coast line of the Arabian Gulf is almost barren except for the scattered distribution of these poorly developed mangrove forests. In contrast mangroves in wet humid equatorial coastlines in south east Asia form extensive tidal forests of up to 45 species with trees of more than 1 m diameter and up to 45 m in height (Clough, 1993). They provide living space for a dependent diverse fauna and flora of several thousand species, and support commercial and recreational fisheries. MacNae (1969) proposed six separate zoogeographical regions within the African, Indo-Malaysian and Pacific mangals. Qatar falls within the " west division" (1). This zoogoegraphical region includes Eastern Africa, Madagascar, the Mascarene Islands and shores of the Red Sea. The results of the present study are discussed in comparison with studies conducted in these countries.

Physical Environment

The climate of the mangrove areas in Qatar is typical of the arid region with high temperature and high evaporation values at a level about 200 mm / month during 6 months each year. Months with high evaporation values are those without rain and have high air temperature values. The rain fall is scanty (54.6 to 76.1 mm/yr) erratic and variable in time and space, and hence there is limited input of terrestrial sedimentation.

Measurements at 2 sites of natural mangrove (N1 & N2) and 1 site of planted mangrove (P1) on a monthly basis shows that the surface water temperature attained minimum values in winter and increased to maximum values during summer and that pH is stable. The slight variation in water and air temperatures was due to daily variation where temperatures were recorded at different times of the day.

The salinities recorded in the present study, although higher on the west coast do not appear to differ greatly from those recorded in the other parts of the Gulf region. Salinity is high due to the absence of terrestrial runoff and high rates of evaporation. Salinity has been suggested to be a limiting factor restricting mangrove height as Price *et al* (1987) found a significant inverse correlation between the two factors along the Red Sea of Saudi Arabia. Similarly, Por *et al* (1977) suggested that in Sinai (Gulf of Aqaba, Red Sea) salinity is probably the main factor restricting the number of mangrove species, as well as some plant and animals species normally associated with mangrove. However, Chapman (1984) suggested that low temperature rather than salinity is the main limiting factor, and Jones (1986) considered temperature to be responsible for absence of mangroves in Kuwait.

In summer, pH was lowest in natural mangroves, perhaps reflecting the high organic content of the soil. However, salinity, pH of sea water and soil pH varied slightly between natural mangrove, planted mangrove and salt-marsh sites except at Zekrit on west coast, suggesting that these conditions are not the major limiting factors for the distribution of macrobenthic fauna of Qatar.

Tidal inundation may partly explain why crabs tolerant to desiccation dominate the higher intertidal mangrove zones, while soft bodied animals are abundant in the lower intertidal zones.

The high salinity at the west coast of Qatar is reflected in a poor growth of *A. marina*. It has been suggested that salinity controls growth so that at Zekrit (P5) on the west coast at 60-90‰ salinity 8.5 year old trees reach only 45 cm in height, whilst on the east coast (P1, P3 and P5) at 43‰ they grow to 200 cm over the same period (Suda and Al-kuwari, 1989). It is also a major limiting factor on the distribution of macrobenthic fauna at this site where only 2 species (*S. crabricauda* and *M. messor*) were found.

Sediment Characteristics

The main trend observed along all transects at different sites was that of decreasing mean grain size from the upper shore line to the lower shore. Between sites natural mangrove showed a smaller grain size compared to that of the planted mangrove areas (Tab. 5). This decrease in grain size is probably related to the extensive pneumatophore system of mangroves which acts to slow water motion and cause settlement of fine sediment particles in established mangrove areas. This is also reflected in the higher level of silt and clay in natural mangroves which has been accumulated over a long time in comparison to planted mangroves which have only been in existance for 10 years.

The sorting patterns at all study sites range from moderately sorted to poorly sorted, within the coarse and medium sediments. The values of skewness range between near symmetrical to strongly coarsely skewed, sediments of the intertidal zone generally tending to be negatively skewed. Measurements of kurtosis give an indication of the variety of sediments at the study sites. These variations of kurtosis can be used to distinguish different environments of deposition. The general distribution of kurtosis patterns ranged between platykurtic and leptokurtic, associated with sediment located within the mangroves and salt marsh, while moderately kurtic values were associated with open shore coarse and medium sediments. Unfortunately detailed data for substrate particle size zonation throughout mangroves is lacking for the Arabian Gulf. In Oman, Hywel-Davies (1994) found that particle size was fairly uniform throughout the mangal, with fine to very fine sands dominating. Similar particle sizes have been recorded from mangals throughout the region (MacNae & Kalk, 1962; Icely & Jones, 1978; Day, 1974: Ismail & Ahmed, 1993).

Substrate Moisture and Organic Content

The acidity of mangrove soil is probably due to the activity of bacteria on oxidizable sulphur (Hart, 1959). A greater level of organic material and substrate moisture was found in natural mangrove substrates than in salt-marsh or planted mangrove sites. This may be attributed to the presence of higher levels of organic material, derived partly from the trees themselves. Mean organic matter and moisture content were higher and grain size lower in natural mangrove, while planted mangrove areas had a higher grain size, but lower organic and moisture content (Tab. 8). The lowest organic content was found in the planted mangrove substrate at P2 which had highest mean grain size. There were, however, some differences in the relative proportions of the grain size within the substrates of a mangrove mud flat. Al-Dhakhira (N3) contained a notably higher proportion of clay and silt and also a high water content than other natural sites. The non-linear correlation between mean grain size and mean organic matter shows a strong relationship so that the highest organic matter is found with a small grain size of sediment less than 0.05 mm; organic content then decreases with increasing mean grain size of sediments (Figs. 18, 19 & 20). The percentage of organic matter has previously been shown to be inversely related to sediment texture (Bader, 1954; Newell, 1965; Phillips, 1972; Ismail, 1985; Ismail and Ahmed, 1993). This is in agreement with Anderson (1972) who also found that the smaller the particle size, the higher the percentage organic material became.

As most mangrove macrofauna consume organic detritus of various types, (Odum and Heald, 1972, 1975), this may explain why species diversity and number of individuals in each zone of the mangrove and salt-marsh sites biotopes are often correlated with the organic material and particle size. Hence the decrease in species diversity observed between different sites (Tab. 13) is probably related to the lower organic content. To substantiate this link the feeding habits of common crab species are considered in chapter 5.

Oxygen Concentration

Tidal flooding brings seawater rich in oxygen to the intertidal soils. This aerated seawater penetrates the soil and contributes to the oxygen supply of the soils (Böer, 1994). The degree of penetration is again dependent upon the particle size of substratum and it is obvious from stations at the different sites studied that the upper intertidal zone contained highest values of oxygen saturation (24.31 - 34%), while stations located in mangrove areas contained lowest values (7.09%) of oxygen saturation. In addition substrates with a high organic content contain high levels of bacterial action further reducing oxygen. Present measured values of oxygen content are above those considered as minimum values for mangrove plants to be in good condition. In Saudi Arabia, Böer (1994) found that at oil polluted sites at a minimum oxygen value of 5% some mangrove plants were alive, while at none contaminated sites with 9% oxygen all plants were alive. Böer (1994) found *A. marina* developed high numbers of branched pneumatophores and adventitious roots after oiling and attributed this response to low oxygen conditions. The intensity of oiling and the ability to develop new aerial roots contributed to the ability of *A. marina* to survive oil pollution.

Chapman (1976) summarised a number of gas samples obtained from a variety of habitats and soils in mangrove muds of Jamaica and New Zealand (Tab. 16).

Table 16: Gas analyses from mangrove muds.

Locality	% O_2	% CO_2 & H_2S (not separated)
* Mangrove fringe	3.65 - 5.68	8.08 - 9.1
* *Avicennia* on peat	6.26 - 9.61	5.31 - 11.53
* Dead *Avicennia* on salina	2.33 - 2.69	0.11 - 0.74
* *Rhizophora mangle* fringe	2.45 - 11.02	3.89 - 4.97
* Mixed *Rhizophora / Avicennia*	5.79	6.44
* Mixed *Rhizophora / Avicennia* fresh w.	21.59	11.53
**Avicennia* on mud	0.0 - 6.76	0.12 - 7.89
**Laguncularia* on sand	8.81	19.73 (?)
* *Avicennia* on a coral Cay	7.8	10.74
+ Mangrove in Manukau	1.56 - 3.7	3.7 - 12.10
+ Creek mangrove	13.6 - 14.3	1.48 - 4.74
Non-creek mangrove	1.0 - 4.57	1.5 - 4.25

(After Chapman 1976)
* From Chapman (1944). *Avicennia germinans.*
+ From Chapman & Ronaldson (1956) and Sussex (1949). *Avicennia marina* var. *resinifera* mangrove.

From these figures it is obvious that oxygen concentration is normally low and it has been suggested (Chapman, 1944) that the death of *Avicennia* may be attributed to very low oxygen in the soil atmosphere. It also seems that oxygen concentrations in

Rhizophora mangle are even lower than those found in *Avicennia* mangroves. Soil atmosphere composition and enhanced drainage are undoubtedly interrelated and promote mangrove growth (Chapman, 1976; Böer, 1994). Wada (1988) has also suggested that good drainage is indispensable for mangroves in order to remove toxic substances produced in strongly reduced soils in addition to oxygenating the soil. Holes made by animals (burrowers) are the main drainage channels in mangrove soil as the permeability of the fine particle size itself is usually very low. However, in present work attempts to correlate burrow abundance with tree height, pneumatophore number and height were unsuccessful.

This is explained because oxygen conditions in both natural and planted mangroves are not limiting (Tab.6 and Tabs. 11, 17). Arabian Gulf sediments have a high sand content and relatively low organic content (Tabs. 4, 5) in comparison to tropical estuarine mangroves (Chapman, 1976), hence oxygen is unlikely to become limited except under special circumstances such as oil pollution impact (Böer, 1994). Positive correlations between tree height and pneumatophore abundance in both planted and natural sites indicate normal healthy growth conditions for mangroves in both areas (Wada & Seisuwan, 1988).

Burrow temperatures

Almost all mangrove crabs construct burrows which protect them from high evaporation and temperature stresses, predators and aggression from neighbouring crabs. Burrow temperature values for upper and lower shore species may vary considerably. The highest burrow temperatures recorded for *S. crabricauda* on the upper shore at site N1 during June 1994, were 36°C and on the lower shore 34°C for the burrows of *M. depressus* at an air temperature of 40°C. In mangals of uniform sediment composition, zonation appears to be related to tidal exposure (MacIntosh, 1988), with temperature and salinity being causal factors. Species occupying the high shore positions are tolerant of higher temperatures (MacNae, 1968; MacIntosh, 1978), but when air temperatures become higher than the upper thresholds, crabs compensate by retreating into the burrows more frequently or remaining in the burrows for most of the day (MacIntosh , 1978). Similar behaviour was observed during current work with *N. dotilliformis* rarely seen during daylight, while *M. depressus* appeared after the tide on the lower shore.

Biota

Flora

The monospecific stand of *Avicennia marina* found in Qatar is indicative of mangal under stress (Lugo and Patterson-Zucca, 1977) as it is close to the latitudinal limits of the mangal (MacNae, 1968). When mangal are subjected to an increasing number of stressful conditions, tolerances are lowered and the recovery rate decreases (Lugo and Patterson-Zucca, 1977). The mangal response to stressful environmental conditions is a decrease in structural complexity demonstrated by lower species diversity, lower tree height and decreasing leaf size. During present survey most mangrove trees reached only 1-3 m height and rarely exceeded 4 m in height. Chapman (1984) suggested that low temperature, rather than salinity, is the main limiting factor. In South Australia frost appears to be responsible for the relatively short bushes (2.5-3.5 m) of *Avicennia marina* (Lear and Turner, 1977). Similarly, in the Arabian Gulf stunted individuals (1-3 m) of this species (Basson *et al.*, 1977) occur in the region where winter temperatures fall to nearly 0°C (Price *et al.*, 1987). Por *et al.* (1977) suggest that in Sinai salinity is probably the main factor restricting the number of mangrove species, as well as the plant and animal species normally associated with the mangal (Price *et al.*, 1987). As in Qatar it is unlikely that temperature is the limiting factor with winter temperatures are well above freezing, it is suggested that salinity is the main factor controlling growth and faunal size.

Most flora and fauna especially macrobenthic are mainly governed by the nature of substrate, amount of oxygen, soil salinity and water salinity. There is no fresh water in the tidal area in Qatar and rainfall is low throughout the year with high evaporation especially during summer. The salinity of the sea water in the east coast of Qatar is lower than that of the west coast and *Avicennia marina* planted in 1981 do not exceed 0.5 m in height, while those planted in the same year at (P1, P3, P5) on the east coast exceed 2 m in height. Suda and Al-Kuwari (1993) reported that the vegetation ground level was low on the west coast because tidal range is low compared with east coast. Hence at higher shore levels the shore does not receive daily inundation which increases the salinity of the soil. *Avicennia marina* can tolerate up 90‰ salinity in ground water (MacNae, 1968) but this corresponds to a lower salinity tidal water. Mangrove in the north-west of Australia dies out where seawater salinity is only 50‰ because salinities in the mud are substantially higher (Daves, 1970). Dying mangroves occur in tropical regions of strong evaporation (Galloway, 1982) and in such areas particularly high ground water salinities exist (MacNae, 1966; Spenceley, 1976).

Fauna

The major faunal groups found in the Arabian Gulf on intertidal flats and mangrove forest (Basson *et al.*, 1977; Clayton, 1986; Jones, 1986; Ismail and Ahmed, 1993; Apel, 1994) also occur in Qatar saltmarshes and mangals. Present work revealed 17 species of crustaceans, 19 molluscs, 7 annelids and some 30 fish species. Of the 17 crustacean species collected 13-14 species were found in natural mangrove sites (N1 & N2), and between 13-15 species were found in planted mangrove, while 14 species were found in the saltmarsh. Of the 19 molluscan species collected between 9-11 species occurred at natural mangrove (N1 & N3), and between 8-9 species were found in planted mangrove sites (P1 to P4), while only 5 species were found in the saltmarsh. The 7 polychaete species recorded in this study, is low as more than 39 species of polychaetes have been collected from the mud and sand flats of Saudi Arabia (see Ismail and Ahmed, 1993). This is probably related to the size of the area sampled, sampling technique and number of samples collected. However, of the 7 polychaete species collected 6 were found in natural mangrove (N1 & N3) and 4-6 species were found at planted mangrove sites (P1 to P4), while 5 species were found in saltmarsh (S). Crab species diversity at natural mangrove sites in Qatar was 8 - 10 species and at planted mangrove sites from 3-8 species, while on saltmarshes 8 species were found.

Crabs population abundance and distribution

Tab. 17 shows overall mean crab species abundance at natural mangrove, planted mangrove and saltmarsh sites. *Scopimera crabricauda* was present in the upper intertidal zone in sandy substrates. It was found with an overall abundance of 8 individuals 0.25 m^2 at all sites. Most crab species were absent from P5, except *S. crabricauda* and *M. messor* where high salinity restricts the biotic diversity and species distribution on the west coast. Vousden (1987) recognized the same situation on the west coast of Qatar on the muddy shore of Hawar island which is also characterized by an extremely restricted fauna of low diversity tolerating high salinities.

Nasima dotilliformis did not appear at planted mangrove sites and it was restricted to natural mangrove and salt marsh sites in the upper and mid-intertidal zone with an overall abundance of 4 individuals 0.25 m^2 at natural mangrove sites. The absence of *N. dotilliformis* from planted mangrove sites is due to the absence of suitable habitat in form of sediment type on the upper shore. The presence of the sand beach crab *Ocypode rotundata* confirms this. *Ilyoplax frater* was present at saltmarsh and natural mangrove sites with an overall mean abundance of 18 individuals 0.25 m^2 at the latter sites, but was absent from most planted mangrove sites with exception at site P3 where a similar type of sediment occurred. *Macrophthalmus depressus* occurred at all sites on the east coast on the lower shore with an overall mean of 5 individuals 0.25 m^2 and 4 individuals 0.25 m^2 at natural mangrove sites. *Eurycarcinus orientalis* and *Metaplax indica* were present with 1-2 individuals 0.25 m^2 at the most sites. *Serenella leachii* was absent from all natural mangrove sites and planted mangrove P3, P4, P5, and present only at sites P1, P2 in the south of Qatar and at the saltmarsh. This species prefers mud banks that are water-logged at low tide and sediment with a high proportion of sand. Although these habitats were present at most natural mangrove sites, this species did not occur.

Table 17: Over all mean abundance of crab species 0.25 m^2 at natural mangrove, planted mangrove and salt marsh sites.

Species	Natural mangrove	Planted mangrove	Salt marsh
Scopimera crabricauda	8	8	8
Nasima dotilliformis	4	0	7
Manningis arabicum	5	2	14
Ilyoplax frater	18	0*	P
Serenella leachii	0	P	P
Eurycarcinus orientalis	1	1	2
Macrophthalmus depressus	4	5	5
Metaplax indica	1	P	P

P: present; 0* : present only at P3

From Figs. 25-35 which show the overall abundance of the species at different levels it can be concluded that species show similar zonation at all sites and abundance which are dependent on sediment type and organic content. The upper intertidal contained few species with *S. crabricauda* recording the highest abundance at most sandy sites. The upper and mid intertidal species *N. dotilliformis* and *I. frater* at natural mangrove and saltmarsh sites require more consolidated muddy sediments. Therefore the absence of these species from planted mangrove is due to the lack of this habitat. *M. depressus* appears on the mid and lower intertidal at all sites around the east coast with a high abundance during summer. Apel (1994) also found *M. depressus* inhabiting mid and lower shores which contained few other ocypodid crabs, and related this to the difference in grain size and organic carbon content. He also found that *M. depressus* populations were clearly lower between October and January, but high abundant during June-July.

For most crab species between the upper and lower shore the trend of population abundance was to decrease during winter and increase during warmer periods. Most fauna are adapted to a seasonal life-cycle and this is especially true of less mobile organisms. They also show restricted growth periods often associated with the transition periods between winter and summer and *vice versa.* In contrast the swimming crab *Portunus pelagicus* is only found in the intertidal during the cooler winter months and migrates into the subtidal during summer (Vousden, 1987). The lowest Gulf tides occur during the day in winter and during the night in summer (Jones, 1986). This provides intertidal species with protection from direct exposure to extreme winter and summer temperatures.

Most intertidal crab species abundance at different sites increased during summer when temperatures increase. *I. frater* and *N. dotilliformis* do not show any such peak. One possible explanation is that these upper shore crabs stay active all year round whilst the low shore crabs become inactive in winter. The lower shore floods each day and the sea temperatures fall lower on average than air temperatures in winter in Qatar, in contrast the top shore is not inundated and remains warmer than the lower shore in winter. Vousden (1987) reported that *I. frater* with higher abundance (200 individuals m^{-2}) in February and that it was active in summer but restricted to burrows in the winter. Lower shore *M. indica* was only recorded in July and there was no evidence even of burrows in February. *Ocypode rotundata*, also displays seasonal behavior. The towers built by this species along the high tide mark, so evident in summer, are completely absent in winter. Snowden *et al.*, (1991) and Snowden and Clayton (1995) report a somewhat unexpected seasonality for *Ilyoplax stevensi* and *N. dotilliformis* from the upper eulittoral of mud flats in Kuwait. The time of greatest ecological activity, when there were higher proportions of ovigerous females, and when juveniles and migrating post-juveniles entered the population, occurs during winter, which is normally the ecologically- quiescent season in warm-temperature waters (Kinne, 1970; Raymont, 1983). In Qatar these species are reproductively active in spring.

The abundance of other common mangrove and saltmarsh taxa are shown in Tab. 18. The littorinids *Planaxis* and *L. glabrata* are found on the trunks of mangroves both natural and newly planted but are absent from saltmarshes where this habitat is missing. Other mobile species are distributed across all habitats with the exception of *Boleophthalmus boddarti* absent from planted mangroves. This species is an important member of the mangrove and mud flat fauna throughout the Indo-Pacific region (Clayton and Vaughan, 1988), and lives in the upper inter tidal zone burrowing into thick, organically enriched mud which is not yet found in recently planted mangroves.

Table 18: Over all mean abundance of gastropod 0.25 m^2 and mudskipper 10 m^{-2} at natural mangrove, planted mangrove and salt marsh sites.

Species	Natural mangrove	Planted mangrove	Salt Marsh
Planaxis sulcatus	18	22	P
Crerithidea cingulata	244	211	38
Trochus erythraeus	2	1	P
Littorina glabrata	12	5	0
Boleophthalmus boddarti	15	0	12

P: present

Cluster analysis based on the macrobenthic fauna recorded at different sites (Fig. 41) reveals that sites N1 and N3 are relatively richer in species than planted mangrove and saltmarsh sites. This is probably linked to lack of suitable habitat in form of sheltered mud and fine soil texture which reduces evaporation and provides a habitat for burrowers together with rich sources of food. Wave action and extremes of temperatures are considerably reduced on mangrove shores, but most planted mangrove areas still have a high percentage of coarse sands with too little organic matter to support mudliving macrobenthic fauna. At top shore levels the sand barely supports scavengers on the drift line and *O. rotundata*. This sand contains only a low percentage of silt in contrast to natural mangrove and saltmarsh sites where the sandy-muddy sediment at this level supports a richer fauna than that of planted mangrove sites. It is predicted that over time shelter provided by planted mangroves will encourage further sedimentation tending to modify the upper shore and eventually allow species colonisation.

However, although species diversity is higher on natural mangrove shores than on planted mangrove and salt marsh sites it is encouraging that there are many species already shared between all sites. This indicates that after only a relatively short time since planting (10 years) many typical Gulf mangrove species have colonised the new mangroves. The low overall species diversity for all study sites is similar to that recorded by Jones (1994) and Apel (1994) for central Gulf mangroves and saltmarshes, although well below the high diversity seen on mud flats below saltmarshes in Kuwait (Jones, 1986). Here high diversity is thought to be related to lower salinities produced by the Tigris and Euphrates (Jones, 1986). The absence of other key elements of the typical mangrove fauna such as crabs of the genus *Uca* from the central Gulf region is thought to be due to tidal patterns (Jones, 1987). Although quantitative data is as yet lacking, species diversity becomes richer in the southern mangroves of Oman (Vousden, 1989; Hywel-Daves, 1994). Comparison with previous studies conducted in the region, demonstrates that the mangal in Qatar is most similar to that of Saudi Arabia and Bahrain, whilst also expressing some similarity to the rest of the region (Tab. 19).

Table 19: Brachyuran species occurring in Qatar and mangal areas of previous records.

Species	Area of previous records
Ocypode rotundata	Arabian Gulf, Red Sea
Scopimera crabricauda	Arabian Gulf, Red Sea, East Africa
Serenella leachii	Arabian Gulf (Oman), Red Sea, East Africa
Eurycarcinus orientalis	Arabian Gulf, Red Sea, East Africa
Nasima dotilliformis	Arabian Gulf
Ilyoplax frater	Arabian Gulf
Macrophthalmus depressus	Arabian Gulf, Red Sea, East Africa
Macrophthalmus grandidieri	Arabian Gulf, East Africa
Metopograpsus messor	Arabian Gulf, Red Sea, East Africa
Ebalia sp.	Arabian Gulf, East Africa
Portunus pelagicus	Arabian Gulf, Red Sea, East Africa

The crab distribution patterns found in present work have been previously attributed with faunal preferences towards substrate particle size on aspect of faunal zonation which has been extensively documented (MacNae, 1968; Hartnoll, 1973; Sasekumar, 1974; Icely and Jones, 1978; MacIntosh, 1988).

Species common to all transects, always occurred at the same tidal level and any specific distribution on certain transects appears to correlate with the type of sediment, organic matter and degree of saturation of substrate. Exposure to air also appears to be influential as the majority of crab species and highest abundances occur under the shade of the mangal or on the lower shore.

Fishing

Results confirm the role played by mangroves in attracting a high diversity and abundance of fish species. Although further work is required to substantiate reasons why fish congregate in mangroves on the coast of Qatar, it is likely to be a combination of protection, predation and food source. Natural mangroves contained the highest diversity and abundance of species, but it is clear from present work that replanted mangroves attract more species than saltmarsh or open sand beach coastal areas (Tab. 20)

The nursery function of mangrove habitat and inshore water has been well-documented in the Indo-Pacific region and elsewhere in the world (Blaber and Blaber, 1980; Lenanton, 1982; Robertson and Duke, 1987, 1990; Blaber and Milton, 1990; Tzeng and Wang, 1992). It has been postulated that this habitat provides suitable food, shelter, absence of turbulence and reduction in predation. Present handnet fishing near the pneumatophores of *Avicennia marina* supports this as highest catches of juveniles were near pneumatophores which provide shelter for the juveniles allowing them to avoid predation. Most adult fish were caught in open mangrove lagoons by gill and seine nets. Only 2 species were caught by seine and 6 species by gill net on sandy beaches. This may be related to low primary production as sandy shore sediments contain low concentrations of nutrients, which reduce food availability for fish especially bottom feeders. Bottom feeders such as *Liza* sp were found abundantly in mangrove areas, which presumably provide richer feeding grounds for such species.

Table 21: Over all fish caught using hand net (0.7 cm mesh size) at different sites.

Site	Mean No. of fish caught	No. of species
Natural mangrove	19	10
Planted mangrove	12	8
Salt marsh	9	5
Sandy shore	7	7

CHAPTER 3

THE CREATION OF TWO NEW GENERA FOR CLEISTOSTOMA KUWAITENSE AND PARACLISTOSTOMA ARABICUM (JONES & CLAYTON, 1983), TOGETHER WITH DESCRIPTIONS OF THE FIRST ZOEA OF SIX BRACHYURANS FROM QATAR (ARABIAN GULF)

INTRODUCTION

TAXONOMY

Brachyuran crabs are common and widely distributed in the Arabian Gulf and adjacent waters. Comprehensive pioneer taxonomic studies on the brachyurans of the Arabian Gulf were reported by Stephensen (1945), Tirmizi (1980a, 1980b) Tirmizi and Kazmi (1979, 1984), Tirmizi and Ghany (1982, 1988), and Tirmizi *et al.* (1985). Titgen (1983) carried out a study on the coastal zone of Dubai (UAE) and was able to identify 68 species of decapods. These consisted of 1 species of penaeid shrimp, 14 species in 4 families of caridean shrimp, 1 scylarid lobster, 6 species of hermit crabs, 10 species of porcelain crabs and 36 species in 7 families of the brachyura. There were 3 new genera and 19 new species records for the Arabian Gulf, including 1 spider crab of the genus *Menaethiops* new to science.

In 1983 Jones and Clayton carried out a survey along the coast of Kuwait and they revealed a total of 17 species of tropical burrowing crabs belonging to Grapsidae and Ocypodidae including new species of *Cleistostoma* De Haan and *Paracleistostoma* de Man. Manning (1991) reported that neither of these belong in *Cleistostoma* De Haan,1833 or in *Paracleistostoma* de Man as restricted by Manning and Holthuis (1981 : 200). Both of these Gulf crabs key to the couplet containing *Paracleistostoma* and *Serenella* Manning and Holthuis, 1981 in the key to camptandriinid genera (Manning and Holthuis (1981:193-195) (Manning, 1991). However as *Paracleistostoma arabicum* and *Cleistostoma kuwaitense* have all somites of the male abdomen free this distinguishes them from members of both *Paracleistostoma* and *Serenella*, in which the third to fifth somites of the male abdomen are fused. Hence Manning (1991) suggested that *P. arabicum* and *C. kuwaitense* should each be refered to a new genus. In present work a new generic diagnosis is given for these species and a key constructed allowing the new genera to be separated from other members of the Camptandriinae.

LARVAL DESCRIPTIONS

Crab larvae, unlike many adults, can be difficult to identify to species. Even assigning larvae to families or to genera is sometimes a formidable task. The larval stages of many crab species are still unknown, and there is little information available as to morphological variability (Ingle, 1992). The life history of many crab species remains unknown because larval phases are usually quite dissimilar from those of the juvenile and adult forms that they represent, and there is a lack of information as to ontogenetic development. Ingle (1992) states that the principal approach to the solution of this problem is by hatching the eggs and rearing the larvae of known species through the complete development sequence. This method is currently favored because successful rearing from egg to post-larval form not only establishes the irrefutable identity of the material, but also at present is virtually the only means of studying the developmental larval biology.

During the first two decades of this century significant advances were made in the descriptive morphology of larvae. The first description of a brachyuran crab larvae was given by Linnaeus (1767) under the name *Cancer germanus*. The second was given by Slabber (1778) who described and figured two larvae under the name of *Monoculus taurus,* one of which may represent the first-stage zoea of *Carcinus meanas* (Linnaeus) (Cano, 1892b). Larval stages of many inshore species from the NE Atlantic have since been described through the pioneering studies of several investigators (WIlliamson, 1911, 1915; Lebour 1927, 1927a, 1928; Ingle, 1994).

Lebour (1927) described a method for hatching and rearing to spider crab species and in 1928 she described the zoea, megalopa and early crab stages of 25 crab species. Williamson (1992) states that the chracters used in identifying and classifying larvae are, of course, different from those used in identifying and classifying adults, and in some cases the larvae are easier than adults to identify and classify, where as in other cases it is the other way round. In general, however , the classifications indicated by crustacean larvae are quite reconcilable with those indicated by the adults.

In comparison to the NE Atlantic the larvae of brachyuran inhabiting the Arabian Gulf are very poorly documented. Although in the last three decades studies on zooplankton in the Arabian Gulf have been carried out by different authors (Frontier 1963a; Kimor 1973; Al-Attar and Ikenoue 1974; Yamazi 1974; Price 1979, 1982; Michel *et al.* 1986a, 1986b; Al-Aidaroos 1993; Al-Aidaroos and Apel 1994), very little information is available on the decapod larvae of the Gulf. The first detailed quantitative and qualitative study of decapod larvae in the Gulf was carried out by Al - Aidaroos (1992). He studied the decapod larvae in samples collected from the western coast of the Gulf during the spring season and found the following major groups: Penaeidae, Caridea, Anomura and Brachyura. Brachyuran larvae were identified to family level, and comprised the Majidae, Hymenosomatidae, Leucosiodae and Ocypodidae. Al-Aidaroos and Apel (1994) identified basic distribution patterns for decapod larvae, seasonal variations in the abundance and composition within Saudi Arabian Waters. Significant differences were observed in composition and abundance of decapod larvae between stations in bay system and off the open coast. A clear seasonality in the occurrence of decapod larvae was noticed , with a sharp decline in abundance in winter and an increase in March / April. This fluctuation coincides well with the water temperature curve.

As there has been no attempt to identify the larvae of Arabian Gulf brachyuran larvae beyond generic level present work describes the first zoea larval stage for six common intertidal brachyurans.

Materials and Methods

For generic diagnoses adult male and female *Paracleistostoma arabicum* were collected from the mangroves at Al-Dhakhira ,Qatar and *Cleistostoma kuwaitense* collected intertidaly by D. A. Jones from Doha, Kuwait. Specimens were preserved in 5% sea-water formalin and dissected as required.

Ovigerous females of six crabs, *Metopograpsus messor* (Forskal, 1775) (Family : Grapsidae); *Nasima dotilliformis* (Alcock, 1900), *Ilyoplax frater* (Kemp, 1919), *Serenella leachii* (Audouin, 1826) , *Manningis arabicum* (Jones & Clayton, 1983) (Family : Ocypodidae), and *Eurycarcinus orientalis* Milne Edwards, 1867 (Family : Xanthidae) were collected from planted and natural mangrove areas in Qatar. These ovigerous females were maintained in aquaria containing natural sea water of 37 - 39 ‰ salinity at 27 - 30° C until the eggs hatched. Newly hatched larvae were transferred to separate bowls at a salinity 37 - 39 ‰ and temperature of 27 - 30° C.

The first zoea of each species was preserved in 4% buffered formaldehyde and transferred to 70 % ethanol, before dissection under a binocular stereo - microscope. Carapace length (CL) of the zoea was measured from the base of the rostrum to the most posterior margin; rostro dorsal length (RDL) from the tip of the rostral spine to the tip of the dorsal spine; carapace width (CW) was measured as the greatest distance across the carapace. For *Eurycarcinus orientalis* and *Ilyoplax frater* , carapace width was measured as the distance between the tips of the lateral spines. Size measurements were taken for 10 - 13 specimens. Drawings of the entire larvae and dissected appendages were made using a stereo microscope and camera lucida.

Semipermanent mounts of whole larvae and dissected appendages were made using CMC 10 (Turtox Ltd.) and lignin pink (Rodriguez and Jones 1993). Adequate culture facilities were not available to allow progression of zoea beyond first zoea stage. However, 2 species *Serenella leachii* and *Metopograpsus messor* moulted from pre-zoea to first zoea stage without feeding.

RESULTS

TAXONOMY

Family Ocypodidae Rafinesque, 1815

Subfamily Camptandriinae Stimpson, 1858

Manningis, New genus

(Figures: see Jones and Clayton, 1983)

Type species: *Paracleistostoma arabicum* (Jones and Clayton, 1983 :190).

Included species: *Manningis arabicum* (Jones and Clayton, 1983). The genus is monotypic.

Diagnosis: A genus of the subfamily Camptandriinae (Stimpson, 1858) Manning and Holthuis (1981). Carapace broader than long, glabrous with slightly raised epigastric, protogastric and mesogastric lobes, distinct grooves present on either side of intestinal lobe. Antero - lateral margins convex and minutely granulated with 2 indistinct teeth, lateral margins continuing posteriorly as granulate ridges over part of the branchial region. Supra - orbital margins deeply inset and sinuous, sloping obliquely backwards. Front deflexed with antero - lateral angles acute and produced into lobes. Denticulate ridge running from outer end of infra - orbital border to base of antenna. Infra - orbital border bearing row of setae which increase in length covering the cornea towards the antero - lateral margin. Third maxilliped with merus as long as but wider than ischium, distal segments slender. Chelipeds showing sexual dimorphism, especially in adult males; pereiopods sparsely setose, meri without spines. Male abdomen gradually tapering towards terminal somite, completely covering gonopods and with all somites free in both sexes. First abdominal somite, although slightly wider than second, separated from coxae of fifth pereiopods by considerable distance. First gonopods strongly recurved with broad quadrate tip not overlapping base of shaft.

Remarks: As Manning (1991) observed, *Manningis*, originally diagnosed as *Paracleistostoma* (Jones and Clayton, 1983), keys out to the group containing

Paracleistostoma, *Serenella*, and *Telmatothrix* (Manning and Holthius, 1981), but is distinguished from these genera by the presence of free abdominal somites with no evidence of fusion. Free abdominal somites are also found in the genus *Nasima* (Manning, 1991), but in *Nasima* the chelipeds of males and females are similar whereas in *Manningis* they are sexually dimorphic. In addition the apex of the first gonopod crosses the shaft in *Nasima* but fails to reach it in *Manningis*. For further detail see specific description in Clayton and Jones (1983).

Etymology: The genus is named in honour of Dr. Raymond B. Manning of the Smithsonian Institution in recognition of his contribution to crustacean systematics in general, and specifically for his valuable observations on the reorganisation of the present genera within the Camptandriinae.

Leptochryseus, new genus

(Figures: see Jones and Clayton, 1983).

Type species *Cleistostoma kuwaitense* Jones and Clayton, 1983:185.

Included species: *Leptochryseus kuwaitense* (Jones and Clayton,1983). The genus is monotypic.

Diagnosis: A genus of the subfamily Camptandriinae (Stimpson, 1858) Manning and Holthuis (1981). Carapace quadrate, broader than long narrowing anteriorly with single external orbital tooth. Carapace smooth with shallow transverse mesogastic groove and scattering of short setae on branchial regions. Lateral, supra - and infra - orbital margins minutely granulate. Pterygostomial regions granulate with sulcus originating at edge of bucal cavity and running laterally and ventrally. Third maxilliped with merus longer than ischium, dactylus slender. Chelipeds of adults strongly sexually dimorphic. Pereiopods without ventral spines on meri, but outer surfaces of carpus and propodus of the legs 3 and 4 and carpus of leg 5 covered with thick mats of short setae. Abdomen of male tapering evenly towards terminal somite completely covering gonopods; first somite not wider than rest but reaching coxae of fifth pereiopods, all abdominal somites free in both sexes. First gonopods strongly recurved with quadrate tip overlapping shaft.

Remarks: Originally diagnosed as *Cleistostoma* (Jones and Clayton, 1983), but now excluded as all abdominal segments are free (Manning, 1991). *Leptochryseus* is also distinguished from *Manningis* and other related genera as the first abdominal somite reaches the coxae of fifth pereiopods, but is not wider than rest of abdominal somites (Manning and Holthuis, 1981). The presence of sexual dimorphic chelae separates *Leptochryseus* from *Nasima*, which has similar chelae in both sexes. Further specific description is given in Jones and Clayton (1983).

Etymology: This crab, still only known from the original collection site in Kuwait Bay, is a golden yellow colour hence *Lepto* (body) *chryseus* (golden) Greek, the gender is masculine.

Key to Genera of Camptandriinae

(Adapted from Manning and Holthuis, 1981)

1- Male abdomen constricted near fifth somite so that gonopods are partly visible when abdomen is pressed against thorax 2

Male abdomen gradually tapering towards terminal somite, completely covering gonopods, which are not visible when abdomen is pressed against thorax 6

2- Gonopod of male with 2 distinct appendages at the distal end 3

Gonopod of male tapering to narrow pointed apex, without appendages 4

3- Appendages at tip of male gonopod longer than distal recurved part of shaft. Carapace subhexagonal...*Camptandrium*

Appendages at tip of male gonopod short, at most half length of recurved part of shaft. Carapace transverse quadrangular ....*Paratylodiplax*

4- Anterolateral margin of carapace with teeth. Meri of ambulatory legs with distinct subdistal dorsal tooth. Male gonopod drawn out into slender, narrow tip ....*Calabarium*

Anterolateral margin of carapace entire. Meri of ambulatory legs without subdistal dorsal tooth. Male gonopod with tip either short and triangular or with subdistal lobe 5

5- Carapace only slightly wider than long, subhexagonal, without dorsal carina. legs slender, merus of third (= longest) leg more than 3 times as long as wide. Male gonopod with broad subapical lobe. Fifth abdominal somite of male only slightly constricted...*Ecphantor*

Carapace distinctly wider than long, transversely quadrangular, with distinct transverse ridge. Legs broad, merus of third leg about twice as long as wide. Male gonopod regularly narrowing to triangular tip, without subapical lobe. Fifth male abdominal somite strongly constricted in basal part..*Deiratonotus*

6- First somite of male abdomen reaching coxae of fifth pereiopods 7

First somite not reaching coxae of fifth pereiopods...8

7- First somite male abdomen much wider than other somites 9

First somite male abdomen no wider than other somites.......*Leptochryseus*, new genus

8- Merus of pereiopods with blunt spines on lower (flexor).................*Leiopocten*

Merus without ventral spines...10

9- Male gonopod ending in a pointed apex, which is not swollen. Chelipeds with strong sexual dimorphism...*Cleistostoma*

Male gonopod ending in blunt swollen apex. Male with chelipeds small, not different from those of females (dactylus of chelipeds without molar like tooth) ....*Ilyogynnis*

10- Carapace with anterolateral margins without teeth......................................11

Carapace with anterolateral margins of carapace with distinct or indistinct teeth 12

11- Chelipeds males and females similar and abdominal somites free ....*Nasima*

Chelipeds of males and females sexually dimorphic and male abdominal somites 3-5 fused...13

12- Male abdominal somites 2-4 fused...14

Male abdominal somites all free......................................*Manningis*, new genus

13- Male gonopods swollen distally, provided with 1 or more distal appendages, which are at least half as long as recurved part of shaft. Apex of gonopod usually lying well free from basal part of shaft. Carapace with greatest width before middle...*Paracleistostoma*

Male gonopods tapering to narrow, pointed or blunt apex, not widened distally and without distal appendages. Gonopods so strongly recurved that tip lies over basal part of shaft. Carapace with greatest width behind middle ....*Serenella*

14- Anterolateral margin of carapace with 2 teeth, of which posterior is very distinct, larger than anterior. Lateral margins of carapace converging posteriorly. Chelipeds showing strong sexual dimorphism. Propodi of second to fifth pereiopods longer than wide. Male gonopod not widened distally, distal margin deeply incised; morphological outer half of apex of gonopod slender and digitiforix............................*Telmatothrix*

Anterolateral margin of carpace with 2 low teeth, posteriormost less distinct than anterior. Lateral margins of carapace diverging posteriorly. Chelae of male small, of same shape and size as those of female. Propodi of second to fifth pereiopods hardly longer than wide. Male gonopod slightly widened distally, without an appendage, apex of gonopod not incised; morphological outer half of apex of gonopod a wide and blunt lobe, wider than long ....*Tylodiplax*

LARVAL DESCRIPTIONS

The measurement of first zoea and /or pre- zoea of each species is shown in Table 1.

Table 1 : mean size and standard deviation in mm of rostrodorsal length (RDL), carapace width (CW) and carapace length (CL) for pre-zoea and / or zoea of six brachyuran species raised in the laboratory at 27 - 30° C.

Species	Stage	RDL	CW	CL
S. leachii	Pre-zoea	-	0.32 ± 0.02	0.40 ± 0.01
S. leachii	Zoea	0.96 ± 0.04	0.65 ± 0.01	0.59 ± 0.02
M. messor	Pre-zoea	-	0.52 ± 0.02	0.42 ± 0.02
M. messor	Zoea	1.29 ± 0.06	0.40 ± 0.02	0.52 ± 0.03
E. orientalis	Zoea	0.96 ± 0.05	0.64 ± 0.02	0.63 ± 0.02
N. dotilliformis	Zoea	0.69 ± 0.02	0.46 ± 0.02	0.34 ± 0.02
M. arabicum.	Zoea	1.53 ± 0.08	0.26 ± 0.01	0.32 ± 0.01
I. frater	Zoea	0.53 ± 0.01	0.48 ± 0.02	0.36 ± 0.01

All larvae died without moulting to the second zoea. The major characters of five species pre and / or first zoea are as follows :

***Serenella leachii* (Audouin, 1826)**

Diagnosis: Pre-zoea.

Pigmentation: Translucent.

Carapace (Fig. 1A): Longer than wide (Table 1); without dorsal spine but with pointed rostral spine; oval sessile eyes.

Abdomen (Fig. 1B): 5 subequal somites, somites 2 and 3 with simple spines on lateral margins; segment 4 with postero lateral extensions reaching to posterior margin of segment 5; no pleopod buds.

Telson(Fig. 1B): Posterior margin with deep median cleft and 3 + 3 plumose setae; furcae without rows of spinules.

Antennule (Fig. 1C): Elongate, maximum width equal to half length, with 2 terminal aesthetascs and 1 simple seta.

Antenna (Fig. 1D): Tapered protopodite, with 2 rows of serrations; exopodite indistinct bearing single seta.

Maxillule (Fig. 1E): Endopod unsegmented with 4 terminal plumose setae; basal endite bilobed with 3 stout terminal plumo-denticulate cuspidate setae and 1 subterminal seta; coxal endite with 3 stout apical setae and 1 subterminal seta.

Maxilla (Fig. 1F): Endopod bilobed with 2 and 1 plumose setae on lobes; basal endite bilobed with 2 plumose setae on distal lobe and 2 setae on proximal lobe; coxal endite, distal lobe with 2 terminal setae and 1 subterminal seta, proximal lobe with 2 terminal setae; scaphognathite with 2 marginal plumose setae and 1 long distal plumose process.

Maxilliped 1 (Fig. 1G): Basis with 3 pairs of setae; 5 segmented endopod with 2,2, 1, 2, 3 plumose setae; exopod unsegmented with 4 terminal plumose setae.

Maxilliped 2 (Fig. 1H): Basis with 2 setae on lateral margin; endopod 3 - segmented , distal segment with 2 terminal setae and 2 subterminal setae, medial segment with 1 seta; exopod unsegmented with 4 terminal plumose setae.

Diagnosis : First Zoea

Pigmentation: Translucent.

Carapace (Fig. 2A): Width shorter than length (Table 1), smooth globose with short curved dorsal spine approximatelly twothirds length of rostral spine; Pair of curved lateral spines on each side of carapace (Fig. 2B); eyes sessile and rounded.

Abdomen (Fig. 2C): 5 somites, 4 subequal somites, second and third somite with 4 pair of dorso - lateral processes, fourth somite with simple spines; no pleopod buds.

Telson (Fig. 2C): Forked, each furca armed with very fine spinules, inner margin of telson provided with 3 +3 setose setae.

Antennule (Fig. 2D): Elongate, maximum width equal to half length, with 2 aesthetascs and 1 simple setae terminally.

Antenna (Fig. 2E): Tapered protopodite, with 2 rows of serrations; exopodite of equal length bearing distal rows of serrations and 2 mediolateral spinules.

Mandible (Fig. 2F): Palp rudimentary with 4 terminal setules and row of shorter marginal setae.

Maxillule (Fig. 2G): Endopod unsegmented with 4 terminal plumose setae; basal endite bilobed with 3 stout terminal plumo denticulate cuspid setae and 3 plumose setae; coxal endite with 3 stout apical setae and 1 subterminal seta.

Maxilla (Fig. 2H): Unsegmented endopod bilobed with 4 terminal plumose setae; basal endite bilobed with 2 and 4 plumose setae on distal and proximal lobes respectively; coxal endite with 3 terminal plumose setae and 1 subterminal seta; scaphognathite with 4 marginal plumose setae and a long distal plumose process.

Maxilliped 1 (Fig. 2I): Basis with 2, 2, 2 pairs of plumose setae; 5 segmented endopod with 2, 2 short, 1, 1 long and 4 plumose setae; exopod unsegmented bearing 3 terminal long plumose setae and 1 subterminal plumose seta.

Maxilliped 2 (Fig. 2J): Basis with 2 plumose setae; endopod 3 - segmented, distal segment with 3 terminal simple and 1 subterminal setae; exopod unsegmented with 3 terminal plumose setae and 1 subterminal seta.

Figure 1: *Serenella leachii*: pre-zoea A, lateral view; B, ventral view of abdomen; C, antennule; D, antenna; E, maxillule; F, maxilla; G, first maxilliped; H, second maxilliped. Scale lines represent 0.1mm.

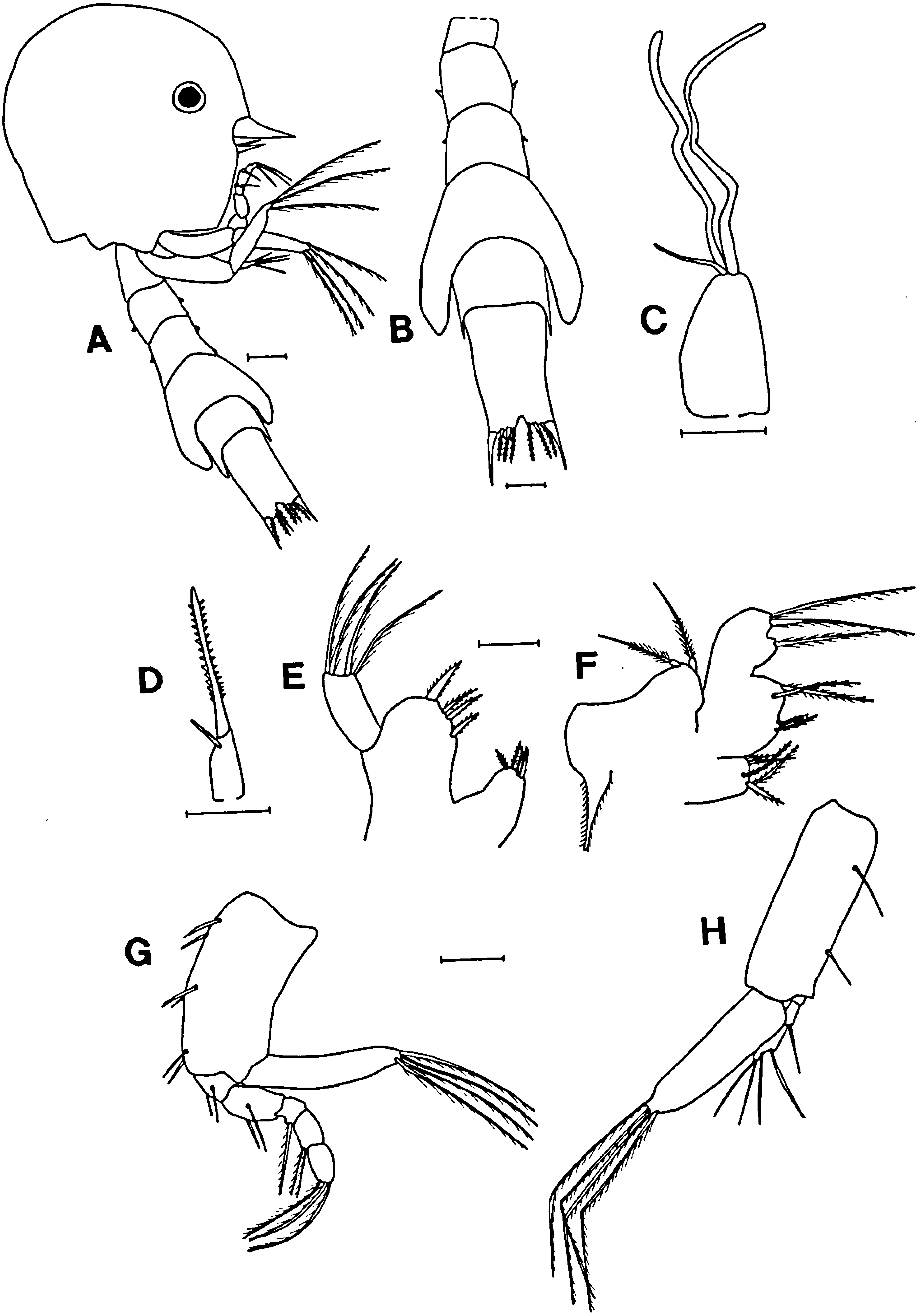

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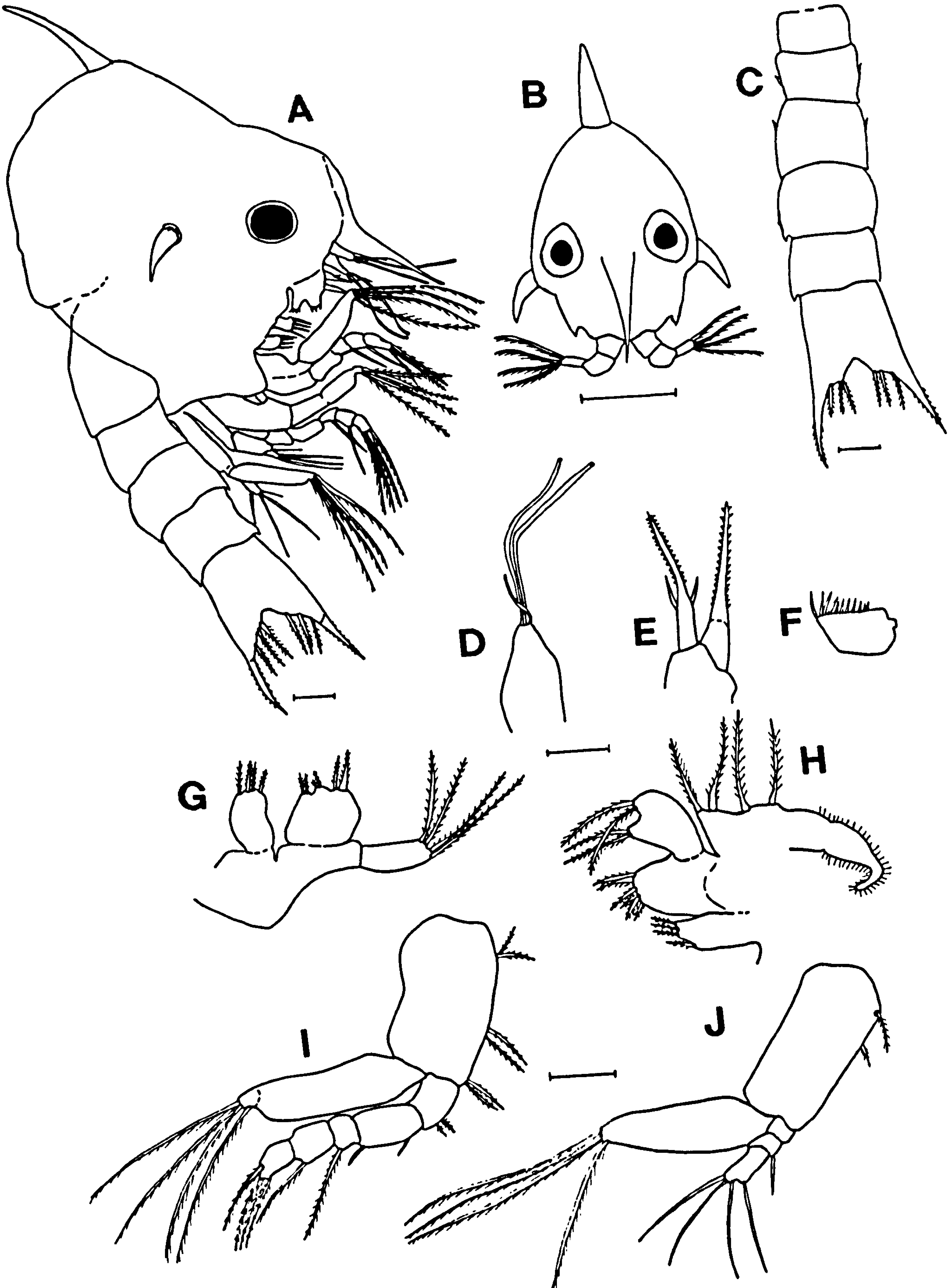
Figure 2: *Serenella leachii*: first zoea A, lateral view; B, frontal view of carapace; C, ventral view of abdomen; D, antennule; E, antenna; F, mandible; G, maxillule; H, maxilla; I, first maxilliped; J, second maxilliped. Scale lines represent 0.1mm.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Metopograpsus messor

Diagnosis: Pre-zoea

Pigmentation: Translucent.

Carapace (Fig. 3A): Wider than long (Table 1); without dorsal spine, but with very short rostral spine; oval sessile eyes.

Abdomen (Fig. 3B): 5 somites, third somite longest.

Telson (Fig. 3B): Posterior margin concave and bearing 3 + 3 telson setae, furcae with rows of fine spinules. The lateral margin with lobes.

Antennule (Fig. 3C): Unsegmented with 2 unequal small terminal aesthetascs and 1 small simple seta.

Antenna (Fig. 3D): Tapered protopodite with 2 rows of serrations.

Maxillule (Fig. 3E): Endopod unsegmented with 3 plumose terminal setae; basal endite bilobed, distal lobe with 1 spine, proximal lobe with 3 plumose setae; coxal endite, distal lobe with 1 seta, proximal lobe with 3 setae.

Maxilla (Fig. 3F): Endopod bilobed with 3 terminal plumose setae and 1 subterminal seta; basal endite bilobed with apical groups of 2 and 2 setae on distal and proximal lobes respectively, coxal endite with 2 groups of 2 and 2 plumose setae; scaphognathite with 3 marginal plumose setae and long distal process.

Maxilliped 1 (Fig. 3G): Basis with no setae; 5- segmented endopod with 4 terminal plumose setae on distal segment; exopod unsegmented with 3 terminal plumose setae.

Maxilliped 2 (Fig. 3H): Basis without setae; unsegmented endopod with 2 terminal and 1 subterminal setae; unsegmented exopod with 4 short terminal plumose setae.

Diagnosis: First Zoea

Pigmentation: Translucent.

Carapace (Fig. 4A): Shorter than long (Table 1), smooth globose with short dorsal spine approximately 2/3 longer than rostral spine; eyes rounded and sessile.

Abdomen (Fig. 4B): 5 somites, first 4 subequal with fifth somite broader than the rest with postero lateral margins lobed and overlapping the telson. Third somite with pair of dorso-lateral processes, fourth somite with postero-lateral processes; no pleopod buds.

Telson (Fig. 4B): Forked, each furca bearing very fine spinules, inner margin of telson provided with 3 + 3 setae.

Antennule (Fig. 4C): Elongate, maximum width equal to half length, with 2 long aesthetascs and 1 terminal simple seta of half length of aesthetascs.

Antenna (Fig. 4D): Tapered protopodite, with 2 rows of serrations.

Mandible (Fig. 4E): Palp rudimentary with unequal setules.

Maxillule (Fig. 4F): endopod with 4 terminal and 1 subterminal setae; basal endite bilobed with 3 stout terminal plumo denticulate cuspidate setae and 2 plumose setae; coxal endite with 3 stout apical setae 1 short seta and 1 subterminal seta.

Maxilla (Fig. 4G): Unsegmented endopod bilobed with 2 terminal plumose setae and 1 subterminal plumose seta; basal endite bilobed with 3 and 4 plumose setae on distal and proximal lobes respectively, coxal endite with 2 groups of 3, and 2, terminal plumose setae and 1 subterminal seta; scaphognathite with 4 marginal plumose setae and 1 long distal plumose process.

Maxilliped 1 (Fig. 4H): Basis with 2, 1, 2, 1 groups of lateral setae; 5 - segmented endopod with 1, 2 , 1, 2, 4 setae; 2 - segmented exopod, distal segment with 4 terminal long plumose setae and proximal segment with 1 subterminal seta.

Maxilliped 2 (Fig. 4I): Basis with 2, 2, 1 groups of lateral plumose setae; endopod 2 - segmented, distal segment with 4 setae and proximal segment with 1 seta; exopod unsegmented with 4 terminal plumose setae.

Figure 3: *Metopograpsus messor*: pre-zoea A, lateral view; B, ventral view of abdomen; C, antennule; D, antenna; E, maxillule; F, maxilla; G, first maxilliped; H, second maxilliped. Scale lines represent 0.1mm.

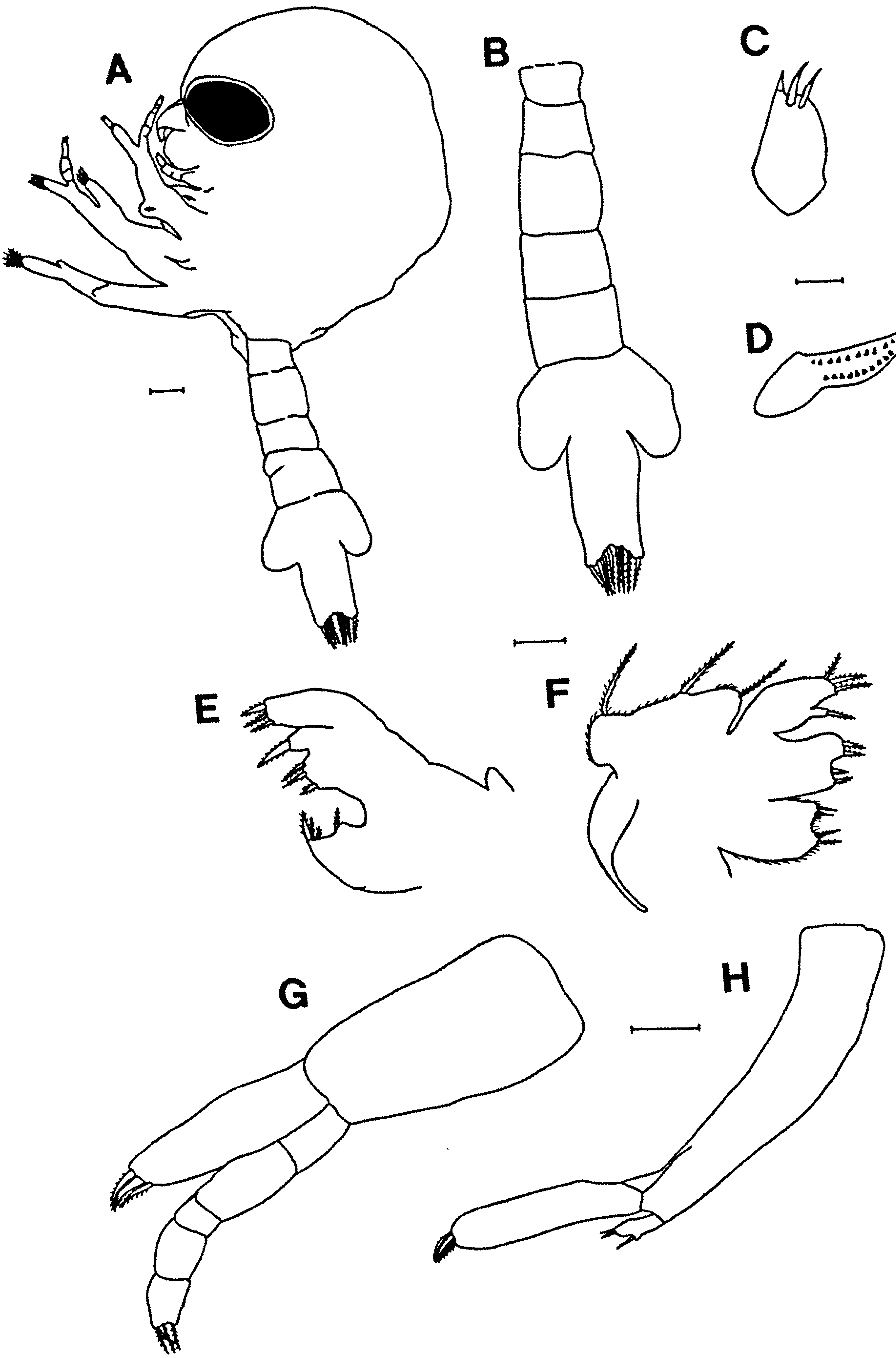
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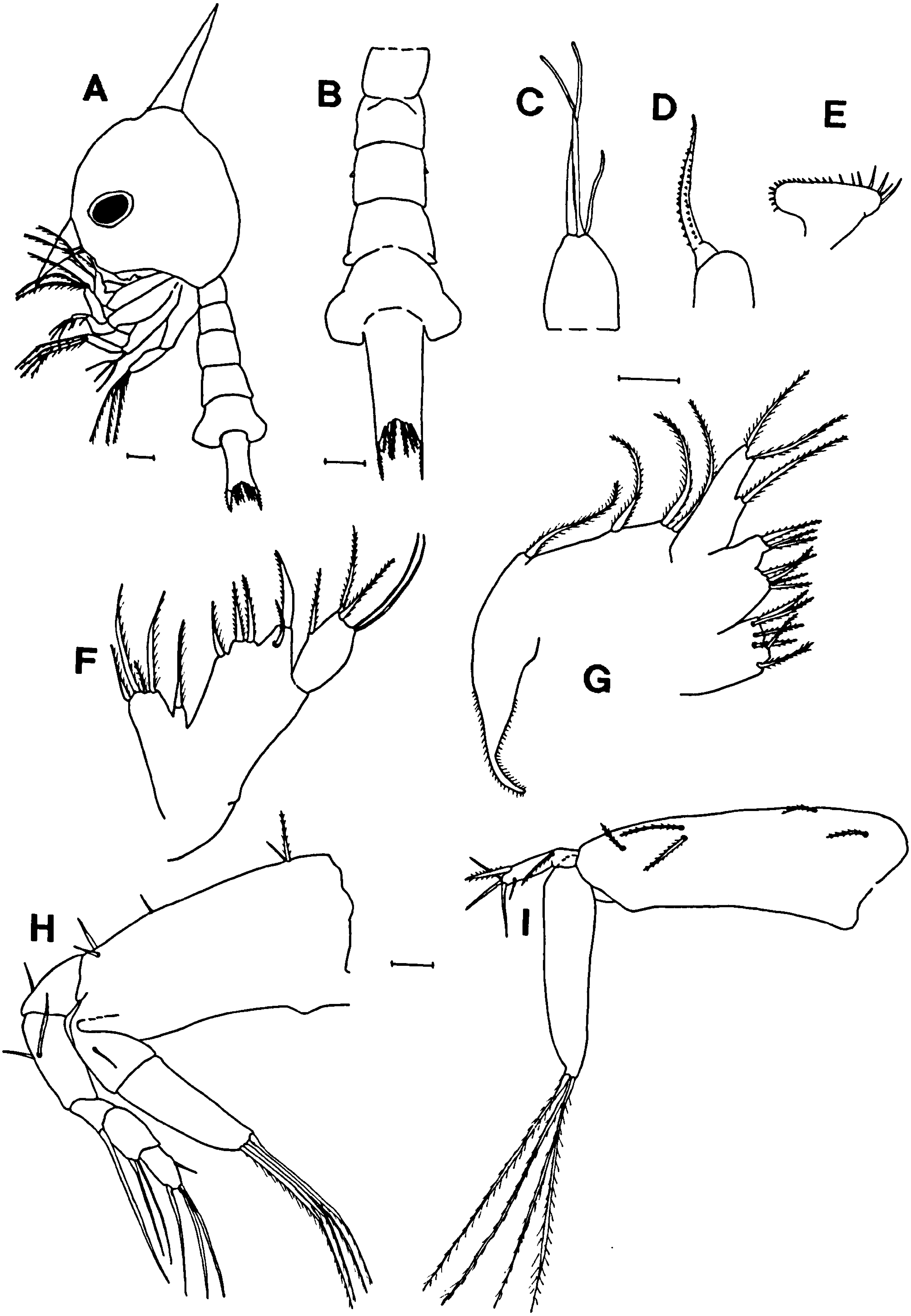
Figure 4: *Metopograpsus messor*: first zoea A, lateral view; B, ventral view of abdomen; C, antennule; D, antenna; E, mandible; F, maxillule; G, maxilla; H, first maxilliped; I, second maxilliped. Scale lines represent 0.1mm.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Eurycarcinus orientalis

Diagnosis: First zoea

Pigmentation: Translucent.

Carapace (Fig. 5A): Wider than long (Table 1); dorsal spine curved and approximately 3 times length of rostral spine, pair of small lateral carapace spines (Fig. 5B); eyes sessile and rounded.

Abdomen (Fig. 5C): 5 subequal somites and telson; second somite with a pair of dorse lateral processes; no pleopod buds.

Telson (Fig. 5D): Posterior margin with deep narrow cleft and 3 + 3 telson setae; furcae with rows of very fine spinules, and setose lateral spines.

Antennule (Fig. 5E): Elongate and conical maximum width equal to half length, with 3 aesthetascs and 1 simple terminal seta.

Antenna (Fig. 5F): Protopodite gradually tapers with 2 rows of serrations on distal half; exopodite 6/7 of total length of protópodite also with distal row of serrations.

Mandible (Fig. 5G): Palp rudimentary with setules.

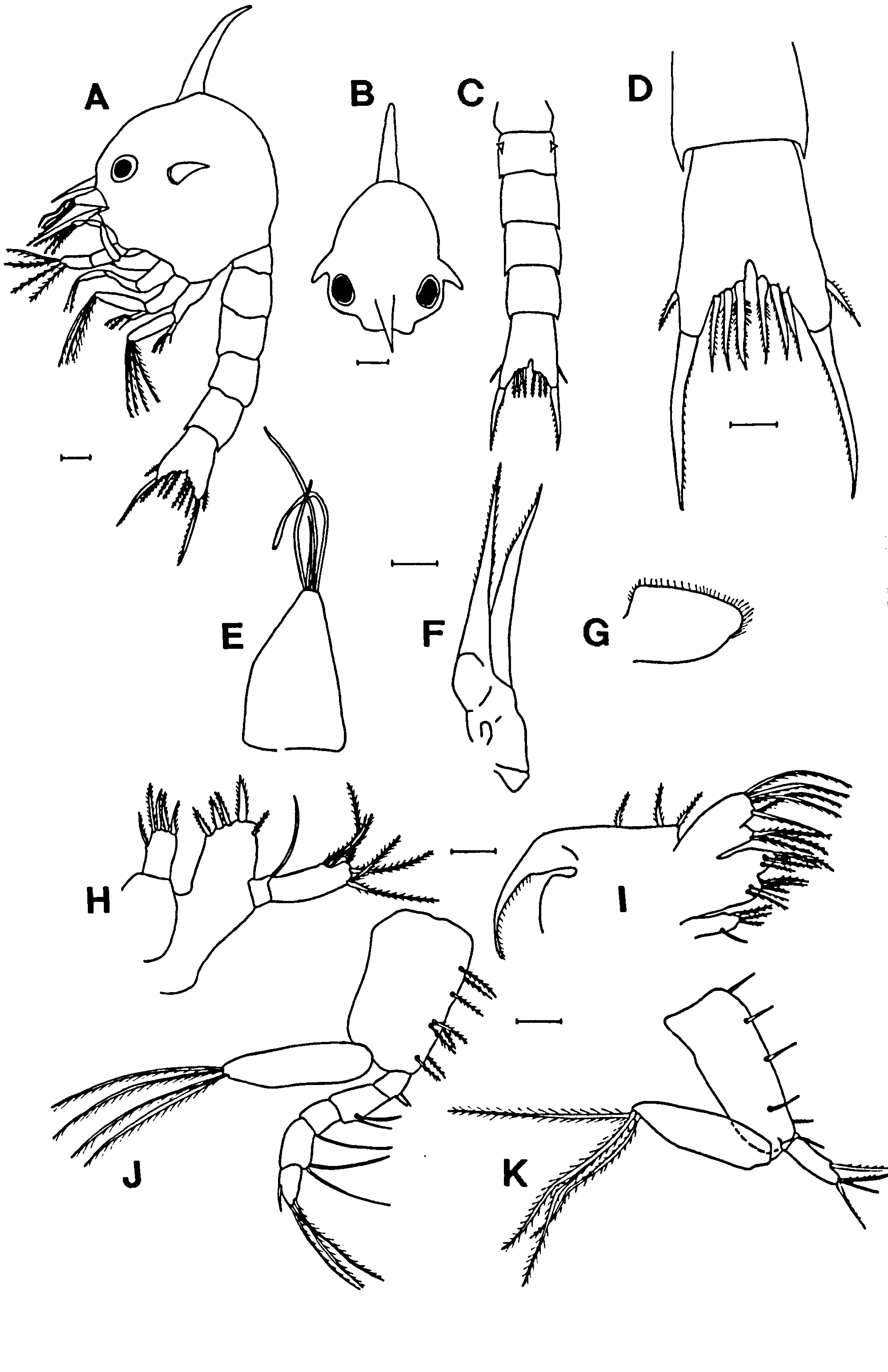
Maxillule (Fig. 5H): Endopod 2 - segmented, distal segment with 4 terminal plumose setae and 2 subterminal setae, proximal segment with 1 terminal seta; basal endite bilobed with 2 stout terminal plumo-denticulate cuspid setae and 3 plumose setae; coxal endite with 4 stout apical setae and 1 subterminal seta.

Maxilla (Fig. 5I): Endopod bilobed, distal lobe with 5 setae, proximal lobe with 3 setae; basal endite bilobed with apical groups of 4 and 5 plumose setae on distal and proximal lobes respectively, coxal endite with 3 terminal plumose setae and 1 lateral plumose seta; scaphognathite with 3 marginal plumose setae and a long distal plumose process.

Maxilliped 1 (Fig. 5J): Basis with 2, 1, 3, 2 groups of lateral plumose setae; 5 - segmented endopod with 2, 2, 1, 2, setae and terminal segment with 3 plumose setae and 1 simple seta; exopod unsegmented with 4 terminal plumose setae.

Maxilliped 2 (Fig. 5K): Basis with 5 setae; 2 - segmented endopod, distal segment with 3 terminal and 1 subterminal plumose setae, proximal segment with simple seta; exopod unsegmented with 4 long plumose setae distally.

Figure 5: *Eurycarcinus orientalis*: first zoea A, lateral view; B, frontal view of carapace; C, ventral view of abdomen; D, ventral view of telson; E, antennule; F, antenna; G, mandible; H, maxillule; I, maxilla; J, first maxilliped; K, second maxilliped. Scale lines represent 0.1mm.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Nasima dotilliformis

Diagnosis:First zoea

Pigmentation: Translucent.

Carapace (Fig. 6A): Wider than long (Table 1); dorsal spine slightly curved and approximately equal in length to rostral spine; eyes sessile and rounded.

Abdomen (Fig. 6B): 5 subequal somites, segment 2 with a pair of anteriorly directed lateral processes, segment 3 with a pair of posteriorly directed lateral processes and segment 4 broader than other segments; no pleopod buds.

Telson (Fig. 6B): Posterior margin with deep median cleft and 3 pairs of plumose setae; furcae without spinules.

Antennule (Fig. 6C): Elongate, maximum width equal to half length, with 2 terminal aesthetascs and 1 simple terminal seta.

Antenna (Fig. 6D): Tapered protopodite, with 2 rows of serrations; exopodite of equal length starting from the base of serrated region of protopodite and with 1 minute simple seta.

Maxillule (Fig. 6E): Endopod unsegmented with 3 terminal setae; basal endite bilobed with 3 stout terminal plumodenticulate cuspid setae and 2 plumose setae; coxal endite with 3 stout apical setae.

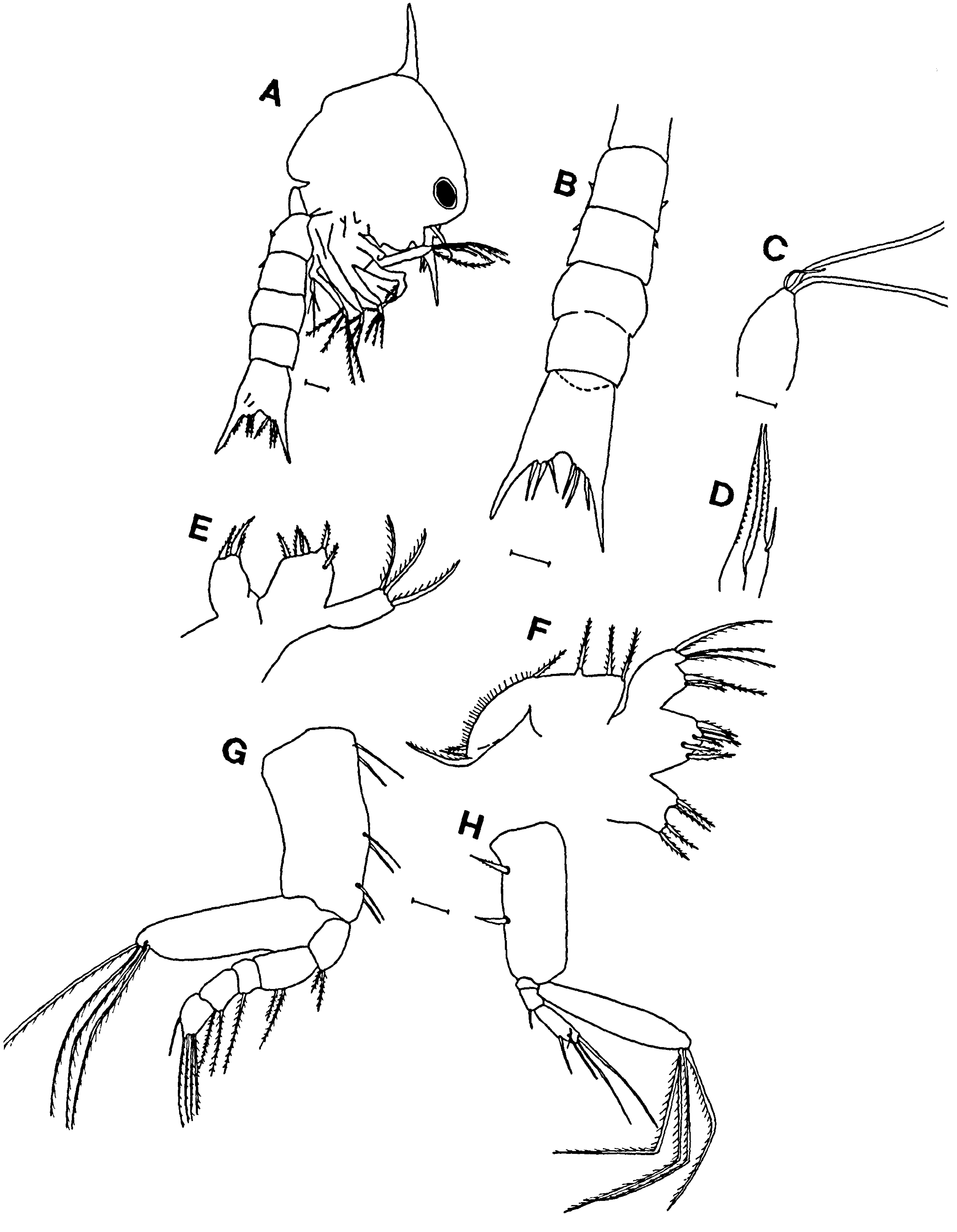
Maxilla (Fig. 6F): Endopod bilobed, distal lobe with 3 plumose setae, proximal lobe with 2 plumose setae; basal endite bilobed with apical groups of 3 and 3 plumose setae on distal and proximal lobes respectively, coxal endite with 2 groups of 2 + 2 plumose setae; scaphognathite with 4 marginal plumose setae, 1 long and 2 short distal plumose processes.

Maxilliped 1 (Fig. 6G): Basis with 2, 2, 2, groups of lateral setae; 5 - segmented endopod with 2,2,1,2,5 plumose setae; exopod unsegmented with 4 long plumose setae.

Maxilliped 2 (Fig. 6H): Basis with 1 and 1 lateral setae; 3 - segmented endopod, distal segment with 2 terminal setae and 3 subterminal setae, segment 2 with 1 seta and segment 3 without seta; exopod unsegmented with 4 long terminal plumose setae.

Figure 6: *Nasima dotilliformis*: first zoea A, lateral view; B, ventral view of abdomen; C, antennule; D, antenna; E, maxillule; F, maxilla; G, first maxilliped; H, second maxilliped.

Scale lines represent 0.1mm.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Manningis arabicum, new genus

Diagnosis: First zoea

Pigmentation: Translucent.

Carapace (Fig. 7A): Longer than wide (Table 1); dorsal spine curved and approximately twice length of rostral spine; eyes rounded and sessile.

Abdomen (Fig. 7B): 5 subequal somites and telson; no pleopod buds.

Telson (Fig. 7B): Forked, each furca with rows of very fine spinules; inner margin of telson provided with 3 pairs of plumose setae.

Antennule (Fig. 7C): Elongate, maximum width equal to half length, with 2 terminal aesthetascs and 1 simple seta.

Antenna (Fig. 7D): Protopodite gradually tapering and bearing small sharp serrations; exopodite bearing spine on distal tip of protopodite twothirds length protopodite.

Maxillule (Fig. 7E): Endopod 2 segmented, distal segment with 4 terminal plumose setae and 1 subterminal seta, proximal segment with 1 terminal seta; basal endite bilobed with 3 stout terminal plumodenticulate cuspid setae and 2 plumose setae; coxal endite with 4 stout apical setae and 1 subterminal seta.

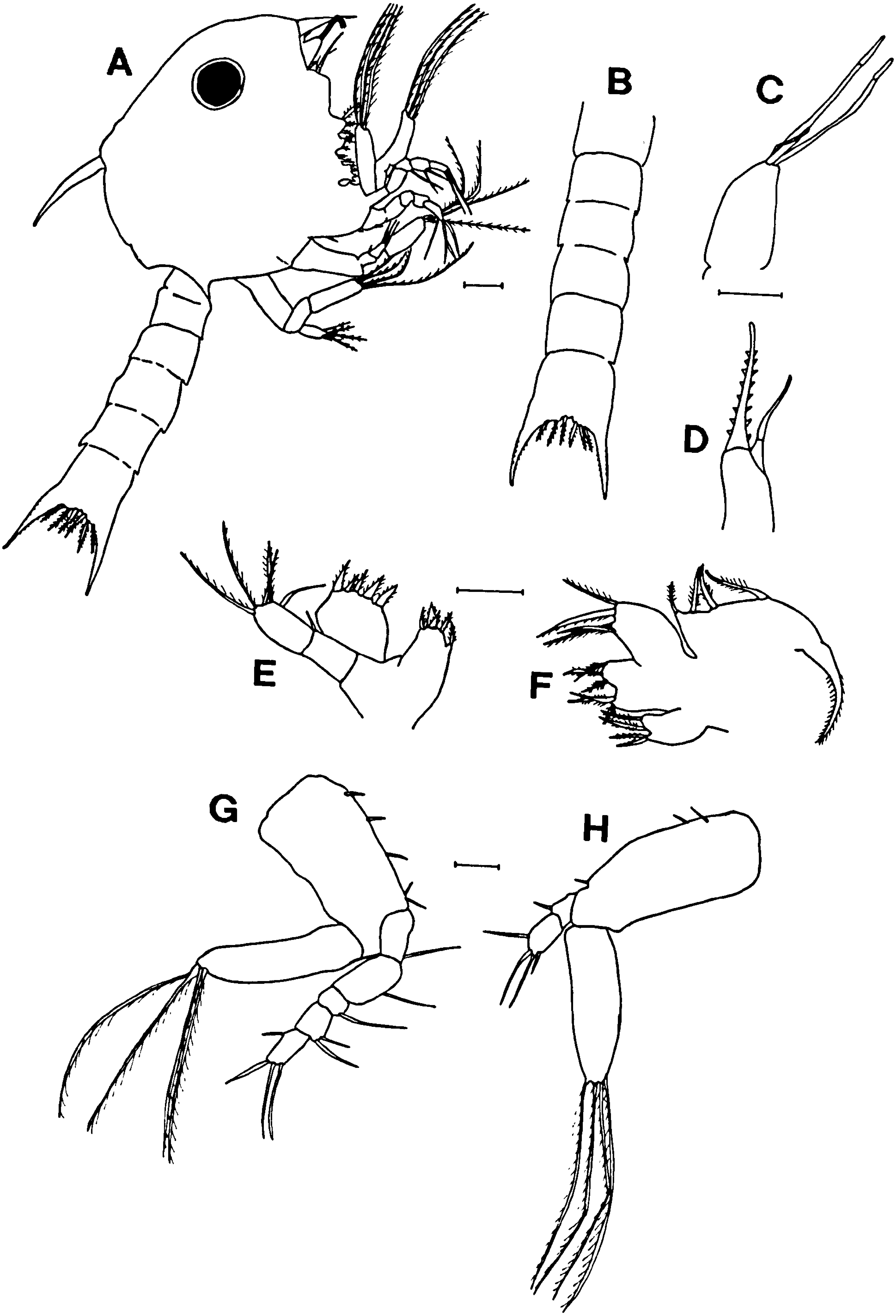
Maxilla (Fig. 7F): Endopod bilobed with 2 terminal plumose setae on each lobe; basal endite bilobed with 3 setae on proximal and 3 setae on distal lobes; coxal endite with 2 terminal plumose setae on each lobe; Scaphognathite with 4 marginal plumose setae and a long distal plumose process.

Maxilliped 1 (Fig. 7G): Basis with 4 groups of 1, 1, 1, 2 setae; 5 - segmented endopod with 1, 1, 1. 2 setae, distal segment with 3 terminal setae and 1 subterminal seta; exopod unsegmented with 4 terminal plumose setae.

Maxilliped 2 (Fig. 7H): Basis with 2, 1, setae; endopod 2 - segmented, distal segment with 4 setae and proximal segment with 1 seta; exopod unsegmented, bearing 4 long terminal plumose setae.

Figure 7: *Manningis arabicum*: first zoea A, lateral view; B, ventral view of abdomen; C, antennule; D, antenna; E, maxillule; F, maxilla; G, first maxilliped; H, second maxilliped.

Scale lines represent 0.1mm.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Ilyoplax frater

Diagnosis: First zoea

Pigmentation: Translucent.

Carapace (Fig. 8A): Wider than long (Table 1); dorsal spine longer than length carapace, rostral spine approximately twothirds length of dorsal spine; pair of lateral spines (Fig. 8B) on each side of carapace; eyes rounded and sessile.

Abdomen (Fig. 8C): 5 subequal somites, second and third somites with pair of posteriorly directed dorsal lateral processes; no pleopod buds.

Telson (Fig. 8C): Elongate with posterior margin with deep median cleft and 3 + 3 plumose setae; long furcae without rows of spinules.

Antennule (Fig. 8D): Elongate, maximum width equal to 3 times total length, with 2 terminal aesthetascs and 1 simple seta.

Antenna (Fig. 8E): Protopodite elongate gradually tapering, with 2 rows of serrations; exopodite approximately 1/2 of total length of protopodite and without any setae.

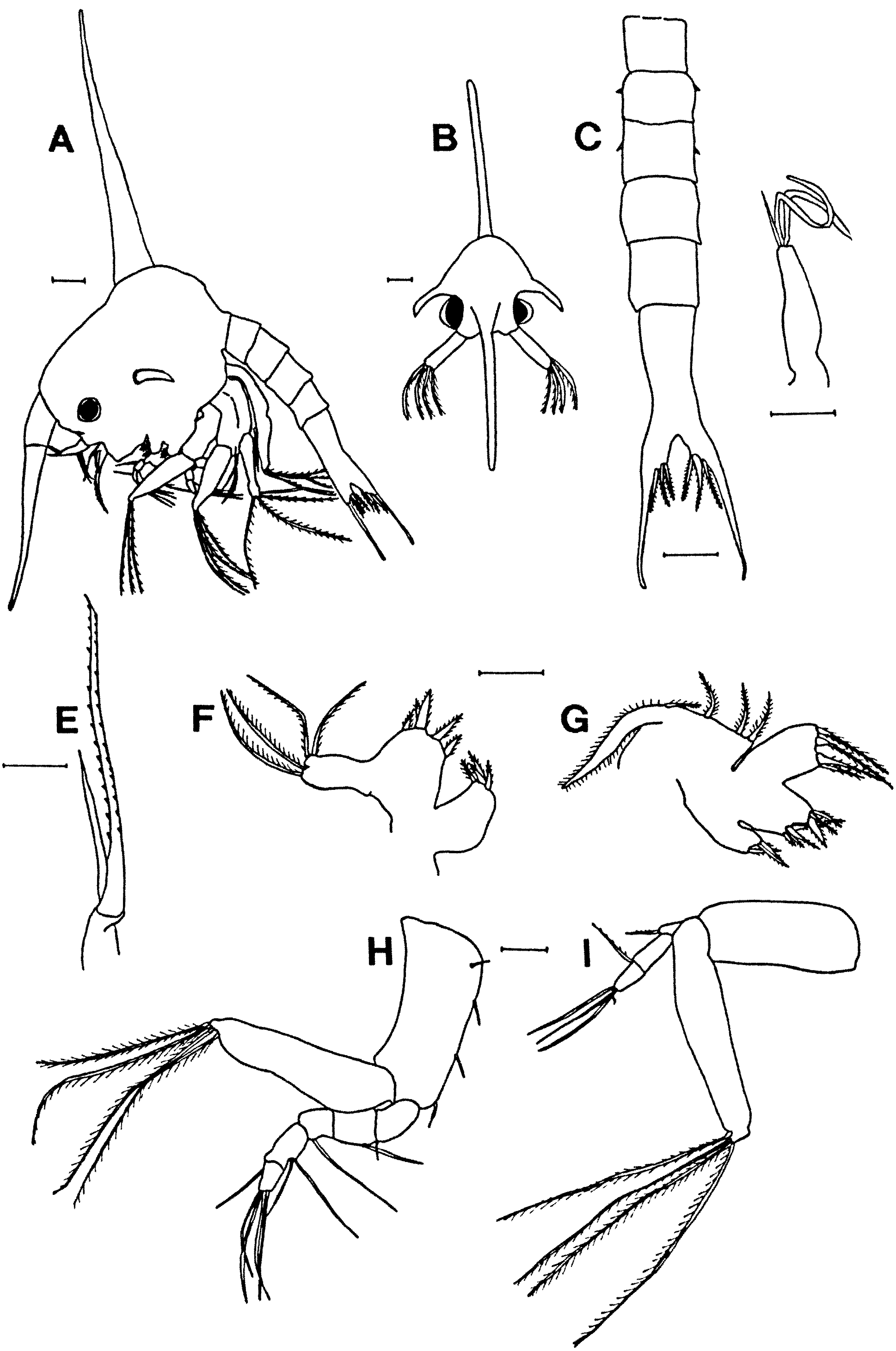
Maxillule (Fig. 8F): Endopod unsegmented with pairs of terminal plumose setae on each lobe; basal endite with 5 stout terminal plumodenticulate cuspid setae; coxal endite with 2 stout apical setae on each lobe.

Maxilla (Fig. 8G): Endopod bilobed with pairs of plumose setae on each lobe; basal endite bilobed with apical groups of 3 and 4 setae on distal and proximal lobes; coxal endite with pairs of stout apical setae; scaphognathite with 4 marginal plumose seta, and a long distal plumose process.

Maxilliped 1 (Fig. 8H): Basis with 1, 1, 1, 1 setae; 5 - segmented endopod, segments 1, 2, 3, with 1 seta each, segment 4 with 2 subterminal setae and distal segment with 4 terminal setae and 1 subterminal seta. Exopod with 4 long terminal setae.

Maxilliped 2 (Fig. 8I): Basis without setae; 3 - segmented endopod, distal segment with 3 long setae and 1 minute seta, other segments with 1 seta on each; exopod unsegmented with 4 terminal plumose setae.

Fig. 8. *Ilyoplax frater*: first zoea A, lateral view; B, frontal view of carapace; C, ventral view of abdomen; D, antennule; E, antenna; F, maxillule; G, maxilla; H, first maxilliped; I, second maxilliped. Scale lines represent 0.1mm.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DISCUSSION

The developmental characteristics of the first zoea of the six species collected from the coast of Qatar are summarised in Table 2. Specific differences between these zoeae are evident in the following characters: setation of the endopod and coxal endite of the maxillule; setation of the basis and endopod of the first and second maxilliped, shape of telson and presence of lateral processes of the abdomen. Although these zoea originate from the Xanthidae, Grapsidae and Ocypodidae there does not appear to be any distinct larval character allowing family separation. The only other common intertidal Gulf crab for which larval descriptions are available is *Macrophthalmus depressus* (see Pasupathi and Kannupandi, 1988). The first zoea of this species may be distinguished from the above species by the presence of postero-latero-marginal teeth on the carapace and the number of setae on the coxal and basal endites of the maxillule.

Table 2 : Distinguishing characteristics of the first zoeae of six crab species.

Character	*M. messor*	*E. orientalis*	*S. leachii*	*N. dotilliformis*	*M. arabicum*	*I. frater*
Antennule						
Aesthetascs + seta	2+1	3+1	2+1	2+1	2+1	2+1
Maxillule						
Setation of endopd	4,1	4,2,1	2,2	3	5,1	2,2
Setation of basal endite	3,2	2,3	3,3	3,2	2,3	3,2
setation of coxal endite	4,1	4,1	3,1	3	4,1	2,2
Maxilla						
Setation of endopd	2,1	5,3	2,2	3,2	2,2	2,2
Setation of basal endite	3,4	4,5	2,4	3,3	3,3	3,4
setation of coxal endite	3,2,1	3,1	3,1	2,2	2,2	2,2
Scaphognathite	4,1	3,1	4,1	4,1,2	4,1	4,1
Maxilliped 1						
Setation of basis	2,1,2,1	2,1,3,1	2,2,2	2,2,2	1,1,1,2	1,1,1,1
Setation of endopod	1,2,1,2,4	2,2,1,2,4	2,2,1,1,4	2,2,1,2,5	1,1,1,2,4	1,1,1,2,5
Setation of exopod	4,1	4	4	4	4	4
Maxilliped 2						
Setation of basis	2,2,1	5	2	1,1	2,1	no seta
Setation of endopod	4,1	4,1	0,3,1	5,1,0	4,1	4,1,1
Setation of exopod	4	4	4	4	4	4
Abdomen						
Segments with lateral processes	3rd & 4th segments	2nd segment	2nd & 3rd segments	3rd segment	absent	2nd & 3rd segments

CHAPTER 4

BIOLOGY AND POPULATION DYNAMICS OF MANGROVE AND SALTMARSH CRABS COLLECTED FROM QATAR.

INTRODUCTION

The available information on population biology and ecology for crab species in the Arabian Gulf is rare and there are no previous studies on the coast of Qatar. In Kuwait , Jones and Clayton (1983) and Collins *et al* (1984) described aspects of the distribution, zonation and feeding for *Nasima dotilliformis* (*Cleistostoma dotilliforme*, Jones & Clayton, 1983), *Leptochryseus kuwaitense* (*Cleistostoma kuwaitense* Jones & Clayton, 1983), *Manningis arabicum* (*Paracleistostoma arabicum* Jones & Clayton, 1983) and *Uca sindensis*. Clayton (1988) examined social spacing in *Leptochryseus kuwaitense*. Snowden *et al* (1991) described the population biology of *Ilyoplax stevensi* and the same authors, (1994) described the ecology of *Tylodiplax indica*. More recently, Snowden and Clayton (1995) studied aspects of the life history and seasonal ecology of *Nasima dotilliformis* on Kuwait mud flats. In Saudi Arabia , Apel (1994) produced an identification key for intertidal Brachyura and described natural fluctuations and seasonal variations of populations for crab species on the east coast of Saudi Arabia.

The objective of present work is to study the biological characteristics of 5 crab species inhabiting salt marsh and mangrove habitats in Qatar. From a monthly field sampling programme over the period June 1993 - June 1994 carapace width - weight relationship, size frequency, sex-ratio, and breeding biology of common intertidal species has been examined. Studies on the reproductive cycles of each species are based on the incidence of ovigerous (berried) females in the population. The 5 species of crabs included in this study are from 3 different families, the Ocypodidae included in this work are *Nasima dotilliformis, Serenella leachii,* and *Macrophthalmus depressus*. For the family Grapsidae only 1 species is represented by *Metopograpsus messor*, and *Eurycarcinus orientalis* is from the Xanthidae. Although all the species chosen are usually found together in the same soft substrate habitats associated with salt marsh and mangrove, they demonstrate different feeding habits ranging from sediment deposit (Ocypodidae) to omnivorous opportunistic (Grapsidae) and carnivorous (Xanthidae).

As this investigation is the first one of its kind in Qatar, it is hoped that study on the biology and population dynamics of these species will provide information on their recruitment to the salt marsh and mangrove habitats in Qatar.

MATERIALS AND METHODS

Sampling of 5 species of intertidal crabs was conducted from June 1993 - June 1994. The intertidal burrowing crabs *N. dotilliformis, S. leachii, E. orientalis* and *M. depressus* were collected by digging from their burrows. *M. messor* was collected from the undersurface and crevices of large boulders. The crabs were brought to the laboratory alive for examination. The sample of each species was separated into sexes on the basis of the size and shape of abdomen. All crabs were measured individually for carapace width (CW) to the nearest 0.1 cm and weighed to the nearest 0.001g. Carapace width and wet weight, were recorded to establish the biometric relationship between CW vs. Wt, for both sexes in each species. In all cases the abdomen of the females was lifted and examined to determine ovigerous females.

All procedures followed in the course of field and laboratory activities were standardised and performed by the same person using the same instruments, as a precaution to prevent and avoid bias which might affect the results.

To examine the size composition, the CW data of monthly samples were grouped into size classes of 0.5 cm intervals for *M. messor, E. orientalis* and *M. depressus*, while 0.4 cm intervals for *N. dotilliformis* and *S. leachii*, in order to obtain as many size groups with clear modes as possible. Thus, size frequency distributions were obtained for each sex for each species. Size at maturity and breeding season for females of the 5 crab species were determined by incidence of total females and ovigerous females in different size-classes and monthly samples.

The sex ratio of each species was obtained for size-classes and monthly samples. To achieve this , the CW data was sorted into discrete size classes. Chi-square (χ^2) test was used in order to determine the statistical significance where crabs deviated from a population having 1 : 1 sex ratio. All χ^2 values were tested at $df = 1$, $P < 0.05$ using the statistical table (critical values of the χ^2 distribution (Zar, 1984).

Carapace width - weight relationships were calculated for each species. The simple exponential (= power function) non - linear regression modal $y = a\ x^b$

was used to describe the relationship between the dependent variable (y) which is normal weight and its derivatives, and the independent variable (x), the crab width. This regression modal becomes linear when the attributes in the equation are log - transformed and can be re - expressed as:

$$\text{Log } W = a + b \log CW$$

Where log is the logarithm to the base 10; (W) is the weight in g, (CW) the carapace width, (a) is the intercept, and (b) is regression slope. The linear equation was fitted separately for males, females and total samples of each species. The correlation co-efficient and standard error of 'b' were calculated following standard statistical procedures.

RESULTS

Detailed analysis reveals that the weight of the 5 species inhabiting the intertidal zone of the Qatar coast varies in both sexes of each species to some extent from one season to another.

Metopograpsus messor

Carapace width-weight relationship

The logarithmic relationships between carapace width - weight of males, females and total sample (males and females) for this species are as follows:

Male	log W = 2.8281 log CW - 0.3214
Female	log W = 2.6443 log CW - 0.3066
Total (male and female)	log W = 2.7921 log CW - 0.3245

The relationship between carapace width and weight is graphically represented in Fig. 1.

The males of *M. messor* were found to be heavier than females throughout the year (Fig. 2). The regression equation obtained for both sexes in all seasons shows that the weight is in favour of males with increasing size range. For a given width, e.g., 2 cm CW males weight in winter is the highest weight observed (3.57 g) decreasing to 3.36 g during spring (-5.9%) with a further decline to 3.04 g during summer (14.8), and an increase upto 3.41 g during winter (4.5%). For the female crabs, the weight decreased from 3.25 g in winter down to 3.08 g during spring (-5.2%), with a further decrease to 2.90 g during summer (-10.8%), and increase to 3.06 g during the autumn (5.2%). In winter the weight was 5.9% more than the weight observed in autumn (Tab. 1).

Table 1: Non-linear regression equations for the carapace width - weight relationships for males and females of *M. messor*, by season, from June '93 - June '94. Weight for a given size.

Season	Male		Female	
	Equation	Wt.g for crab with CW 2 cm	Equation	Wt.g for crab with CW 2 cm
Winter	$W = 0.505\ CW^{2.823}$	3.57	$W = 0.509\ CW^{2.677}$	3.25
Spring	$W = 0.479\ CW^{2.809}$	3.36	$W = 0.541\ CW^{2.511}$	3.08
Summer	$W = 0.3.99\ CW^{2.927}$	3.04	$W = 0.443\ CW^{2.709}$	2.90
Autumn	$W = 0.457\ CW^{2.899}$	3.41	$W = 0.482\ CW^{2.666}$	·3.06

Comparison of the weight loss with mean temperature of cold and warm seasons, (12° C and 28.9° C for winter and summer, respectively), shows variation according to size of crab (Tab. 2). This Table shows that in summer males with 2 cm CW and 3 cm CW lost 14.8% and 11.2%, respectively, of the weight observed during winter.

Table 2: Seasonal changes in mean weight for males and females of *M. messor* during winter and summer for the data collected between Jun. '93 - Jun. '94.

		Male		Female	
Season	Mean temp. °C	2 cm	3 cm	2 cm	3 cm
Winter	12.8	3.57	11.23	3.25	9.63
Summer	28.9	3.04	9.97	2.90	8.69

Carapace width-weight ratio

Weight - width ratios of the overall sample of 13 months data for males and females (n=494, n=306, respectively, for CW ranged from 0.5 - 3.5 cm), show that for most size males mean weights were heavier than those obtained for females. The differences in weight for both sexes in the range of size classes from 0.5 - 1.5 cm, gradually increased in the classes > 1.5 cm. The same pattern was found in the mean width, with the exception of size classes 0.5 - 1.0, 1.0 - 1.5, and 1.5 - 2.0 cm.

which favoured females. The weight - width ratios of males were higher specially in all larger size classes, and the ratio increased as size increased (Tab. 3).

Table 3: Carapace width - weight for male and female *M. messor* collected from the coast of Qatar (Jun. '93 - Jun. '94).

Carapace width (cm)	Male				Female			
	No. of Crab	Mean width (cm)	Mean weight (g)	Weight / width %	Weight / width %	Mean width (cm)	Mean weight (g)	No. of Crab
0.5 - 1.0	60	0.82±0.1	0.30±0.1	36.59	39.2	0.97	0.38	1
1.0 - 1.5	140	1.24±0.1	0.93±0.3	75.0	85.2	1.35±0.1	1.15±0.3	33
1.5 - 2.0	148	1.75±0.1	2.38±0.6	136.0	127.8	1.76±0.2	2.25±0.5	117
2.0 - 2.5	128	2.23±0.1	4.61±0.97	206.7	182.8	2.21±0.1	4.04±0.8	111
2.5 - 3.0	127	2.75±0.1	8.44±1.5	306.9	236.7	2.67±0.1	6.32±1.5	42
3.0 - 3.5	39	3.17±0.1	12.32±2.5	388.0	344.07	3.14±0.1	10.8±0.5	2

Sex ratio

It can be seen from Tab. 4 that there were significantly more males in all size - classes, except for 1.5 - 2.5 cm. The monthly sex-ratios significantly differ at the 5% level during June - July '93, November '93 and January '94 to June '94. Highest values of significance were in April '94 (Tab. 5).

Table 4: Sex ratio of *M. messor* for different carapace width-size class.

Size - class	No. of Male	No. of female	Total	% of Male	% of Female	Chi-square
(0.5 -1.0)	60	1	61	98.4	1.6	57.1*
(1.0 -1.5)	140	33	173	80.9	19.1	66.2*
(1.5 -2.0)	148	117	265	55.9	44.2	3.6
(2.0 -2.5)	128	111	239	53.6	46.4	1.2
(2.5 - 3.0)	126	43	169	74.6	25.4	40.8*
(3.0 - 3.5)	39	2	41	95.1	4.8	33.4*

* denotes a significant difference from 1 : 1 ratio ($df = 1$, $P<0.05$).

Table 5: Sex ratio of *M. messor* for different months.

Month	No. of male	No. of female	Total	% of male	% of female	Chi-Square
Jun-93	26	6	32	81.3	18.8	12.5*
Jul.	37	14	51	72.6	27.5	10.4*
Aug.	23	19	42	54.8	45.2	0.38
Sep.	17	10	27	62.9	37.0	1.81
Oct.	41	27	68	60.3	39.7	2.88
Nov.	30	14	44	68.2	31.8	5.82*
Dec.	24	28	52	46.2	53.9	0.31
Jan-94	64	19	83	77.1	22.9	24.4*
Feb.	100	41	141	70.9	29.1	24.7*
Mar.	70	37	107	65.4	34.6	10.2*
Apr.	80	18	98	81.6	18.4	39.2*
May	61	32	93	65.6	34.4	9.0*
Jun.	68	42	110	61.8	38.2	6.2*

* denotes a significant difference from 1 : 1 ratio (df = 1, $P<0.05$).

Size composition and distribution

The total collected number of crabs of *M. messor* was 641 males and 307 females ranging in CW from 0.51-3.46 cm and 0.97-3.18 cm, respectively. In terms of weight males ranged from 0.063-16.34g, whereas females were from 0.38-10.48g. Tab. 6 shows that the mean CW for male ranged from a minimum of 1.63±0.63 cm during March '94, while the maximum of 2.27±0.71 cm was recorded during August '93. Female mean values for the same periods were generally lower, ranging from 1.83±0.39 cm to 2.03±0.13 cm respectively, the maximum mean for females was 2.33±0.52 cm during April. In terms of wet weight, the minimum and maximum means for males and females were found to range from 2.99±0.34 to 6.01±3.79 g; and 2.87±1.54 to 3.33±1.47g, respectively, during the above-mentioned periods. The maximum mean wet weight of female was 5.34±2.99 during April '94. Fig. 3 shows that there was a single mode at (1.5 - 2.0 cm). in the carapace width distributions of all males and females collected during the survey and a single mode, at size (2.0 - 2.5 cm), in the ovigerous female data set. The size frequency for the population of *M. messor* tended to be concentrated in the smaller and mid range size classes from December '93 - March '94, and there were more individuals in the large size-classes from April '94 - June '94 (Fig. 4).

Table 6: seasonal changes in mean carapace width and weight for male and female *M. messor* collected from coast of Qatar (Jun-93 to Jun-94).

Month	Male			Female		
	No. of crabs	Carapace width (cm)	Wet weight (g)	No. of crabs	Carapace width (cm)	Wet weight (g)
Jun-93	26	2.02±0.70	4.06±3.73	6	2.32±0.44	3.22±1.43
Jul.	37	1.95±0.69	3.78±3.18	14	2.06±0.57	3.62±2.23
Aug.	23	2.27±0.71	6.01±3.79	19	2.03±0.13	33.3±1.47
Sep.	17	2.21±0.51	4.47±2.53	10	1.93±0.13	2.58±0.61
Oct.	41	1.90±0.80	4.34±4.23	27	2.02±0.42	3.39±1.97
Nov.	30	1.84±0.71	3.55±3.45	14	1.97±0.37	3.12±1.52
Dec.	24	1.79±0.77	4.68±4.39	28	2.13±0.45	4.05±2.14
Jan-94	64	1.97±0.69	3.70±3.76	19	2.06±0.34	3.77±1.53
Feb.	100	1.74±0.66	3.30±3.47	41	1.83±0.46	2.88±2.08
Mar.	70	1.63±0.64	2.99±3.34	37	1.83±0.39	2.87±1.54
Apr.	80	1.94±0.76	4.53±4.10	18	2.33±0.52	5.34±2.99
May	61	2.24±0.52	5.02±0.95	32	1.97±0.39	3.20±1.42
Jun.	68	2.18±0.58	4.88±3.38	42	2.11±0.28	3.53±1.17

Reproduction season

The smallest crab observed bearing eggs was 1.4 cm in carapace width and the largest was 2.85 cm in CW. Fig. 21 shows the percentage of ovigerous crabs in different size-classes. The maximum number is seen in the size range between 2.5-3.0 cm in CW.

Ovigerous females of this species were found over a 5 month period and August appears to be the peak breeding time with the highest percentage of ovigerous females (63.2%) followed by a fall during the next month to 40%. A total of 27 ovigerous females were collected, out of which 11 belonged to 2.0 - 2.5 cm size class. The remaining were in the 2.0 - 3.0 cm size class (Fig. 22).

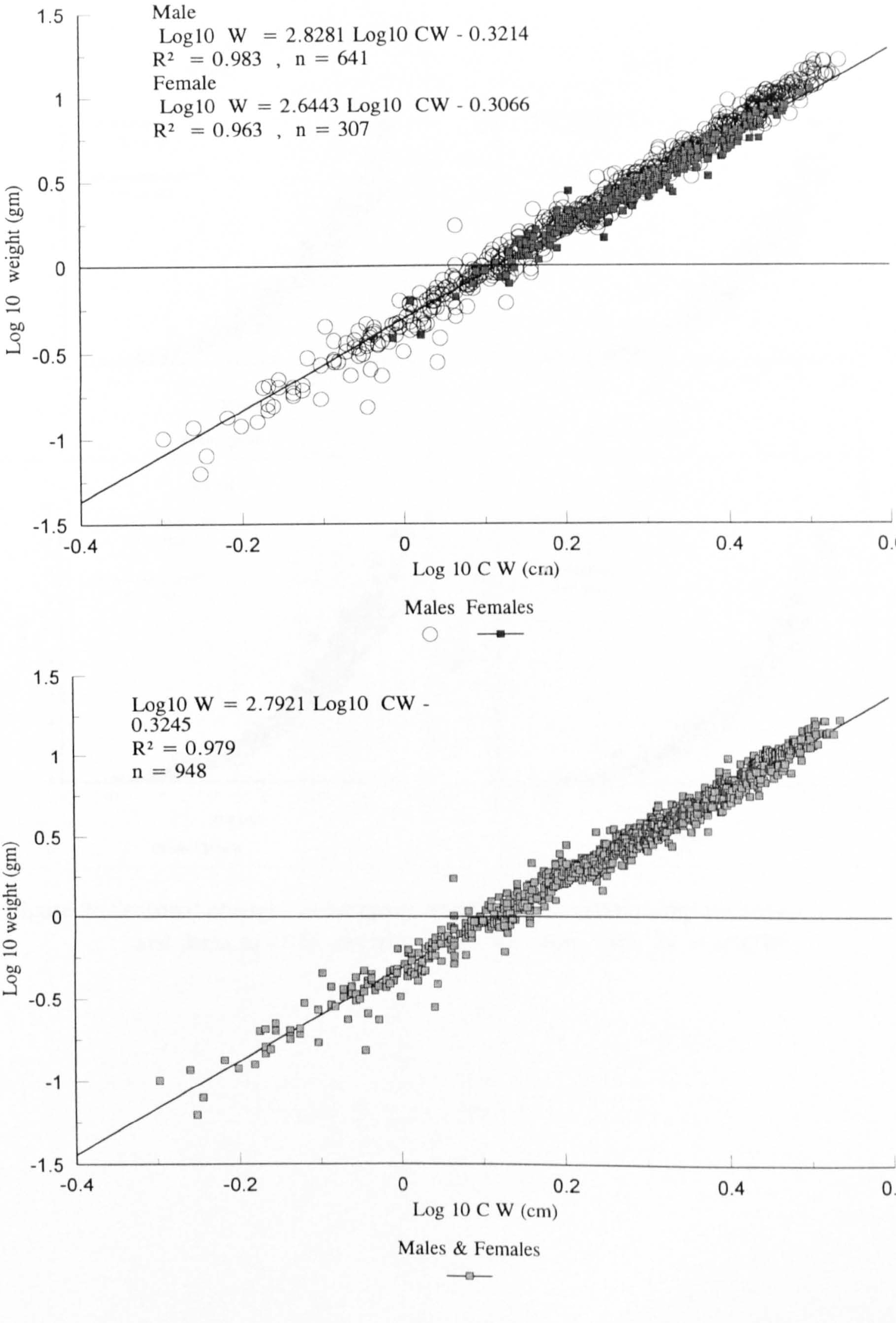


Figure 1: Estimated regression of Log 10 weight against Log 10 C W for *Metopograpsus messor*.

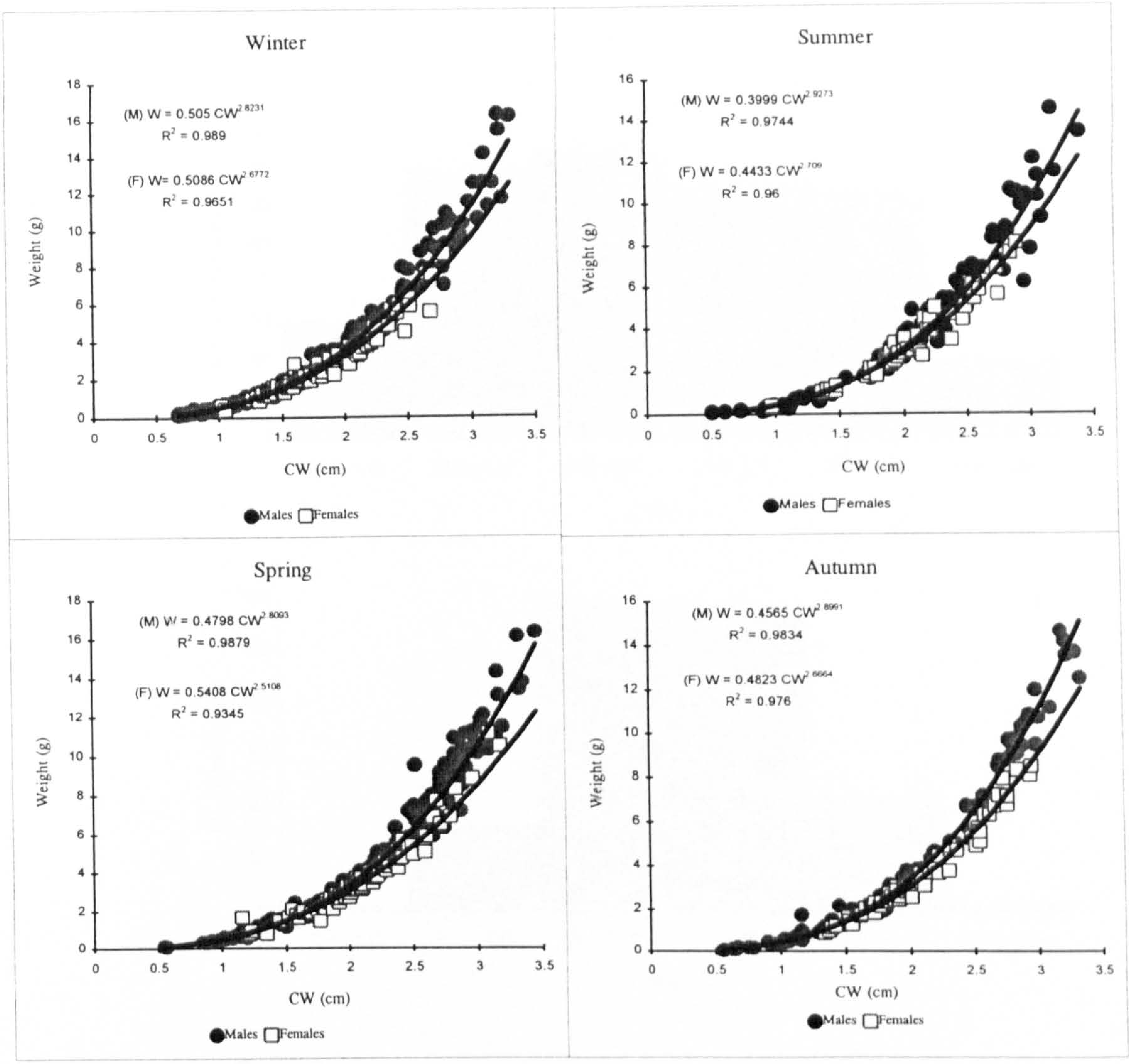


Figure 2: Seasonal changes in carapace width-weight relationship for males and females of *M. messor* (Jun. '93 - Jun. '94). $W = a*CW^b$.

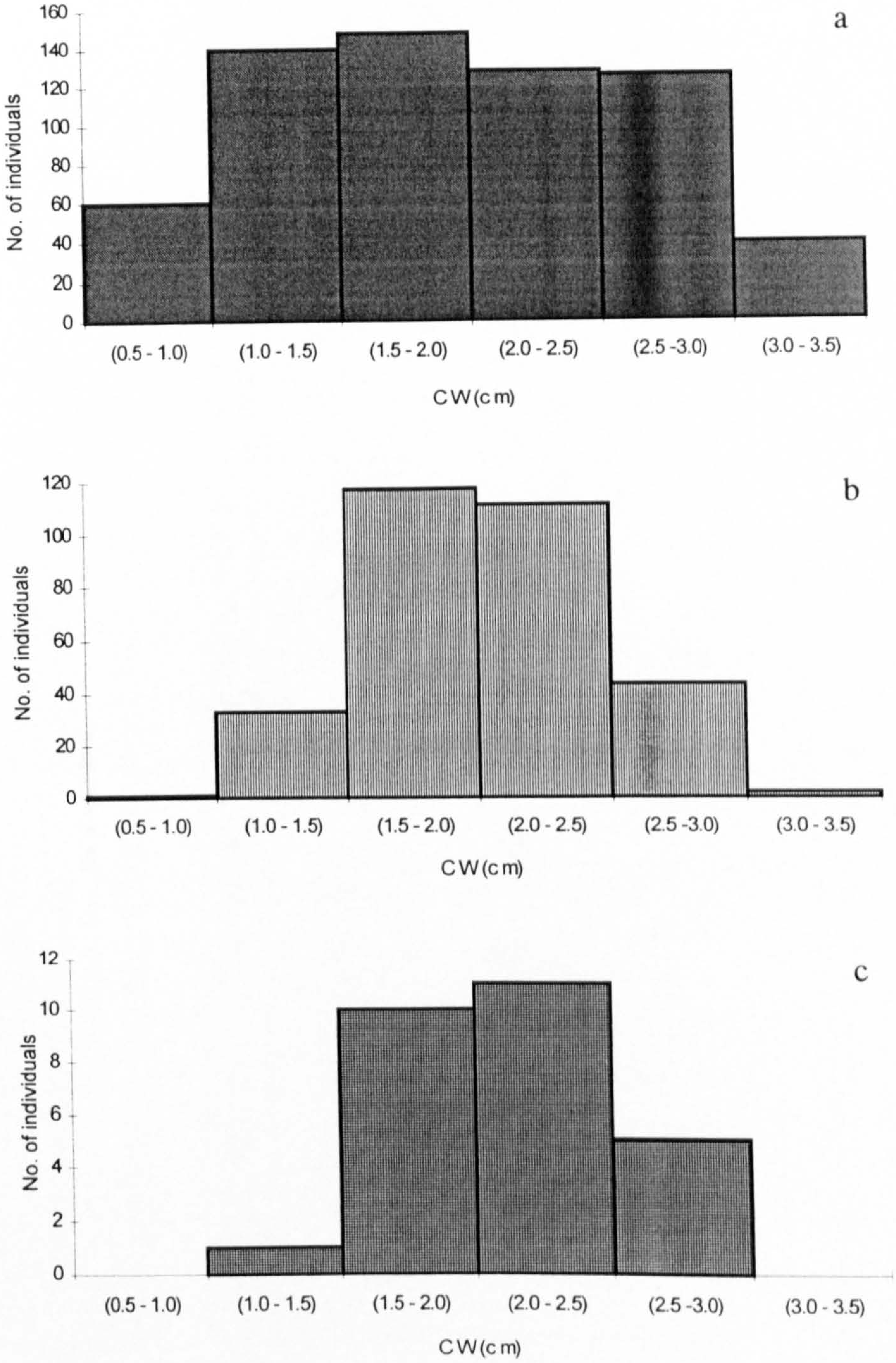


Figure 3: Carapace width (CW) distribution of *Metopograpsus messor* of (a) males, (b) females and (c) ovigerous females.

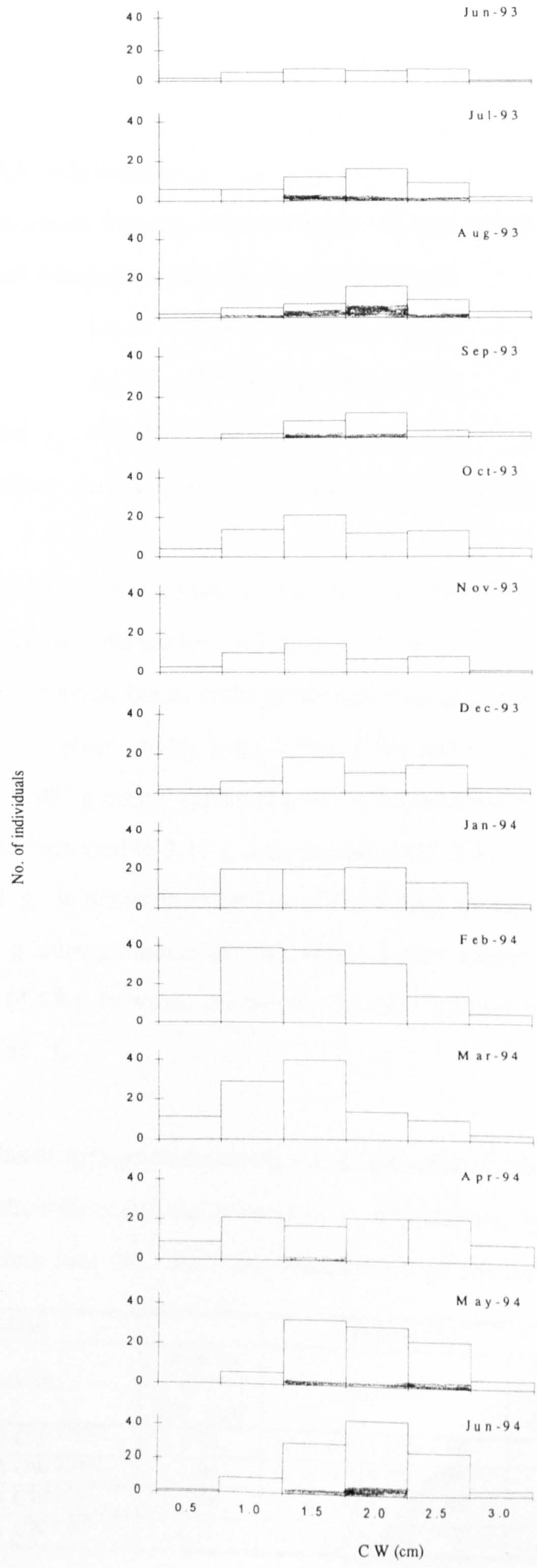


Figure 4: *Metopograpsus messor* carapace width (CW) frequency distributions based on monthly samples (black = ovigerous females).

Nasima dotilliformis

Carapace width-weight relationship

The logarithmic relationships between carapace width - weight of males, females and total sample (males and females) for this species are as follows:

Male $\log W = 2.9430 \log CW - 0.2401$

Female $\log W = 2.5465 \log CW - 0.2413$

Total (male and female) $\log W = 2.8623 \log CW - 0.2485$

The relationship between carapace width and weight is graphically represented in Fig. 5.

In this species males were found to be heavier than females throughout the year (Fig. 6). The regression equation obtained for both sexes in all seasons shows that females with CW <0.6 cm are heavier, but as crabs grow bigger the increase in weight is in favour of males. For a given width, e.g., 1.5 cm CW, males weight in winter of 1.83 g increased to 1.96 g during spring (23.64%), but declined to 1.68 g during summer (8.52%), and increased to 2.11 g during autumn (25.6%). For the females, the weight was 1.52 g in winter increased to 1.76 g during spring (15.79%) , but decreases upto 1.61 g during summer (8.5%), with a further slightly increase upto 1.6 g during autumn (4.4%). In winter the weight was 10.5% lower than the weight recorded in autumn (Tab. 7).

Table 7: Non - linear regression equations for the carapace width - weight relationships for males and females of *N. dotilliformis*, by season, from June '93 - June '94. Weight for a given size.

Season	Male		Female	
	Equation	Wt.g for crab with CW cm	Equation	Wt.g for crab with CW cm
Winter	$W = 0.547\ CW^{2.974}$	1.83	$W = 0.584\ CW^{2.366}$	1.52
Spring	$W = 0.565\ CW^{3.0681}$	1.96	$W = 0.545\ CW^{2.889}$	1.76
Summer	$W = 0.554\ CW^{2.735}$	1.68	$W = 0.603\ CW^{2.419}$	1.61
Autumn	$W = 0.664\ CW^{2.857}$	2.11	$W = 0.635\ CW^{2.405}$	1.68

Comparison of the weight loss with mean temperature of cold and warm seasons, (as above-mentioned for previous species) shows variation according to size of crab (Tab. 8). This table shows that females with 1 cm CW and 1.5 cm CW gain 8.3% and 5.6%, respectively. In contrast, in summer the weight of males of 1.5 cm CW lose (-6.67%) of the weight recorded during winter.

Tables 8: Seasonal changes in mean weight for males and females of *N. dotilliformis* during winter and summer for data collected between Jun. '93 - Jun. '94.

Season	Mean temp. °C	Male 1 cm	Male 1.5 cm	Female 1 cm	Female 1.5 cm
Winter	12.8	0.54	1.80	0.55	1.52
Summer	28.9	0.55	1.68	0.60	1.61

Carapace width-weight ratio

Weight - width ratio for both sexes in size classes between 0.3 - 1.8 cm are presented in Tab. 9. The data for both sexes show similar changes in body form as they grow. However, in terms of mean weight, males were heavier than females. The male weight is higher in the range of size classes from 0.9 - 1.2, 1.2 - 1.5, and 1.5 - 1.8 cm, while the remaining size - classes are in favour of females. The same pattern was noticed in the mean width, with the exception of size - classes of 0.6 - 0.9 and 0.9 - 1.2 cm, which are slightly higher in females.

Table 9: Carapace width - weight for male and female *N. dotilliformis* collected from the coast of Qatar (Jun. '93 - Jun. '94).

Carapace width (cm)	Male				Female			
	No. of Crab	Mean width (cm)	Mean weight (g)	Weight / width %	Weight / width %	Mean width (cm)	Mean weight (g)	No. of Crab
0.3 - 0.6	2	0.50±0.0	0.09±0.0	18				
0.6 - 0.9	64	0.75±0.1	0.26±0.1	34.7	38.8	0.85±0.1	0.33±0.1	5
0.9 - 1.2	38	1.04±0.1	0.84±0.9	80.8	78.3	1.06±0.1	0.83±0.9	51
1.2 - 1.5	45	1.36±0.1	1.47±0.3	108.1	91.0	1.33±0.1	1.21±0.2	51
1.5 - 1.8	35	1.59±0.1	2.18±1.4	137.1	116.8	1.61±0.1	1.88±0.4	7

Sex ratio

Males formed 92.8% of the population at size-classes (0.6-0.9 cm) and were also present in a high proportion (83.3%) in the 1.5-1.8 cm size-classes. Females amounted to more than 50% in the medium size-classes. The sex-ratio of the size-classes (0.9-1.2 cm) and (1.2-1.5 cm) size-classes in favour of females, but were not significantly different from a population having 1:1 ratio of the above-mentioned size-classes (χ^2 = 0.19, *df*= 1, P<0.05; χ^2 = 0.38, *df*=1, P<0.05 respectively) (Tab. 10). The sex ratio was in favour of females in the months of February '94 to March '94, while an equal ratio males and females was present in August '93. Chi-square values are significant at 5% level from April '94 to June '94 (Table 11).

Table 10: Sex ratio of *N. dotilliformis* for different carapace width-size class.

Size - class	No. of Male	No. of female	Total	% of Male	% of Female	Chi-square
(0.3 - 0.6)	2	-	2	100.0	-	
(0.6 - 0.9)	64	5	69	92.8	7.3	50.5*
(0.9 - 1.2)	38	51	89	42.7	57.3	1.9
(1.2 - 1.5)	45	51	96	46.9	53.1	0.38
(1.5 - 1.8)	35	7	42	83.3	16.7	18.7*

* denotes a significant difference from 1 : 1 ratio (*df* = 1, P<0.05).

Table 11: Sex ratio of *N. dotilliformis* species for different months.

Month	No. of male	No. of female	Total	% of male	% of female	Chi-Square
Jun-93	8	7	15	53.3	46.7	0.07
Jul.	7	3	10	70.0	30.0	1.6
Aug.	7	7	14	50.0	50.0	0.0
Sep.	9	4	13	69.2	30.8	1.92
Oct.	7	4	11	63.6	36.4	0.82
Nov.	8	3	11	72.7	27.3	2.27
Dec.	9	5	14	64.3	35.7	1.14
Jan-94	6	5	11	54.6	45.5	0.09
Feb.	8	11	19	42.1	57.9	0.47
Mar.	12	19	31	38.7	61.3	1.6
Apr.	23	11	34	67.7	32.4	4.2*
May	33	16	49	67.4	32.7	5.9*
Jun.	47	19	66	71.2	28.8	11.9*

* denotes a significant difference from 1 : 1 ratio (df = 1, $P<0.05$).

Size composition and distribution

A total of 289 specimens of *N. dotilliformis* were sampled , comprising 184 males and 114 females ranging in CW from 0.5 - 1.78 cm and 0.73-1.7 cm, respectively. In terms of wet weight, males ranged from 0.093-2.793g, whereas females were from 0.285-2.317g. Tab. 12 shows that the mean CW for males ranged from a minimum of 0.83 ± 0.20 cm during January '94 and a maximum of 1.48 ± 0.61 cm during July '93. Female mean values during July '93 were generally higher with a maximum of 1.43 ± 0.23 cm minimum values of 1.05 ± 0.06 cm occurring during October. In terms of wet weight the minimum and maximum means for males were found to range from 0.41 ± 0.23g to 1.62 ± 0.30 g during the above-maintained period, while the females ranged from 0.73 ± 0.18 to 1.35 ± 0.06g over the same periods. There were 2 modes, at 0.6-0.9 cm and 1.2-1.5 cm , in the carapace width (CW) distributions of all males collected during the study (Fig. 7), and equal modes, at size ranging from (0.9-1.2 cm) and (1.2-1.5 cm) in the females. A single mode, at size range (1.2-1.5) occurred in the ovigerous female data set.

The size frequency distributions of 298 *N. dotilliformis* specimens, ranging in size from 0.3-1.5 cm, is presented in (Fig. 8). The smallest sizes in October to November '93 indicate recruitment. It would appear that recruitment into the population occurs in August - October with these cohorts forming the largest size groups by the following summer.

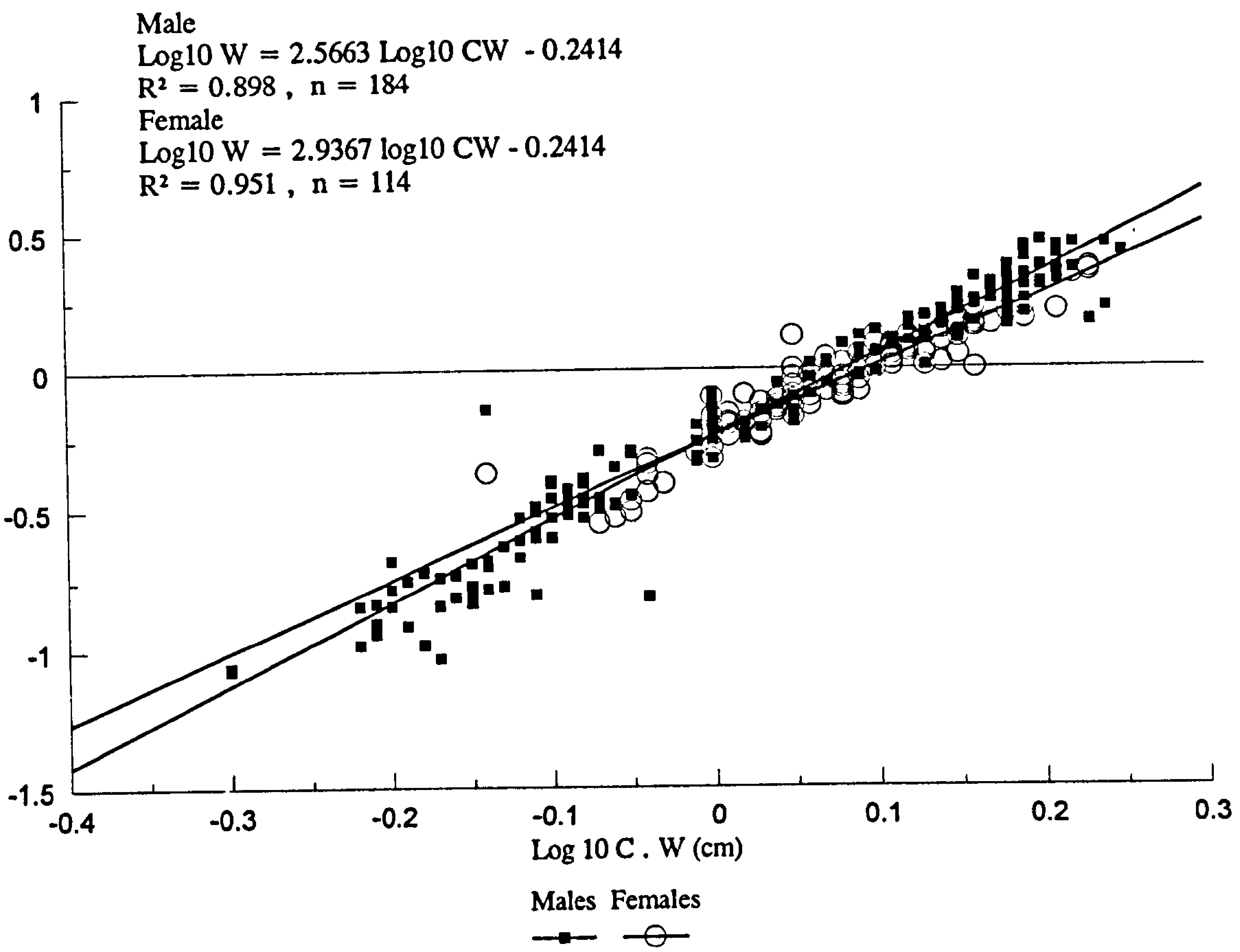
Table 12: seasonal changes in mean carapace width and weight for male and female *N. dotilliformis* collected from coast of Qatar (Jun-93 to Jun-94).

Month	Male			Female		
	No. of crabs	Carapace width (cm)	Wet weight (g)	No. of crabs	Carapace width (cm)	Wet weight (g)
Jun-93	8	1.39±0.18	1.35±0.49	7	1.28±0.17	1.14±0.34
Jul.	7	1.48±0.16	1.62±0.30	3	1.41±0.01	1.35±0.06
Aug.	7	1.33±0.25	1.43±0.68	7	1.20±0.11	0.95±0.27
Sep.	9	1.04±0.37	0.96±0.97	4	1.10±0.21	0.71±0.30
Oct.	7	0.92±0.36	0.71±0.62	4	1.43±0.23	1.52±0.62
Nov.	8	1.02±0.25	0.83±0.54	3	1.05±0.06	0.73±0.18
Dec.	9	1.10±0.35	1.08±0.88	5	1.17±0.19	1.12±0.39
Jan-94	6	0.83±0.20	0.41±0.23	5	1.30±0.26	1.24±0.63
Feb.	8	0.95±0.36	0.69±0.88	11	1.19±0.24	0.93±0.48
Mar.	12	0.96±0.28	1.05±1.69	19	1.24±0.17	0.99±0.33
Apr.	23	1.07±0.31	0.77±0.52	11	1.11±0.27	0.73±0.49
May	33	1.06 ±0.37	0.93±0.87	16	1.20±0.20	1.35±1.53
Jun.	47	1.21±0.33	1.28±0.87	19	1.18±0.15	0.97±0.33

Reproduction season

The smallest crab observed bearing eggs was 0.89 cm in CW and the largest was 1.63 cm CW. The percentage of ovigerous females in different size-classes is shown in Fig. 21. The maximum number was seen in the size range of 1.2-1.5 cm.

A total of 51 ovigerous *N. dotilliformis* were encountered over 7 months. The major peaks were in March (84.2%) and April (72.7%). As shown in Fig. 21, ovigerous females were present in the 0.3 - 1.8 cm size range with a maximum in the 1.2 - 1.5 cm size - class (54.9%) (Fig. 22).



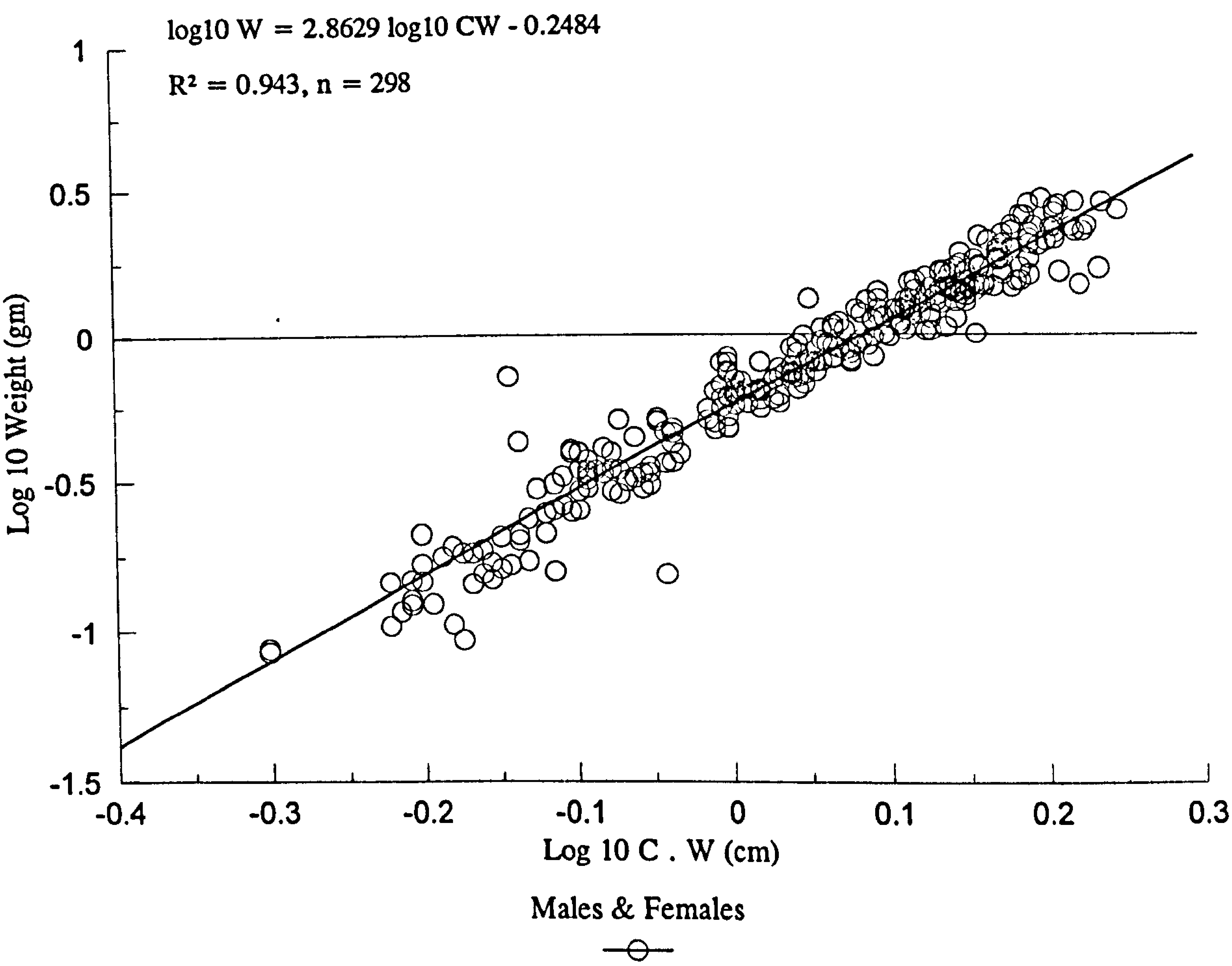


Figure 5: Estimated regression of Log 10 weight against Log 10 carapace width (C W) for *Nasima dotilliformis*.

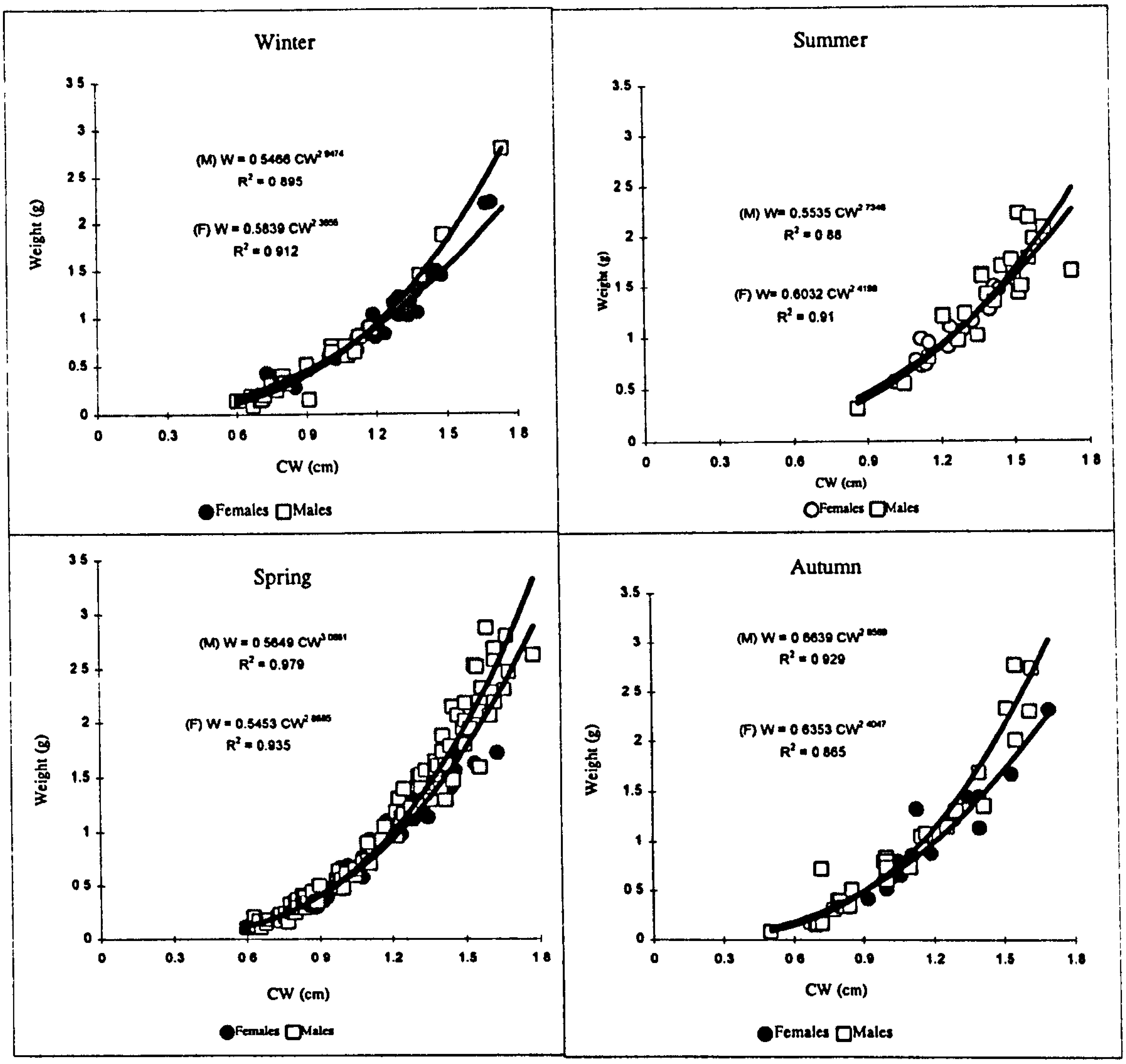


Figure 6: Seasonal changes in carapace width-weight relationship for males and females of *N. dotilliformis* from Jun. '93-Jun. '94. W=a*CWb, a and b values are given

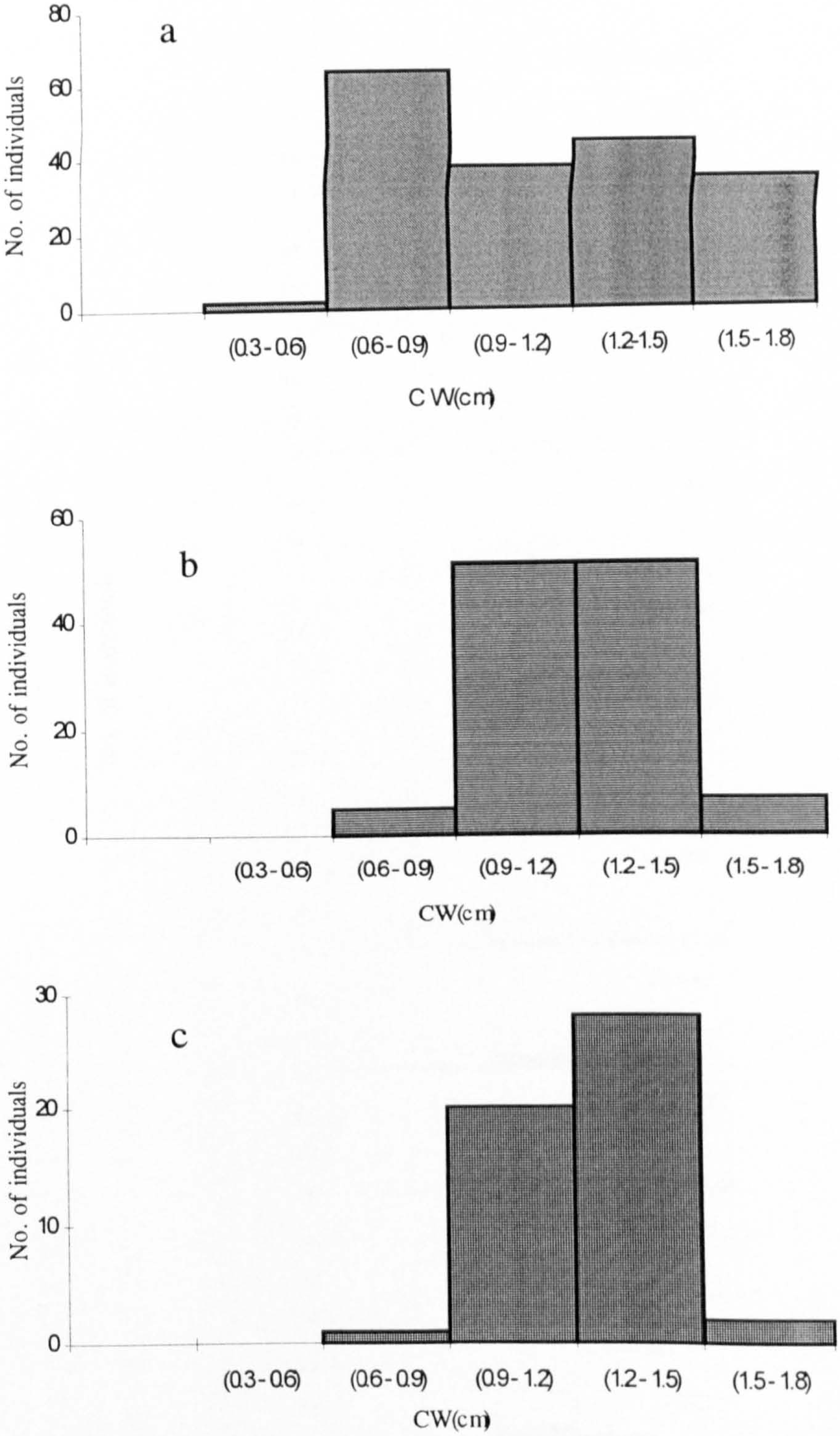


Figure 7: Carapace width (CW) distribution of *Nasima dotilliformis* of (a) males, (b) females and (c) ovigerous females.

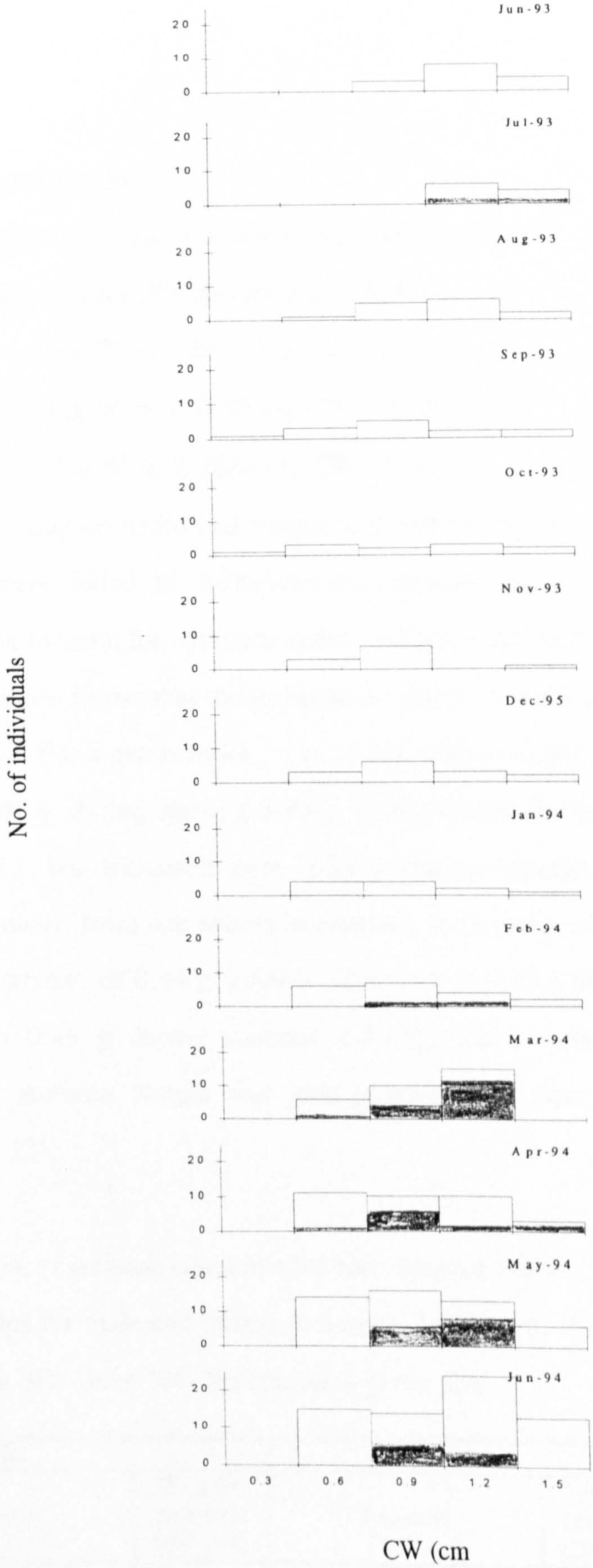


Figure 8: *Nasima dotilliformis* carapace width (CW) frequency distribution pased on monthly samples (black = ovigerous females).

Serenella leachii

Carapace width-weight relationship

The logarithmic relationships between carapace width - weight of males, females and total sample (males and females) for this species are as follows:

Male $\log W = 2.8314 \log CW - 0.3148$

Female $\log W = 2.7780 \log CW - 0.3508$

Total (male and female) $\log W = 2.7687 \log CW - 0.3418$

The relationship between carapace width and weight is shown in Fig. 9.

Males of this species were found to be heavier than females throughout the year (Fig. 10). The parabolic formula for carapace width - weight relationship, obtained for both sexes in all seasons shows that the increase in weight as crabs grow bigger is in favour of males. For a given width , e.g., 1 cm, males weight in winter of 0.51 g declined to 0.48 g during spring (-5.9%), with a further decline to 0.45 g during summer (-11.8%), but increased upto 0.53 g during autumn (3.8). For females, the weight fluctuated from one season to another, for a given width, e.g., 1 cm, female weight in winter of 0.44 g slightly increases to 0.45 g during spring (2.2%), but declines to 0.43 g during summer (-4.4%), and increases to 0.46 g during autumn (6.5%). Autumn weight was just (4.6%) more than the weight recorded in winter (Tab. 13).

Table 13: Non-linear regression equations for the carapace width - weight relationships for male and female *S. leachii*, by season, from June '93 - June '94. Weight for a given size.

Season	Male		Female	
	Equation	Wt.g for crab with CW 1 cm	Equation	Wt.g for crab with CW 1 cm
Winter	$W = 0.509\ CW^{2.979}$	0.51	$W = 0.443\ CW^{2.792}$	0.44
Spring	$W = 0.481\ CW^{2.915}$	0.48	$W = 0.449\ CW^{2.844}$	0.45
Summer	$W = 0.453\ CW^{2.819}$	0.45	$W = 0.434\ CW^{2.843}$	0.43
Autumn	$W = 0.531\ CW^{2.853}$	0.53	$W = 0.463\ CW^{2.678}$	0.46

Comparison of the weight loss with the mean temperature of cold and warm season, shows variation according to the size of crab (Tab. 14). Females with 1 cm CW and 1.3 cm CW lost 2.3% and 1.09%, respectively, of their body weight during summer. In contrast, the weight of males of 1 cm CW and 1.3 cm CW lost 11.8% and 14.4%, of their body weight during summer.

Tables 14: Seasonal changes in mean weight for males and female *S. leachii* during winter and summer of the datat collected between Jun. '93 - Jun. '94.

		Male		Female	
Season	Mean temp. °C	1 cm	1.3 cm	1 cm	1.3cm
Winter	12.8	0.51	1.11	0.44	0.92
Summer	28.9	0.45	0.95	0.43	0.91

Carapace width-weight ratio

In the present study, a total of 166 males and 333 females of this species were examined for weight - width ratios. The data set for both sexes shows similar changes in body form as they grow. At the size 0.1-0.4 cm females dominated and males were not observed throughout the period of study at this size class (Tab. 15).

Table 15: Carapace width - weight for male and female *S. leachii* collected from the coast of Qatar (Jun. '93 - Jun. '94).

	Male				Female			
Carapace width (cm)	No. of Crab	Mean width (cm)	Mean weight (g)	Weight / width %	Weight / width %	Mean width (cm)	Mean weight (g)	No. of Crab
0.1 - 0.4					10.3	0.39±0.0	0.04±0.0	1
0.4 - 0.7	3	0.43±0.03	0.05±0.01	11.6	12.8	0.5±0.04	0.06±.02	53
0.7 - 1.0	57	0.59±0.1	0.12±0.1	32.5	32.5	0.8±0.1	0.26±0.1	252
1.0 - 1.3	106	0.90±0.1	0.39±0.2	63.1	63.1	1.11±0.1	0.70±0.9	77

Sex ratio

Females occurred in a higher percentage than males in size-classes of 0.4 cm to 1.3 cm. The 1:1 ratio was found to be significant at the 5% level for (0.7-1.0 cm) and (1.0-1.03 cm) size-classes where males were low (29.6% and 23.8% respectively) (Tab. 16). The monthly sex-ratios were mostly in favour of females but from October '93-November '93 in favour of males excepting February '94 which was dominated by females (100%). Chi-square values are not significant at the 5% level from July '93 to November '93 and from January '94 to April '94. In the remaining months (December '93, May - June '94) the χ^2 values were significant at 5% level with a preponderance of females (Tab. 17).

Table 16: Sex ratio of *S. leachii* for different carapace width-size class.

Size - class	No. of Male	No. of female	Total	% of Male	% of Female	Chi-square
(0.1 - 0.4)	2	1	3	66.7	33.3	0.33
(0.4 -0.7)	59	62	121	48.8	51.2	0.07
(0.7 - 1.0)	81	193	274	29.6	40.4	45.8*
(1.0 - 1.3)	24	77	101	23.8	76.2	27.8*

* denotes a significant difference from 1 : 1 ratio (df = 1, $P<0.05$).

Table 17: Sex ratio of *S. leachii* for different months.

Month	No. of male	No. of female	Total	% of male	% of female	Chi-Square
Jun-93	6	18	24	25.0	75.0	6.0
Jul.	4	7	11	36.4	63.6	0.82
Aug.	7	14	21	33.3	66.7	2.33
Sep.	5	7	12	41.7	58.3	0.33
Oct.	13	8	21	61.9	38.1	1.19
Nov.	31	30	61	50.8	49.2	0.02
Dec.	4	15	19	21.1	78.9	6.37*
Jan-94	2	10	12	16.7	83.3	5.33
Feb.	-	19	19	-	100.0	-
Mar.	11	33	44	25.0	75.0	11.0
Apr.	29	38	67	43.3	56.7	1.21
May	24	71	95	25.3	74.7	23.3*
Jun.	30	63	93	32.3	67.7	11.7*

* denotes a significant difference from 1 : 1 ratio (df = 1, $P<0.05$)

Size composition and distribution

Total numbers of *S. leachii* collected consisted of 166 males and 333 females. Males ranged in CW from 0.40-1.33 cm and females from 0.39-1.34 cm. In terms of wet weight, males ranged from 0.043-1.227 g, whereas females were from 0.044-0.863 g. Tab. 18 shows that the mean CW for males ranged from a minimum of 0.59±0.21 cm during March '94 to a maximum of 0.88±0.20 cm during June '94. The mean CW for females ranged from a minimum of 0.72±0.12 cm during April "94 to a maximum of 0.95±0.15 cm during February '94. In terms of wet weight, the minimum and maximum means for males was found to range from 0.16±0.15 g during October '93 to 0.53±0.28 during December '93. The minimum and maximum means for females was from 0.18±0.10 g during April '94 to 0.49±0.97 during May '94. The CW frequency distribution (Fig. 11) shows a single mode at size ranges (0.7-1.0 cm) of all males, females and ovigerous females collected during the survey.

Table 18: seasonal changes in mean carapace width and weight for males and females of *S. leachii* collected from coast of Qatar (Jun-93 to Jun-94).

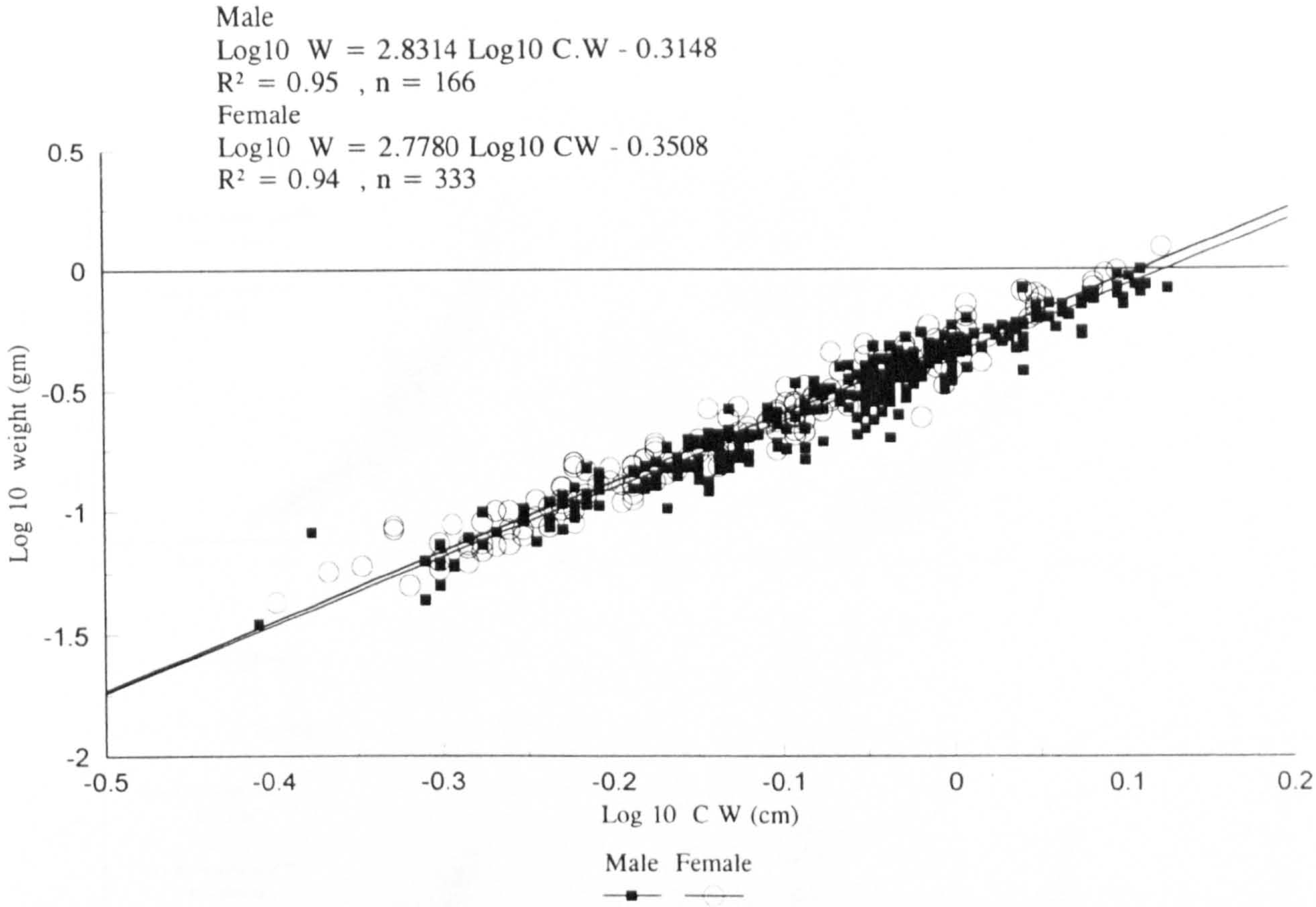
Month	Male			Female		
	No. of crabs	Carapace width (cm)	Wet weight (g)	No. of crabs	Carapace width (cm)	Wet weight (g)
Jun-93	6	0.77±0.16	0.24±0.11	18	0.89±0.12	0.32±0.10
Jul.	4	0.84±0.14	0.33±0.11	7	0.80±0.13	0.25±0.09
Aug.	7	0.75±0.15	0.19±0.08	14	0.80±0.13	0.22±0.11
Sep.	5	0.63±0.17	0.23±0.17	7	0.83±0.11	0.31±0.13
Oct.	13	0.64±0.19	0.16±0.15	8	0.81±0.17	0.28±0.15
Nov.	31	0.83±0.21	0.37±0.27	30	0.77±0.24	0.28±0.23
Dec.	4	0.92±0.21	0.53±0.28	15	0.91±0.19	0.41±0.19
Jan-94	2	0.70±0.09	0.18±0.04	10	0.89±0.13	0.35±0.15
Feb.	-	-	-	19	0.95±0.15	0.41±0.17
Mar.	11	0.59±0.21	0.28±0.10	33	0.93±0.20	0.40±0.23
Apr.	29	0.74±0.18	0.24±0.17	38	0.72±0.12	0.18±0.10
May	24	0.80±0.17	0.29±0.18	71	0.90±0.19	0.49±0.97
Jun.	30	0.88±0.20	0.37±0.27	63	0.92±0.18	0.39±0.19

The carapace width frequency distributions of 499 *S. leachii* during each of the 13 sampling periods is presented on Fig. 12. There are a varying number of modes, few of which can be followed through successive sampling periods. The population tended to concentrated in the larger size classes (0.7-1.0 cm) during June 1993 and from April to June 1994. There were more individuals in smaller and mid range size classes from October 1993 to March 1994.

Reproduction season

The smallest crab bearing eggs was 0.5 cm and the largest was 1.34 cm in CW. The higher percentage of ovigerous females were in the size range between 1.0-1.3 cm (Fig. 21).

Ovigerous females occurred in the population from November to May. The highest percentage of ovigerous females of this species was reached (100%) in February and March which seems to be the period of high breeding activity. A total of 136 ovigerous females were collected in the 0.1 - 1.3 cm size - class (Fig. 22), with a maximum of ovigerous females in the 1.0-1.3 cm size class (44.2%).



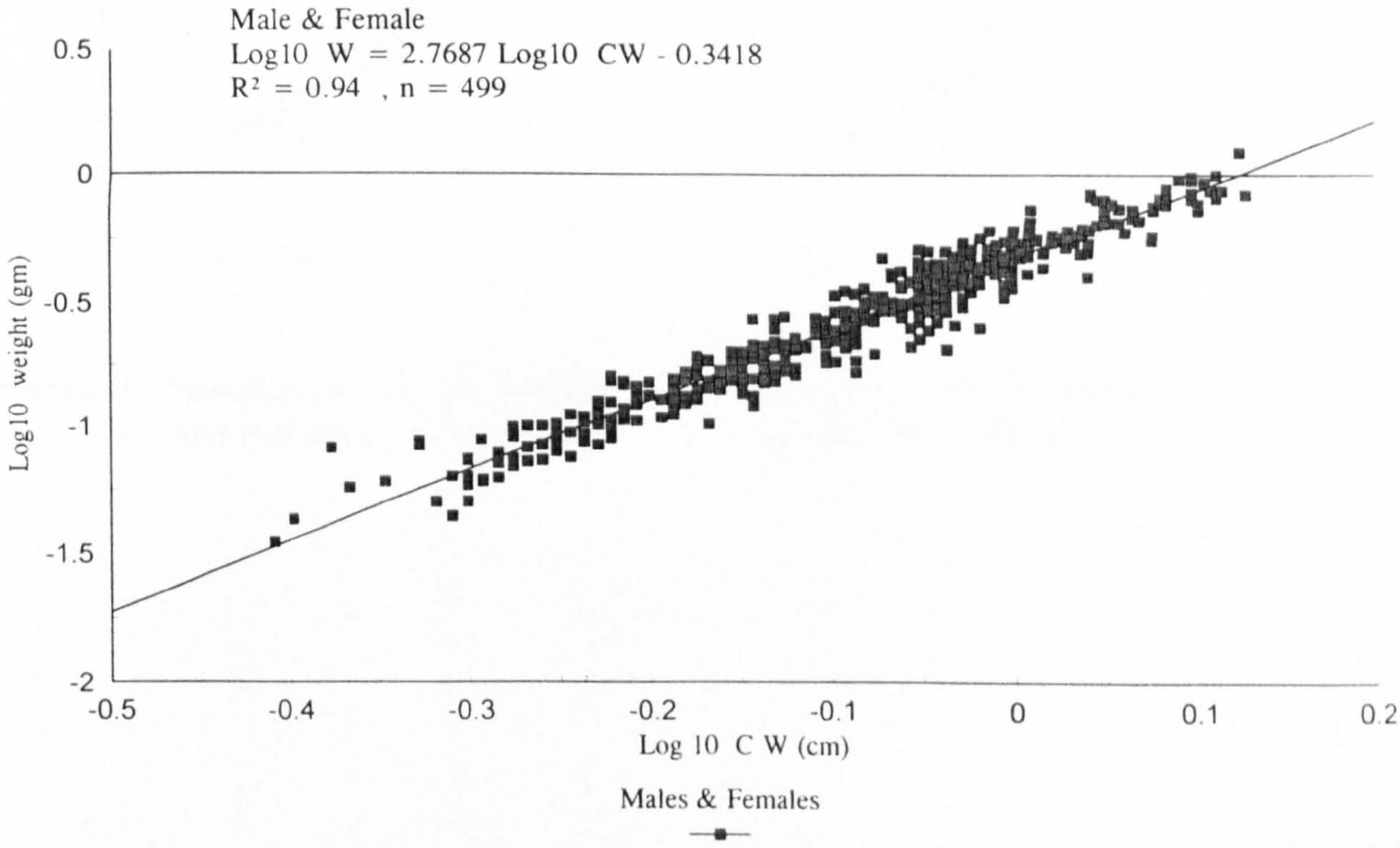


Figure 9: Estimated regression of Log10 W against Log10 carapace width (C W) for *Serenella leachii*.

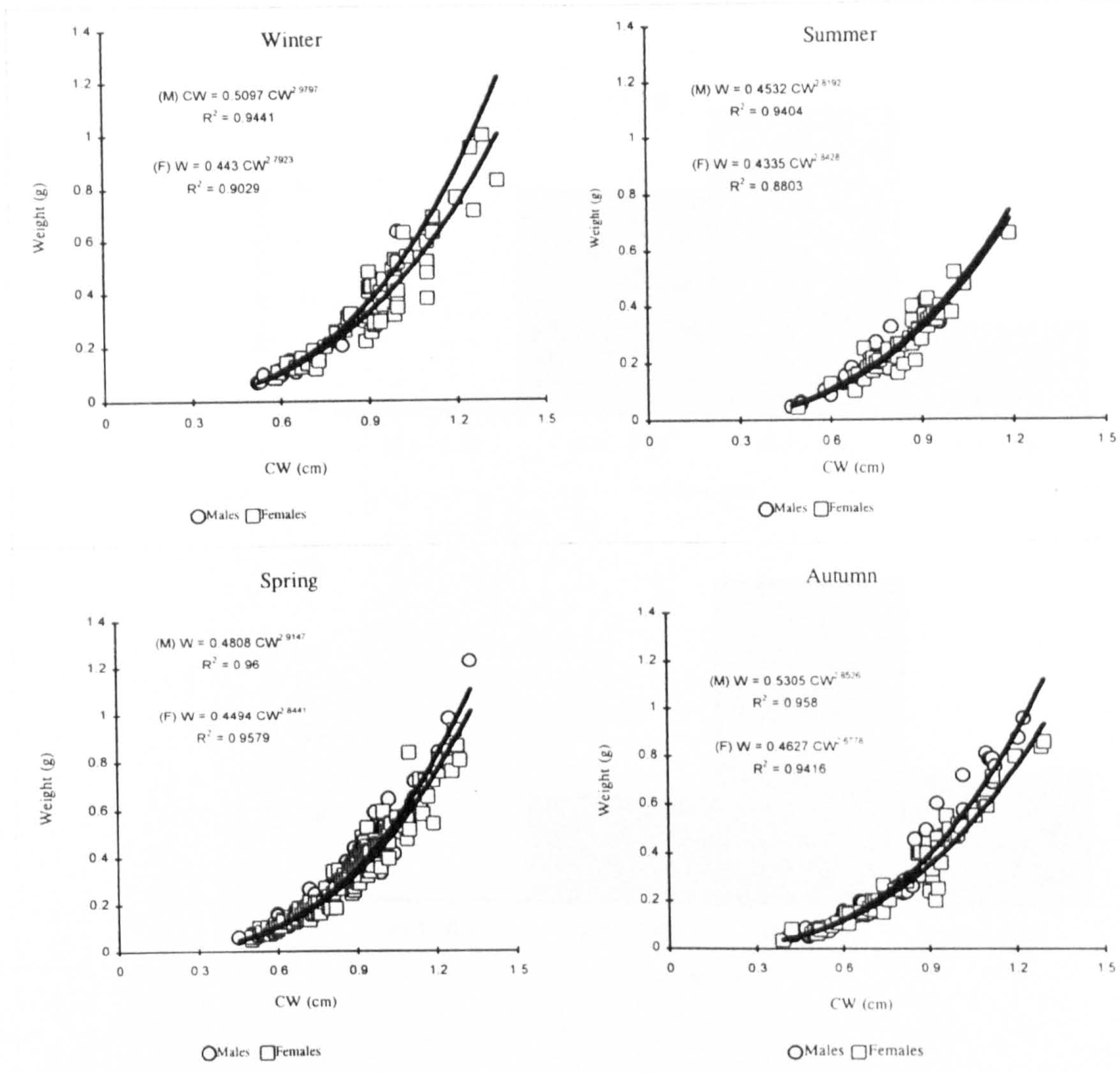


Figure 10: Seasonal changes in carapace width-weight relationship for males and females of *S. leachii* (Jun. '93 - Jun. '94). $W = a*CW^b$.

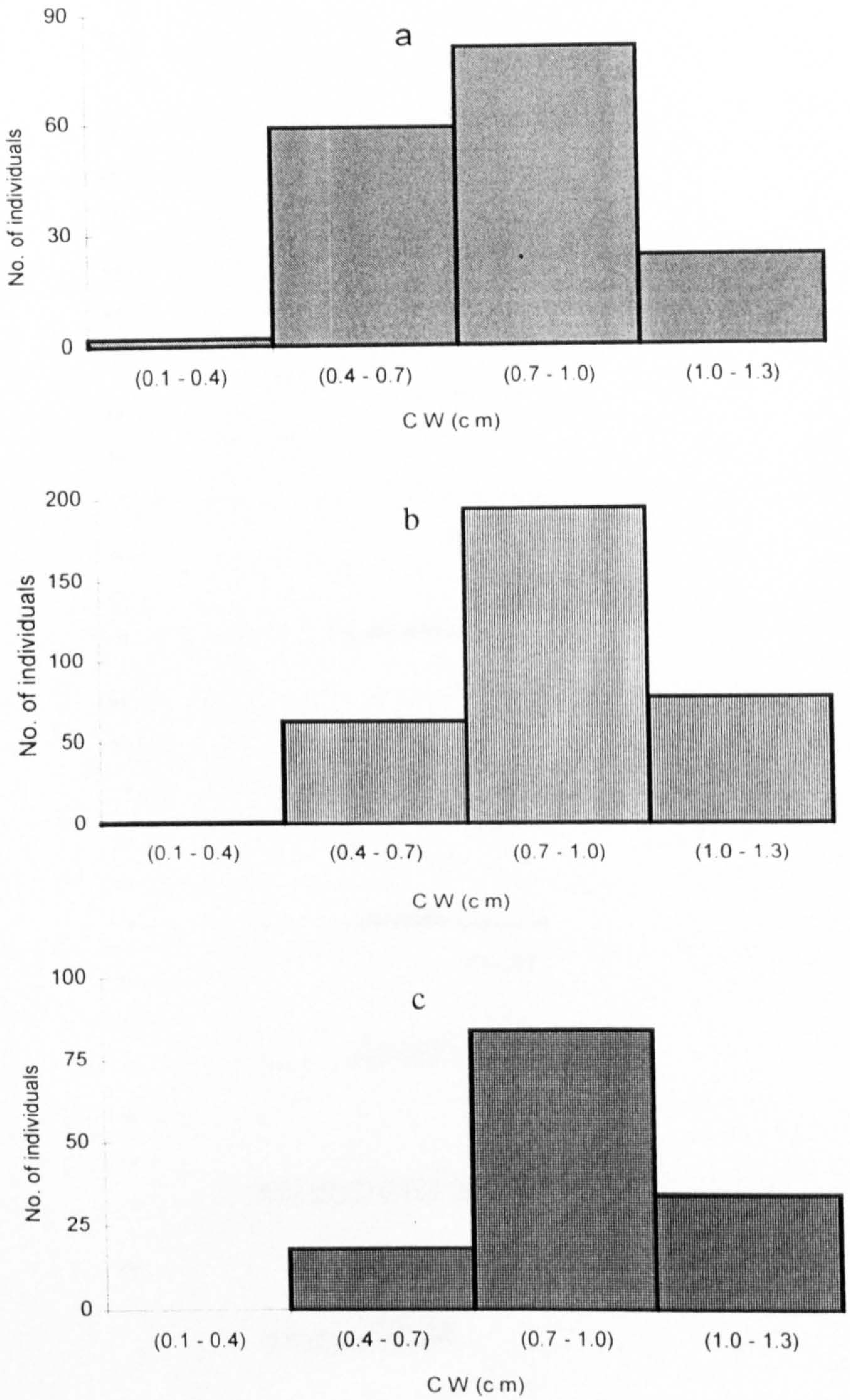


Figure 11: Carapace width (CW) distribution of *Serenella leachii* of (a) males, (b) females and (c) ovigerous females.

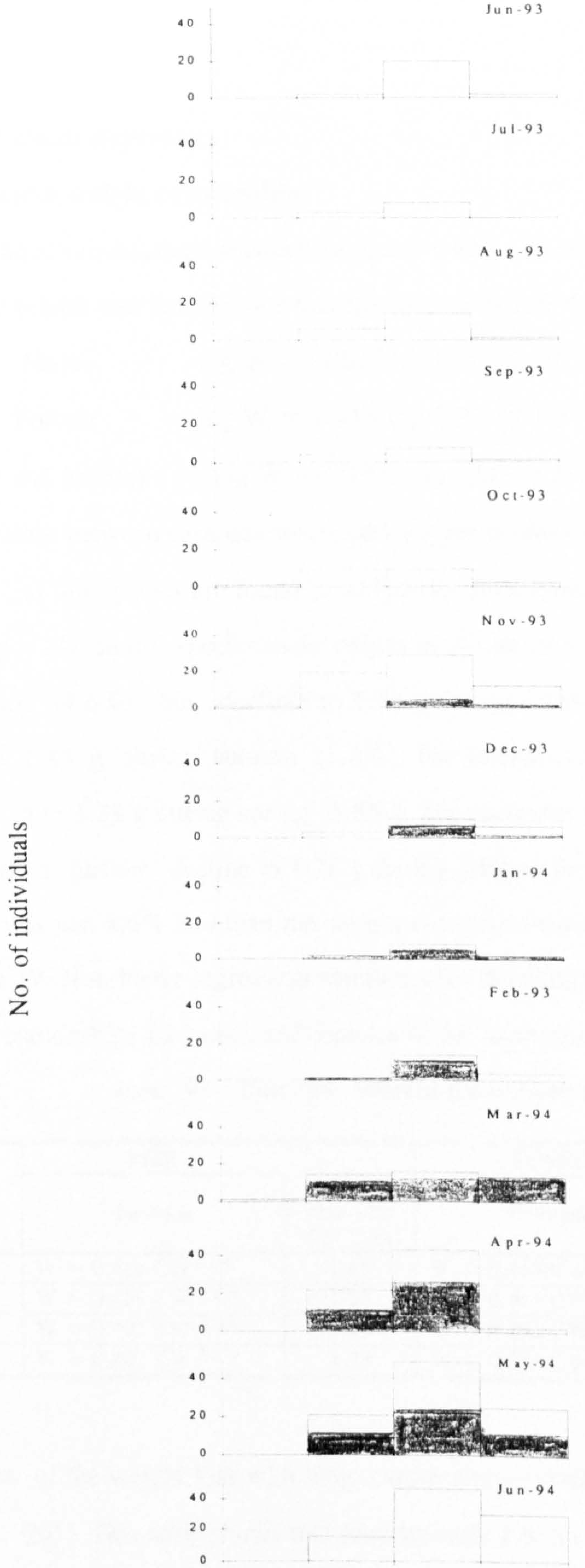


Figure 12: *Serenella leachii* carapace width (CW) frequency distribution based on monthly samples (black = ovigerous females).

Macrophthalmus depressus

Carapace width-weight relationship

The logarithmic relationships between carapace width - weight of males, females and total sample (males and females) for this species are as follows:

Male $\log W = 3.0687 \log CW - 0.3706$

Female $\log W = 2.913 \log CW - 0.3867$

Total (male and female) $\log W = 3.0307 \log CW - 0.3855$

The relationship between carapace width and weight is shown in Fig. 13.

The males of this species are found to be heavier than females throughout the study period (Fig. 14). In this species male weight in winter of 1.45 g increases to 1.52 g during spring (4.6%), but declines to 1.43 g during summer (5.9%), with a slight increase to 1.45 g during autumn (1.4%). For female crabs, the weight increases from 1.31 g to 1.39 g during spring (5.8%), but decreases to 1.31g during summer (5.8%) with a further decline to 1.25 g during autumn (4.6%), but during autumn the weight was just 4.6% less than the weight recorded in winter (Tab. 19).

Table 19: Non-linear regression equations for the carapace width - weight relationships for males and females of *M. depressus*, by season, from June '93 - June '94. Weight for a given size.

Season	Male		Female	
	Equation	Wt.g for crab with CW 2 cm	Equation	Wt.g for crab with CW 2 cm
Winter	$W = 0.414\ CW^{3.09}$	1.45	$W = 0.414\ CW^{2.833}$	1.31
Spring	$W = 0.439\ CW^{3.059}$	1.52	$W = 0.441\ CW^{2.827}$	1.39
Summer	$W = 0.407\ CW^{3.091}$	1.43	$W = 0.391\ CW^{2.989}$	1.31
Autumn	$W = 0.407\ CW^{3.123}$	1.45	$W = 0.344\ CW^{3.185}$	1.25

Comparison of the weight loss with temperature shows variation according to size of crab (Tab. 20). This table shows that females with 1.5 cm CW and 2.5 cm CW are similar, but those of latter size body weight increases by 8.3% during the summer. In contrast, the weight of males of 2.5 cm CW drops by 1.4% in summer, and those of 1.5 cm CW lose 1.7% weight in summer.

Tables 20: Seasonal changes in mean weight for male and female *M. depressus* during winter and summer of the datat collected between Jun. '93 - Jun. '94.

		Male		Female	
Season	Mean temp. °C	1.5 cm	2.5 cm	1.5 cm	2.5 cm
Winter	12.8	1.45	7.02	1.31	5.55
Summer	28.9	1.43	6.91	1.31	6.05

Carapace width-weight ratio

Weight-width ratios for a total of 1134 Specimens of *M. depressus* comprising of 619 males and 515 females were studied during the present investigation (Tab. 21). In all size classes male mean weights were heavier than those obtained for females, with exception of size classes 0.5 - 1.0 cm. which favoured females. In terms of mean width, male are also slightly longer than females.

Table 21: Carapace width - weight for male and female *M. depressus* collected from the coast of Qatar (Jun. '93 - Jun. '94).

	Male				Female			
Carapace width (cm)	No. of Crab	Mean width (cm)	Mean weight (g)	Weight / width %	Weight / width %	Mean width (cm)	Mean weight (g)	No. of Crab
0.5 - 1.0	75	0.81±0.1	0.24±0.1	29.6	48.4	0.91±0.1	0.44±0.6	19
1.0 - 1.5	95	1.29±0.2	1.11±0.9	86.1	73.2	1.27±0.2	0.93±0.5	99
1.5 - 2.0	175	1.75±0.7	3.04±0.7	173.7	125.0	1.76±0.1	2.20±0.5	262
2.0 - 2.5	216	2.24±0.1	5.22±1.2	233.0	175.4	2.15±0.1	3.77±0.9	127
2.5 - 3.0	58	2.60±0.1	8.14±1.5	313.1	189.9	2.66±0.2	5.05±1.5	8

* denotes a significant difference from 1 : 1 ratio ($df = 1$, $P<0.05$).

Sex ratio

The sex ratio of crabs of 0.5-1.0 cm, 2.0-2.5 cm and 2.5-3.0 cm is significant at the 5% level in favour of males and at size 1.5-2.0 cm, in favour of females. The sex-ratio of the crabs in the 1.0-1.5 cm size-class is 0.9:1 in favour of females, but this is not significantly different from a population having 1:1 ratio (χ^2 =0.52, df=1, P<0.05) (Tab. 22). The sex-ratio was in favour of females in months of September '93 (59.3%), October '93 (51.9%), December '93 (62.7%), January '94 (64.2%) and June '94 (51.6%) while in the remaining months males show dominance over females. The highest number of males appeared in the sample of June '93 (72.6%) and in the July '93 sample and a mounted to 74.6% of total sample. χ^2 values are insignificant at the 5% level during months of June -July '93, December '93 to January and April '94 (Tab. 23).

Table 23: Sex ratio of *M. depressus* for different carapace width-size class.

Size - class	No. of Male	No. of female	Total	% of Male	% of Female	Chi-square
(0.5 -1.0)	75	19	94	79.8	20.2	33.4*
(1.0 -1.5)	92	102	194	47.4	52.6	0.52
(1.5 -2.0)	167	270	437	38.2	61.8	24.3*
(2.0 -2.5)	214	129	343	62.4	37.6	21.1*
(2.5 - 3.0)	56	10	66	84.9	15.2	32.1*

* denotes a significant difference from 1 : 1 ratio (*df* = 1, P<0.05).

Table 24: Sex ratio *M. depressus* crab species for different months.

Month	No. of male	No. of female	Total	% of male	% of female	Chi-square
Jun-93	37	14	51	72.6	27.5	10.4*
Jul.	47	16	63	74.6	25.4	15.3*
Aug.	60	54	114	52.6	47.4	0.32
Sep.	37	54	91	40.7	59.3	3.18
Oct.	37	40	77	48.1	51.9	0.12
Nov.	37	26	63	58.7	41.3	1.92
Dec.	25	42	67	37.3	62.7	4.31*
Jan-94	19	34	53	35.9	64.2	4.25*
Feb.	36	27	63	57.1	42.9	1.29
Mar.	62	54	116	53.5	46.6	0.55
Apr.	86	49	135	63.7	36.3	10.1*
May	47	41	88	53.4	46.6	0.41
Jun.	74	79	153	48.4	51.6	0.16

* denotes a significant difference from 1 : 1 ratio (*df* = 1, P<0.05)

Size composition and distribution

The numbers of *M. depressus* collected were 604 males and 530 females, ranging in CW from 0.47-2.98 cm and 0.74-2.97 cm, respectively. In terms of wet weight, males ranged from 0.04-11.161 g, whereas females were from 0.094-9181 g. Tab. 24 shows that the mean CW for males ranged from a minimum of 1.39±0.55 cm during April '94 while the maximum of 2.12±0.37 cm was observed during August '93. The mean CW for females ranged from a minimum of 0.88±0.40 cm during June '94 and a maximum of 1.94±0.36 cm was observed during '93. In terms of wet weight, the minimum and maximum means for males and females were found to range from 1.7±1.90 g to 4.62±2.40 g; and 2.69±1.80 to 3.03±1.77 g, respectively, during the above -mentioned periods. However, the high standard deviation values of CW and Wt. indicates the wide range of crabs used in this investigation. The carapace width frequency distribution of *M. depressus* based on 0.5 cm size-classes, of all males and females in collections is shown in Fig. 15. There was a single mode, at size (2.0-2.5 cm) for all males and a single mode, at size ranged (1.5-2.0 cm) for all females and ovigerous females data sets.

Table 24: seasonal changes in mean carapace width and weight for male and female *M. depressus* collected from coast of Qatar (Jun-93 to Jun-94).

Month	Male			Female		
	No. of crabs	Carapace width (cm)	Wet weight (g)	No. of crabs	Carapace width (cm)	Wet weight (g)
Jun-93	37	2.05±0.30	3.73±1.75	14	1.61±0.30	1.66±0.90
Jul.	47	1.86±0.29	3.13±1.37	16	1.55±0.26	1.43±0.66
Aug.	60	1.84±0.53	3.61±2.88	54	1.66±0.40	2.17±1.40
Sep.	37	2.12±0.37	4.62±2.40	54	1.87±0.23	2.66±0.76
Oct.	37	2.05±0.37	4.30±2.08	40	1.94±0.36	3.03±1.77
Nov.	37	1.95±0.39	3.58±1.75	26	1.66±0.30	1.90±0.94
Dec.	25	2.00±0.40	4.10±2.13	42	1.91±0.27	2.81±0.98
Jan-94	19	1.94±0.63	4.07±2.55	34	1.67±0.43	2.15±1.32
Feb.	36	1.84±0.66	3.67±2.86	27	1.77±0.39	2.32±1.11
Mar.	62	1.54±0.63	2.58±2.55	54	1.76±0.39	2.19±1.14
Apr.	86	1.39±0.55	1.70±1.90	49	1.63±0.40	1.99±1.13
May	47	180±0.61	3.54±2.95	41	1.73±0.37	2.18±1.16
Jun.	74	1.93±0.61	4.57±3.02	79	0.88±0.40	2.69±1.80

Reproduction season

Fig. 21 shows that the small-sized *M. depressus* are found in most months during the sampling periods, and ovigerous females are seen almost throughout the year, with larger size classes during the summer months.

The smallest crab observed bearing eggs was 0.90 cm and the largest was 2.93 cm in CW. The percentage of ovigerous females in different size-classes is shown in Fig. 22. The maximum number was seen in the size range of 2.5-3.0 cm CW, and the minimum number at a CW of 0.5-1.0 cm.

Ovigerous females were found throughout the year except for December, indicating that this species is an almost continuous breeder in Qatar.

In the course of this study a total of 183 ovigerous females of *M. depressus* were collected with 88.9% ovigerous females in September , and a second peak in March with 61.1% ovigerous females. In Fig. 16, the percentage of ovigerous females of *M. depressus* in different size groups is presented. The highest percentage (46.46%) of ovigerous females was in the 2.5 - 3.0 cm size class, but the highest individual number with 38.9 % was in the 1.5-2.0 cm class - size. From Fig. 22 it is obvious that the middle size - classes for all species represent the most active spawners. In the small size - classes the incidence of ovigerous females was comparatively low as was the case with larger individuals.

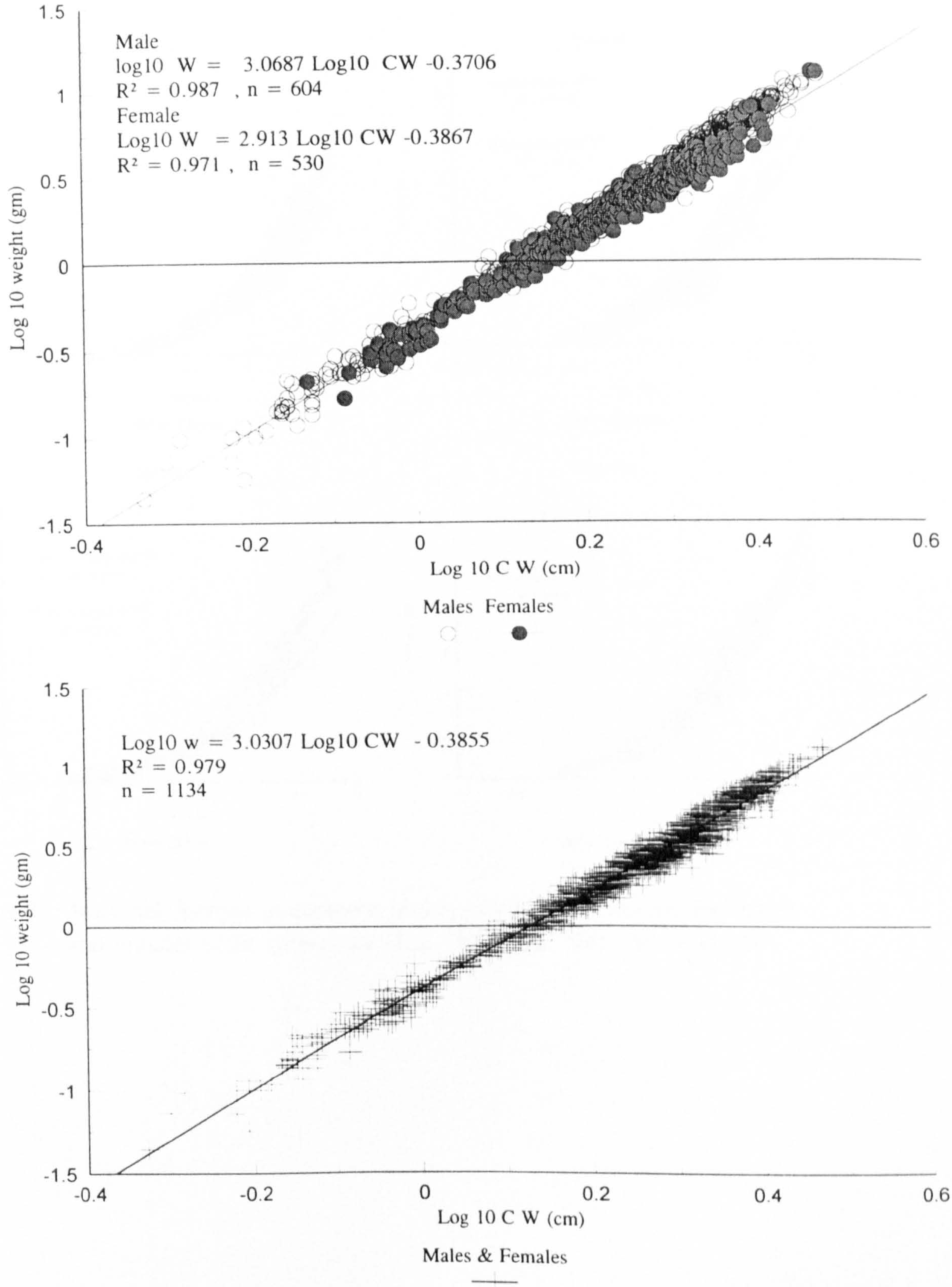


Figure 13 : Estimated regression of Log10 weight against Log10 C W for *Macrophthalmus depressus*.

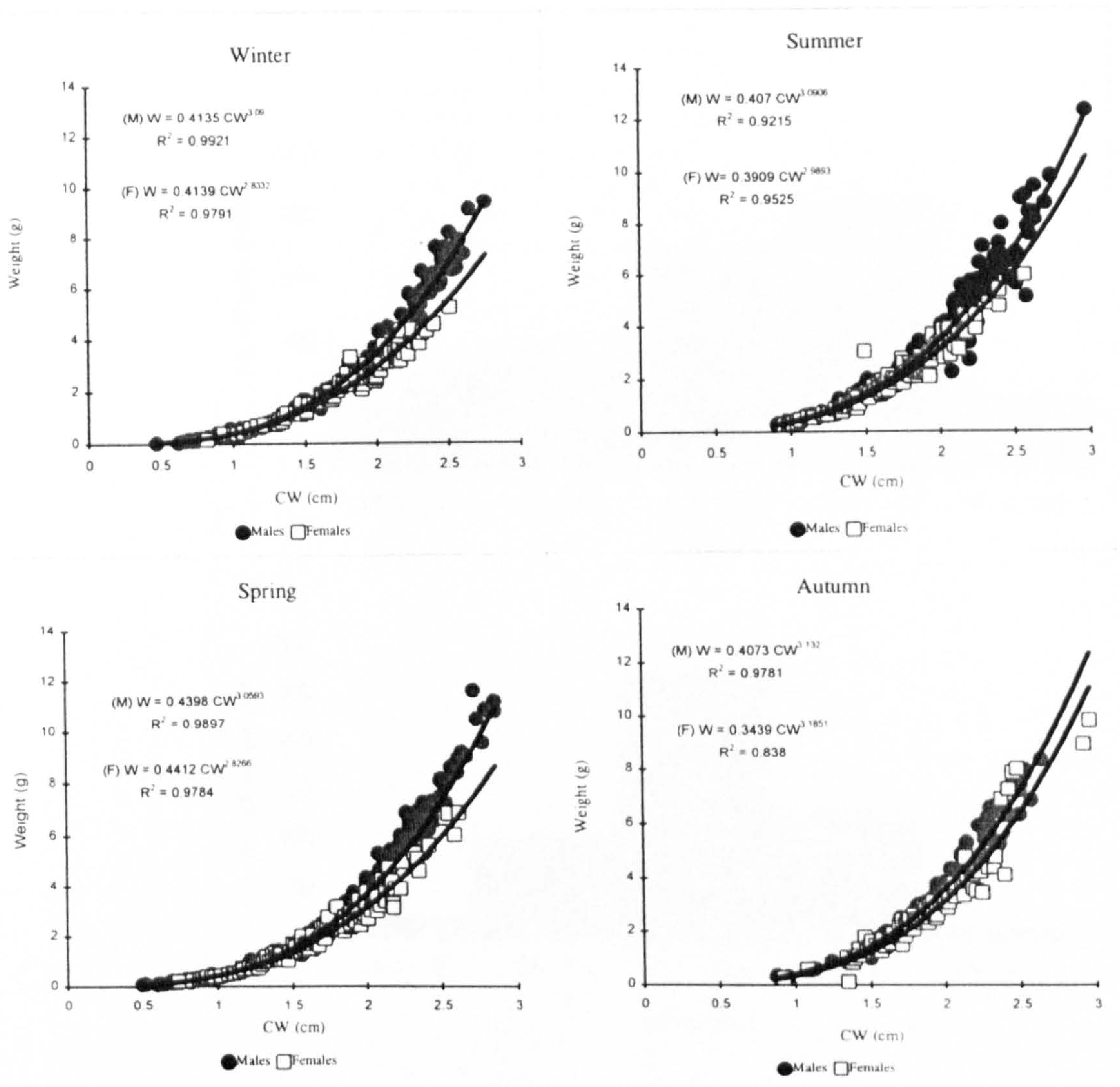


Figure 14: Seasonal changes in carapace width - weight relationship for males and females of *M. depressus* (Jun. '93 - Jun. '94) . $W = a*CW^b$.

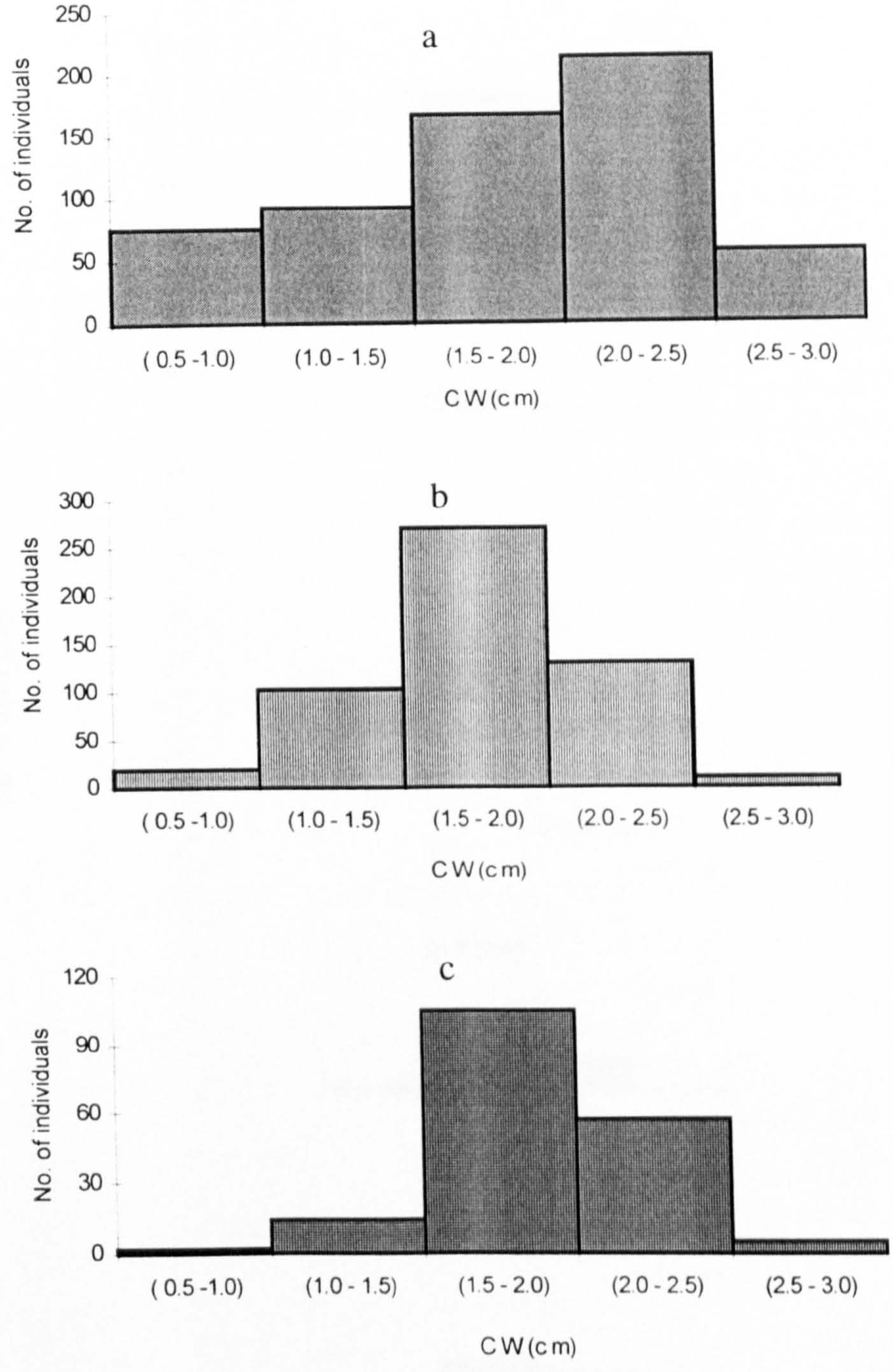


Figure 15: Carapace width (CW) distribution of *Macrophthalmus depressus* of (a) males, (b) females and (c) ovigerous females.

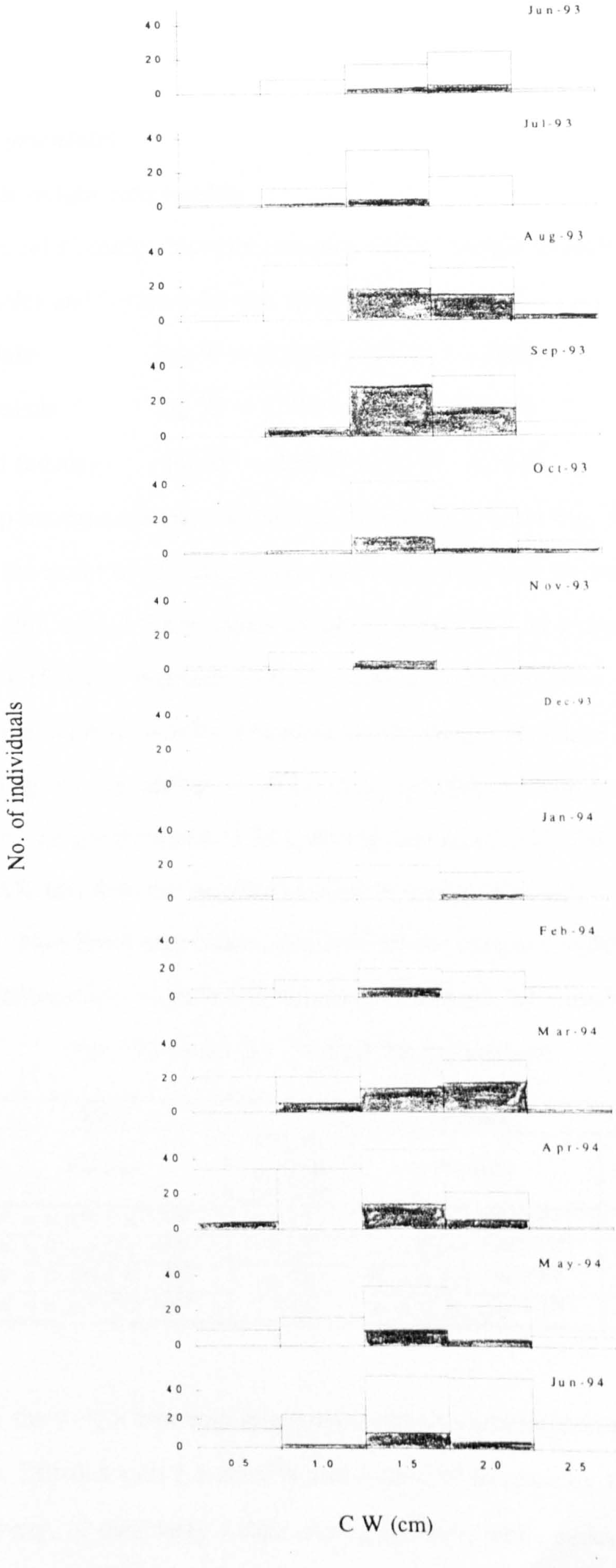


Figure 16: *Macrophthalmus depressus* carapace width (C W) frequency distribution based on monthly samples (black = ovigerous females).

Eurycarcinus orientalis

Carapace width-weight relationship

The logarithmic relationships between carapace width - weight of males, females and total sample (males and females) for this species are as follows:

Male $\log W = 2.9629 \log CW - 0.3818$

Female $\log W = 2.7699 \log CW - 0.3478$

Total (male and female) $\log W = 2.9127 \log CW - 0.3845$

The relationship between carapace width and weight is shown in Fig. 17.

Fig. 18 shows the males of this species are heavier than females throughout the year. For a given width, e.g., 2.5 cm, males weight in winter of 7.17 g declines to 6.07 g during spring (-15.3%), increases to 6.34 g during summer (4.3%), and decreases to 6.05 g during autumn (-4.6%). For females, the weight decreases from 5.77 g in winter to 5.71 g during spring (-1.4%), but increases to 5.84 g during summer (1.7%), and the weight decline to 5.34 g during autumn (8.6%). During autumn the weight was 7.5% less than the weight recorded in winter (Tab. 25).

Table 25: Non-linear regression equations for the carapace width - weight relationships for male and female *E. orientalis*, by season, from June '93 - June '94. Weight for a given size.

Season	Male		Female	
	Equation	Wt.g for crab with CW 2 cm	Equation	Wt.g for crab with CW 2 cm
Winter	$W = 0.676\ CW^{2.578}$	7.17	$W = 0.462\ CW^{2.756}$	5.77
Spring	$W = 0.391\ CW^{2.994}$	6.07	$W = 0.455\ CW^{2.759}$	5.71
Summer	$W = 0.405\ CW^{3.003}$	6.34	$W = 0.427\ CW^{2.855}$	5.84
Autumn	$W = 0.385\ CW^{3.005}$	6.05	$W = 0.361\ CW^{2.938}$	5.34

Comparison of the weight loss with temperature shows variation according to size of crab (Tab. 26). Females with 2.5 cm CW and 4 cm CW increase by 1.2% and 5.8%, respectively, of their body weight during summer, while males with 2.5 cm CW lose 11.6% in summer. In contrast, the weight of males of 4 cm CW increases by 7.5% in summer over weight recorded during winter.

Tables 26: Seasonal changes in mean weight for male and female *E. orientalis* during winter and summer of the datat collected between Jun. '93 - Jun. '94.

		Male		Female	
Season	Mean temp. °C	2.5 cm	4 cm	2.5 cm	4 cm
Winter	12.8	7.17	24.08	5.77	21.06
Summer	28.9	6.34	26.02	5.84	22.36

Carapace width-weight ratio

Weight-width ratio of this species fluctuated. Males CW ranged from 0.5 - 4.5 cm (n=221) and females CW ranged from 1.0 - 4.5 cm (n=191). In terms of weight, male mean weight was heavier than female, with exception of size 1.0 - 1.5 cm which favoured females. The same pattern was found in the mean width (Tab. 27).

Table 27: Carapace width - weight for male and female *E. orientalis* collected from the coast of Qatar (Jun. '93 - Jun. '94).

	Male				Female			
Carapace width (cm)	No. of Crab	Mean width (cm)	Mean weight (g)	Weight / width %	Weight / width %	Mean width (cm)	Mean weight (g)	No. of Crab
0.5 - 1.0	8	0.86±0.1	0.28±0.1	32.6				
1.0 - 1.5	8	1.18±0.2	0.80±0.6	67.8	70.68	1.33±0.1	0.94±0.3	5
1.5 - 2.0	7	1.84±0.1	2.49±0.5	135.3	126.4	1.74±0.1	1.21±0.5	9
2.0 - 2.5	14	2.24±0.1	4.98±2.1	222.3	175.4	2.11±0.8	3.70±0.1	16
2.5 - 3.0	28	2.77±0.1	8.39±1.7	302.9	268.8	2.72±0.2	7.31±1.3	40
3.0 - 3.5	63	3.30±0.2	14.47±2.3	438.5	362.7	3.22±0.1	11.7±1.9	70
3.5 - 4.0	85	3.71±0.1	20.49±2.8	552.3	438.4	3.65±0.1	16.0±6.4	48
4.0 -4.5	8	4.17±0.2	27.64±3.7	662.8	590.5	4.30±0.2	25.4±2.4	3

Sex ratio

Differences in sex-ratios from 1:1 are not significant at the 5% level for most size-classes, with the exception of the size class of (3.5-4.0 cm) which was comprised of males only (Tab. 28). However, the monthly sex-ratios were found to fluctuate, sometimes in favour of females and at other times in favour of males. The overall proportion of males and females did not deviate much from the 1:1 and χ^2 values are not significant at 5% level (Tab. 29).

Table 28: Sex ratio of *E. orientalis* for different carapace width-size class.

Size - class	No. of Male	No. of female	Total	% of Male	% of Female	Chi-square
Eurycarcinus orientalis						
(0.5 - 1.0)	8	-	8	100.0	-	
(1.0 - 1.5)	8	5	13	61.5	38.5	0.69
(1.5 - 2.0)	7	9	16	43.8	56.3	0.25
(2.0 - 2.5)	14	16	30	46.7	53.3	0.13
(2.5 - 3.0)	28	40	68	41.18	58.8	2.12
(3.0 - 3.5)	63	70	133	47.4	52.6	0.37
(3.5 - 4.0)	85	48	133	63.9	36.1	10.3*
(4.0 -4.5)	8	3	11	72.7	27.3	2.27

* denotes a significant difference from 1 : 1 ratio (*df* = 1, P<0.05).

Table 29: Sex ratio of *E. orientalis* for different months.

Month	No. of male	No. of female	Total	% of male	% of female	Chi-square
Eurycarcinus orientalis						
Jun-93	1	5	6	16.7	83.3	2.67
Jul.	29	18	47	61.7	38.3	2.57
Aug.	19	10	29	65.5	34.5	2.79
Sep.	8	12	20	40.0	60.0	0.80
Oct.	9	9	18	50.0	50.0	0.00
Nov.	12	5	17	70.6	29.4	2.88
Dec.	16	12	28	57.1	42.9	0.57
Jan-94	20	12	32	62.5	37.5	2.00
Feb.	26	28	54	48.2	51.9	0.07
Mar.	21	18	39	53.9	46.2	0.23
Apr.	30	20	50	60.0	40.0	2.00
May	14	20	34	41.2	58.8	1.06
Jun.	16	22	38	42.1	57.9	0.95

* denotes a significant difference from 1 : 1 ratio (*df* = 1, P<0.05)

Size composition and distribution

The total *E. orientalis* collected were 221 males and 191 females, ranging in CW from 0.78-4.48 cm and 1.01-4.48 cm, respectively. In terms of wet weight, males ranged from 0.190-35.413 g, whereas females were from 0.343-28.101 g. Tab. 30 shows that the mean CW for males ranged from a minimum of 2.62±0.57 cm during July '93 to a maximum of 3.48±0.40 cm during January '94. The mean CW for females ranged from a minimum of 2.63±0.58 cm during July '93 to a maximum of 3.38±0.39 cm during April '94. In terms of wet weight, the minimum and maximum weight for males and females were found to range from 8.68±5.33 g to 17.31±4.94g; and 7.47±5.63 to 13.81±4.06 g, respectively, during the above-mentioned periods. There was a single mode, at size range (3.5-4.0 cm), in the CW frequency distribution of all males collected during investigation (Fig. 19) and a single mode, at size ranged (3.0-3.5 cm) for all females and ovigerous females.

Table 30: seasonal changes in mean carapace width and weight for male and female *E. orientalis* collected from coast of Qatar (Jun-93 to Jun-94).

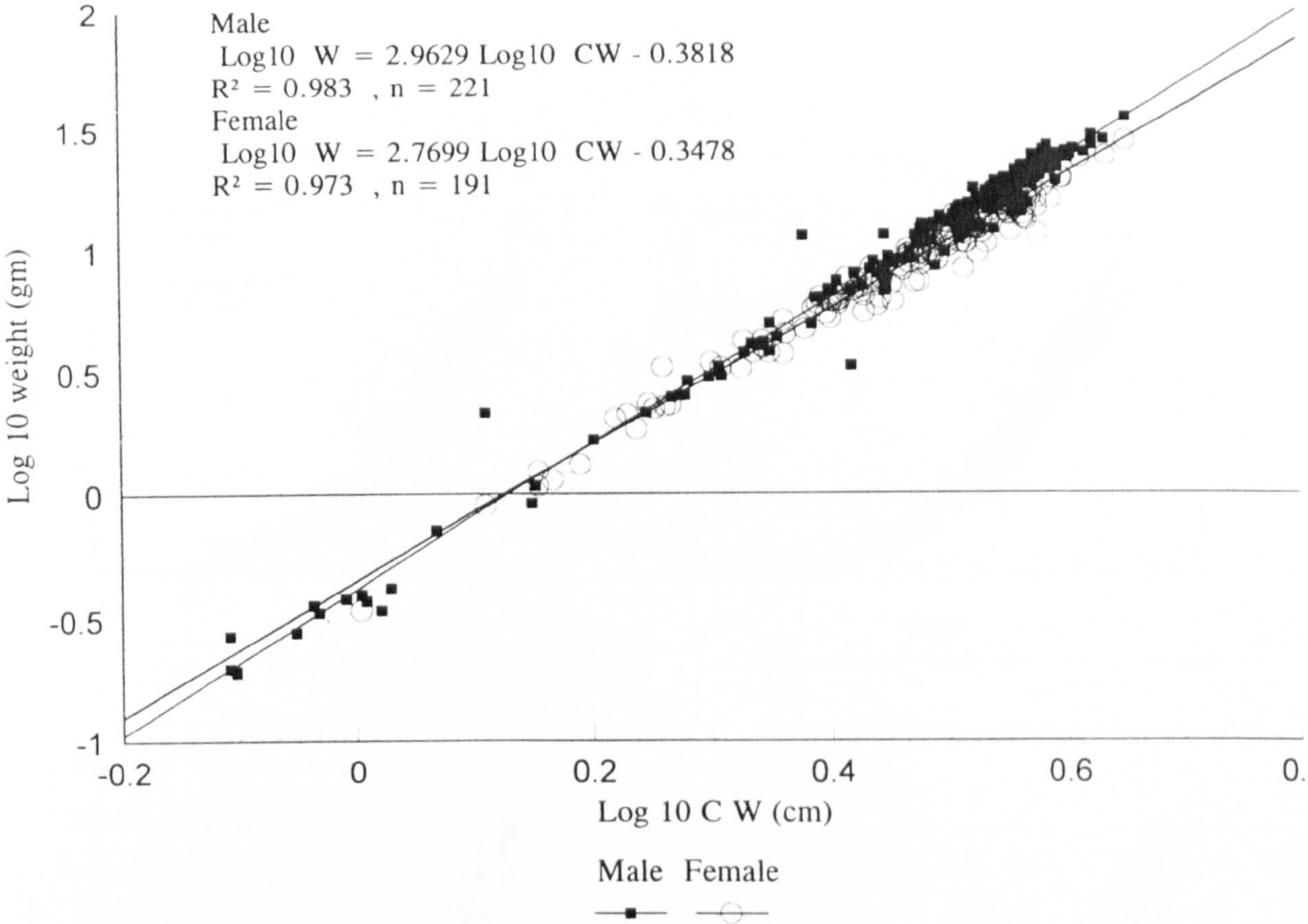
Month	Male			Female		
	No. of crabs	Carapace width (cm)	Wet weight (g)	No. of crabs	Carapace width (cm)	Wet weight (g)
Jun-93	1	4.19±0.00	29.78±0.00	5	3.08±0.48	11.71±5.70
Jul.	29	2.62±0.57	8.68±5.33	18	2.63±0.58	7.47±5.63
Aug.	19	2.87±0.99	13.11±9.38	10	3.23±0.75	13.15±6.33
Sep.	8	3.20±0.97	15.18±8.32	12	2.92±0.74	10.45± 6.25
Oct.	9	3.34±1.01	17.15±7.74	9	3.39±0.31	12.33±2.91
Nov.	12	3.36±0.87	17.42±7.51	5	2.77±1.01	9.19±5.48
Dec.	16	3.48±0.37	16.89±5.60	12	3.36±0.48	13.24±4.21
Jan-94	20	3.48±0.43	17.31±4.94	12	3.16±0.60	10.72±4.30
Feb.	26	3.40±0.40	16.33±5.10	28	2.74±0.62	8.36±4.36
Mar.	21	3.34±0.63	16.66±7.39	18	3.05±0.39	10.32±3.40
Apr.	30	3.18±0.82	14.68±7.52	20	3.38±0.39	13.81±4.06
May	14	2.82±1.16	12.48±8.74	20	3.03±0.73	10.72±5.06
Jun.	16	2.83±1.03	11.48±7.12	22	3.13±0.53	11.12±4.48

The population of *E. orientalis* tended to be concentrated in smaller and medium size-classes during July '93 to September "93 and from April '94 to June '94. There were more individuals in the medium and larger size-classes from December '93 to June '94 (Fig. 20).

Reproduction season

The smallest crab observed bearing eggs was 1.66 cm and the largest was 4.31 cm in CW. The maximum number of ovigerous crabs are seen in the two size ranges (1.5-2.0 cm) and (4.0-4.5 cm) (Fig. 21).

Only 13 ovigerous females of this species appeared in the population during six months (Fig. 22). March to June seem to be the main period of breeding of this species. An initial increase to 11.1% was seen in March followed by a slight decrease during the next months and although 13.6% were found in June of the small number of ovigerous females collected most were found in the size - class 3.0 - 4.0 cm.



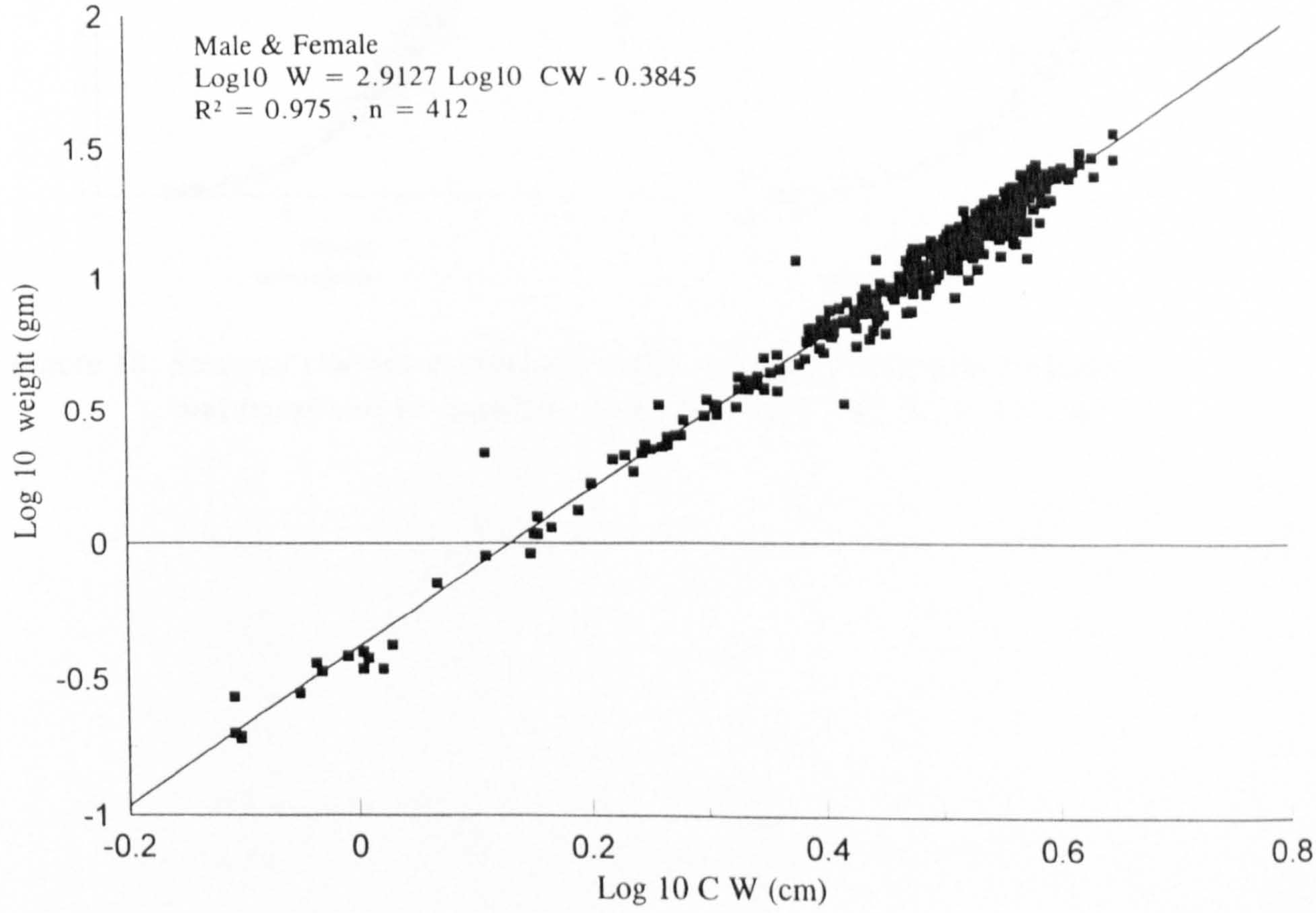


Figure 17: Estimated regression of Log10 weight against Log10 carapace width (CW) for *Eurycarcinus orientalis*.

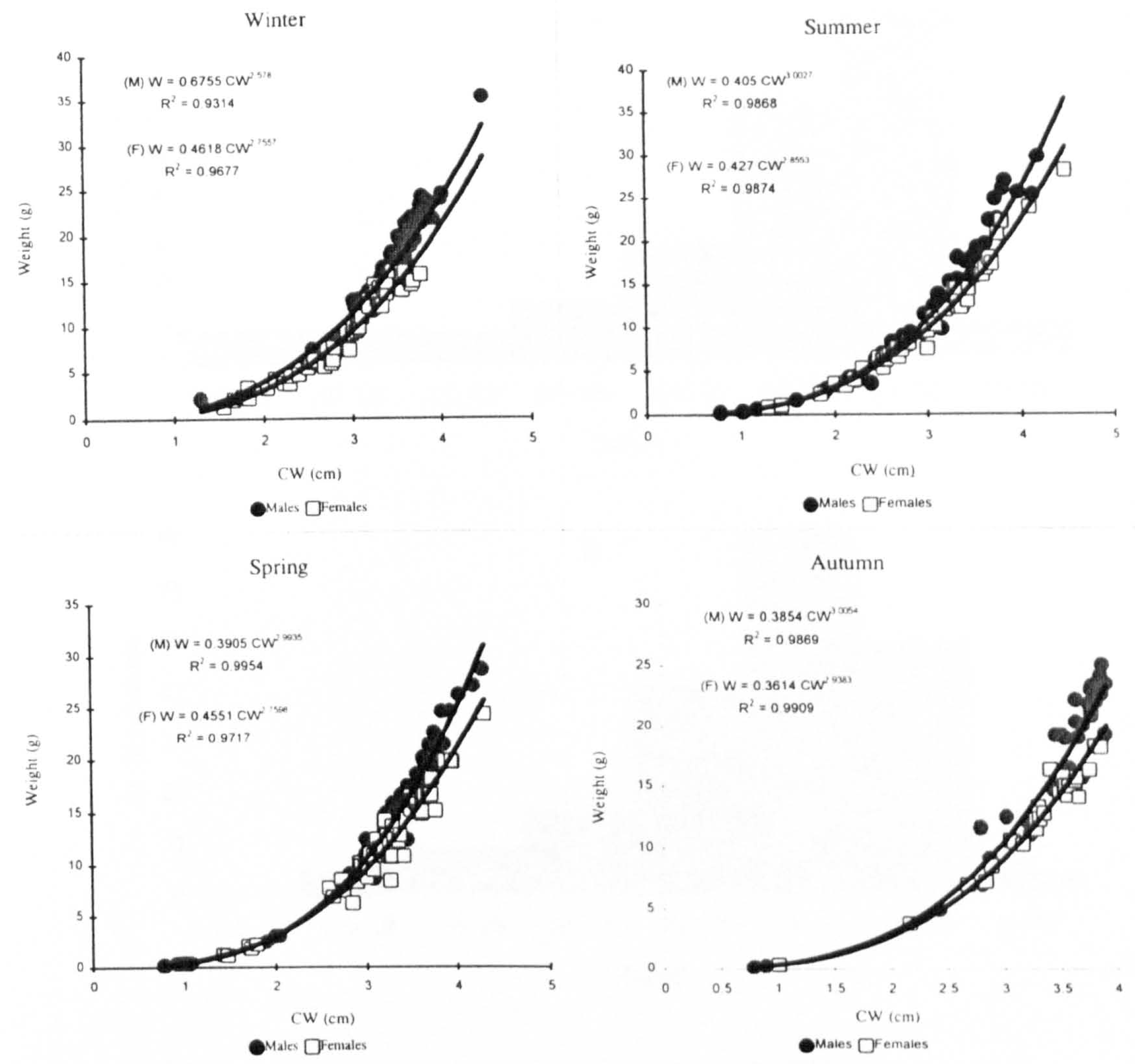


Figure 18: Seasonal changes in carapace width - weight relationship for males and females of *E. orientalis* (Jun. '93 - Jun. '94). $W = A^{*} CW^{b}$.

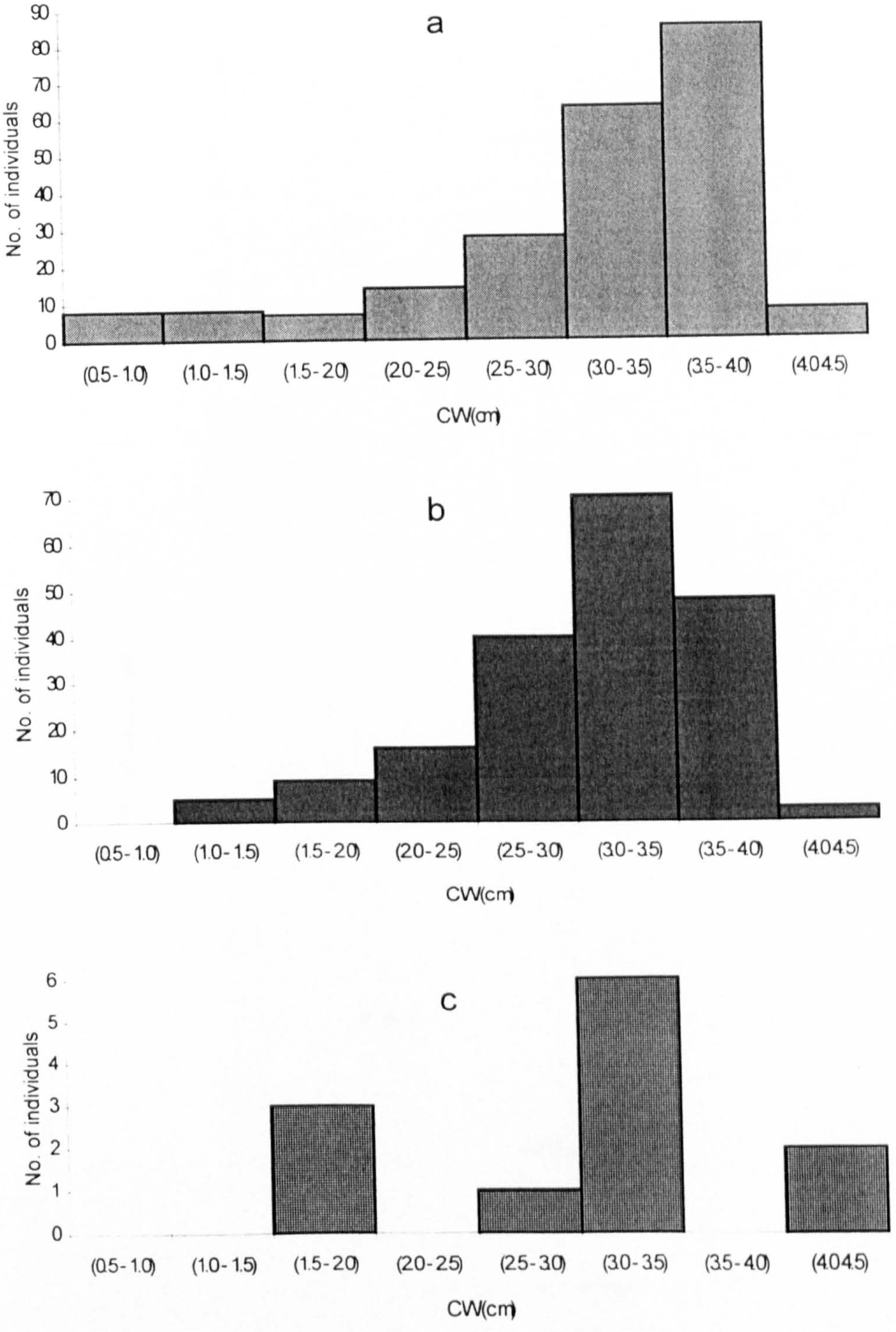


Figure 19: Carapace width (CW) distribution of *Eurycarcinus orientalis* of (a) males, (b) females and (c) ovigerous females.

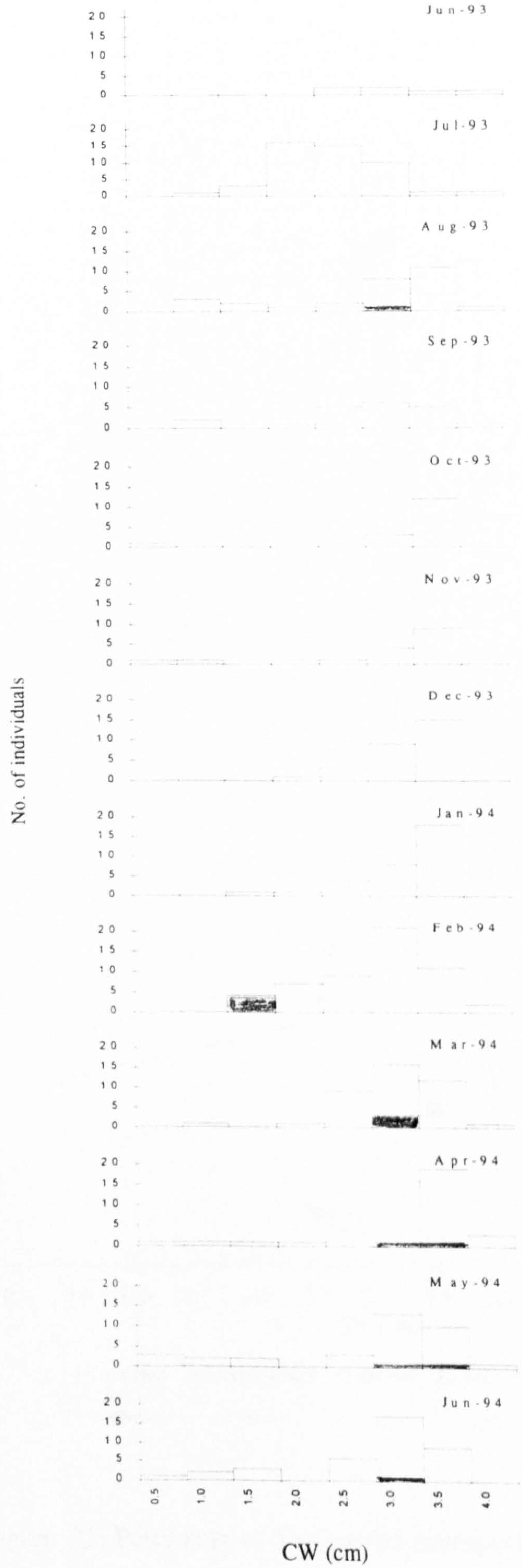


Figure 20: *Eurycarcinus orientalis* carapace width (CW) frequency distribution based on monthly sample (black = ovigerous female)

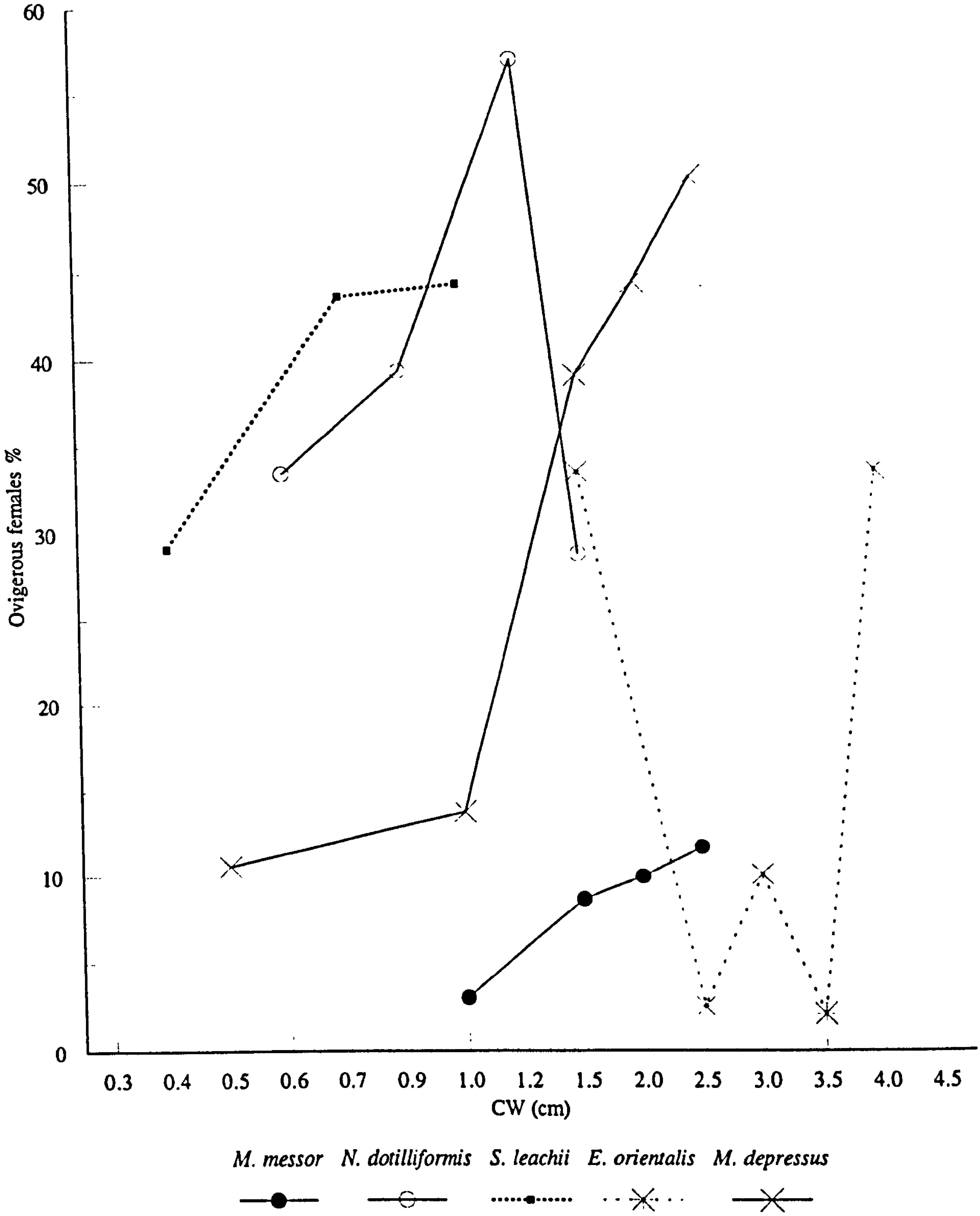


Figure 21: Percentage of 5 ovigerous crab species at different size groups.

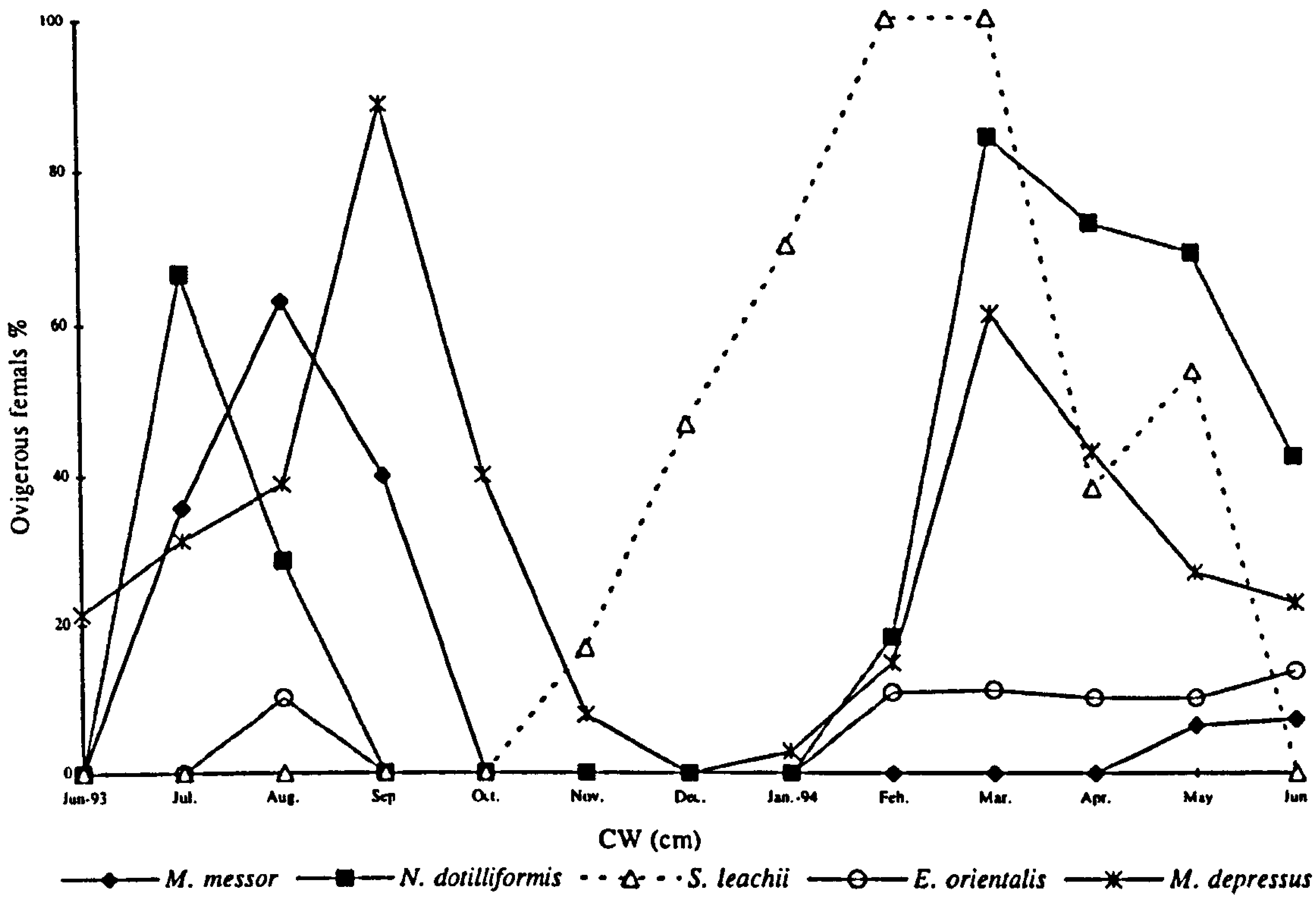


Figure 22: Percentage of ovigerous females of 5 crab species collected from coast of Qatar (Jun. '93 - Jun. '94).

DISCUSSION

Carapace width - weight relationship

Studying the biological characteristics of 5 species of intertidal crabs during the course of this investigation has revealed detailed information on their population dynamics in Qatari waters, including carapace width - weight relationship; sex ratio; size composition; and reproductive season.

Since the values of the (b) for the logarithmic relationships between carapace width - weight equation calculated for these 5 crabs species are close to 3, it can be concluded that the weight of these species increased approximately as the cube of its width. This normal relationship implies that the environment was adequate for all species.

For *N. dotilliformis*, *S. leachii* and *M. depressus* there is little difference between slope values (Figs. 5,9,17) indicating that there is little sexual dimorphism and hence (Figs. 5b,9b,17b) a single regression suffices to describe the species (Hartnoll, 1982). However, for *M. messor* and particularly *E. orientalis* the slope value for the males is higher than for females. This is probably due to the postive allometry of the chelae (Hartnoll, 1982). The former mud deposit feeding species primarily utilise the chelae for collecting and sifting particles and hence show little sexual differentiation whereas the scavenging and predatory male *Metopograpsus* and *Eurycarcinus* grow large chelae typical of other predatory species such as *Cancer pagurus* (Hancock and Edwards 1966).

The carapace width - weight measurements reveal that for the some carapace widths males of all species were heavier than females. Whilst this might be expected for predatory species with large male chelae it is difficult to explain why in present species with similar chelae in both sexes, females should be lighter.

For the females of all species seasonal changes in weight for crabs of the same carapace width occurred with highest weights in winter and lowest in summer. As winter water temperatures drop to 12.8°C and summer temperatures exceed 29°C and salinity varies from 34 to 57‰ this might be explained by water loss from crabs during the summer period (Tagatz, 1965). However, apart from female *M. messor*, which follows the male pattern, females of all other species show greatest seasonal weights during autumn (*N. dotilliformis*, *S. leachii*) or summer (*E. orientalis*, *M. depressus*). For the females of these species it is likely that accumulation of reproductive biomass in connection with spawning masks any environmentally related weight loss.

The only other data on the population structure of present species is for *Nasima dotilliformis* (Snowden and Clayton, 1995) in Kuwait. These authors suggested that in females instar number was variable or widely overlapping size ranges and in males there were instars at 4.75, 7.25 and 9.25 mm. Comparison with present data indicates that in Kuwait neither sexes of this species grow to a large size (males and females 1.5 - 1.78 cm CW) and in Qatar have a median CW of 0.8 cm as opposed to 0.6 cm in Kuwait where temperatures drop to 0°C in January (Jones, 1986). This may reduce growth rates for this species in the north of the Gulf. These authors record a sharp decline in population densities for this species in February (Snowden and Clayton, 1995).

Sex ratio

For *M. messor* an evaluation of the probability of equal abundance of the sexes in each size class, indicates that in most size classes significant departure from expected 1 : 1 ratio in favour of males. Also it is noted that at the size class of (1.5 - 2.5 cm) the sexes are more or less equally abundant. Overall, males of *M. messor* were significantly more common than females with an overall M:F ratio of 2.01 : 1, while the ratio tended to decline during breeding period between August-September. For *N. dotilliformis* the sex ratio in smaller and higher size - classes (0.3 - 0.9 cm and 1.5 - 1.8 cm respectively) is in favour of males, while in mid size class between 0.9 - 1.5 cm there was no significant differences. Overall, males of *N. dotilliformis* were significantly more common than females with an overall M:F ratio of 1.61 : 1, while the ratio tended to decline during the breeding period between February-March. In Kuwait, *Nasima dotilliformis* was investigated by Snowden and Clayton (1995) and they found that none of the sex ratios in the various size classes differed from 1 : 1, indicating that *N. dotilliformis* follows the 'standard' sex ratio pattern of Wenner (1972). For *S. leachii* up to a size class of 0.7 cm there was no significant departure from the expected 1 : 1 ratio, but over 0.7 cm it was a significant at 5% level with a preponderance of females. Overall, female *S. leachii* were significantly commoner than males, while the ratio tended to decline outside the breeding period (October). For *E .orientalis* the sex ratio in the various size classes did not differ from 1 : 1, with the exception of the size class of (3.5 - 4.0 cm) where there was a significant difference at 5% level in favour of males. Overall, males of *E .orientalis* were significantly more common than females with an overall M:F ratio of 1.86 : 1, while the ratio declined during breeding period between February- June. For *M. depressus* the sex ratio in most size classes differed from 1 : 1, with exception of the size class of (1.0 - 1.5 cm). The males, however were significantly more abundant in the smaller and higher size classes, while females were significantly higher in the mid size - class during breeding periods. For most species in the present study there is a trend for either males or females to dominate in populations outside the main reproductive season. As there is no evidence that these species change sex it must be concluded that differing behaviour patterns exist for each sex which lead to under sampling of one or other sex outside the breeding season. Other authors (Haley, 1979; Frith & Brunenmeister, 1980; Dittel *et al.*, 1985; Conde & Diaz 1989) report differences in the ratio according to size for different crustaceans and have proposed many reasons for this population structure. Although deviations from 1 : 1 are more common amongst brachyurans consistent 1 : 1 ratios in ocypodids have been reported by Simons and Jones (1981) and Snowden *et al.*, (1991). In present work it is possible that either non-ovigerous females remain at deeper levels in burrows outside the breeding season, or that males remain on the surface to exhibit territorial displays (Clayton, 1988). Clearly further research into the behaviour of these species is required to substatiate such speculation.

Reproduction season

Determination of size at sexual maturity is not only of scientific interest, but also of practical value as it serves as an important tool in the studies of population dynamics and management of commercially exploited resources (Prasad *et al.*, 1954; Campbell *et al.*, 1986; Jacob *et al.*, 1990; Reeby *et al.*, 1990). In the present investigation females of *M. messor* attain sexual maturity at 1.4 cm in carapace width, and for *N. dotilliformis* the smallest crab observed bearing eggs was 0.89 cm in CW. For *S. leachii* females attain saxual maturity at 0.5 cm and *E. orientalis* at 1.66 cm, while *M. depressus* matures at 0.90 cm. No information is available about size at sexual maturity for males, but it is not unreasonable to assume that the size at first maturity, as for females of the 5 crab species considered in this study, would also occur in small size classes.

In *M. messor* the peak in the number of juvenile crabs shows that recruitment of this species mainly takes place between October - April with a maximum peak between February - March. Therefore the highest peak of breeding which occurs in August, results in the highest peak of recruitment next February. This suggests that the growth rate is high and the life span is of approximately 1 year. In *E. orientalis* the breeding season take place between February - August, with recruitment between October - November and a maximum recruitment during April - May. Following size class modes the recruitment in October breeds next year in June. A large part of the adult crabs was appear to be lost within 1 year.

For ocypodid species, *N. dotilliformis* was found ovigerous for 6 months, and spawning ocurred during summer, with juvenile settlement during autumn and crabs reaching 0.6 cm by November. The rate of growth was slower during winter (December - January), but the growth rate appears to accelerate from February where breeding of this species started in this month at a size of <0.9 cm CW with the highest peak during March at a size range <1.2 cm. At size < 1.5 cm CW most crabs start to disappear which suggests that the life cycle is about 1 year. In contrast, Jones *et al.*, (1994) found newly settled juvenile *N. dotilliformis* during August in Saudi Arabia, and Apel (1994) reported that the recruitment of this species mainly takes place between November and March. In Kuwait, Snowden and Clayton, 1995) found that the percentage of juvenile and ovigerous females were highest in winter (November - March). The same author reported that winter was therefore the ecologically-active season contrary to the summer breeding cycle normally associated with waters of similar latitudes.

Serenella leachii was observed to be ovigerous continuously from November to May with a high peak of 100% during February and March. The spawning season for this species take place between November - May and the earliest juvenile recruitment occurs between October - November. A large part of adult crabs appears to be lost within one year, and this suggests that after spawning they die during summer. In *M. depressus* breeding occurs in all months except December with 2 highest peaks, one during August - September and the other during March - April. Recruitment of juveniles has a high value between March - June and is highest during March - April. Therefore it is likely that August - September spawning results in juvenile recruitment next year in February - April with slow growth due to low temperature in winter. The larvae released in March - April show juvenile recruitment during May - July of the same year indicating a very fast growth rate. The August - September spawning appears the following year during April, but with maximum recruitment between August - September. The 0.5 cm CW group release in June may form February - March spawners next year as the earliest spawners of the year (Fig. 16). This also suggests that the growth rate is rapid and that the life span is of about 1 year.

In contrast, in Saudi Arabia the longest breeding period was 10 months for *M. depressus* (Tab. 31). Ovigerous females of this species were found between February and October, with 2 peaks of ovigerous females in October and in March, but from November to January there was no reproductive activity (Apel, 1994). Tab. 31

summarises known data on reproduction for present species throughout the Gulf. Comparison on recruitment is difficult as this is defined as minimum size of crabs entering sample sizes collected in present work, but other authors (Apel, 1994) collected 5 mm CW crabs from beneath algal mats. It appearly that *N. dotilliformis* restricts its breeding season in Kuwait where summer temperature are in excess of 45°C. In reviewing crustacean breeding patterns, Sastry (1983) showed that there was a definite tendency toward extended reproductive seasons and continous reproduction with decreasing latitude for benthic shallow-water crustaceans. The majority of tropical species tend to breed continously throughout the year or have prolonged breeding seasons compared to species at higher latitudes (Emmerson, 1994). With increasing latitude, breeding seasons become more restricted to the periods of higher water temperature (Giese & Pearse, 1974; Sastry, 1983) and breeding also commences earlier at lower latitudes (Jones, 1977).

However, on the coast of Qatar reproductive season fluctuates from one species to an other. For *S. leachii* the breeding season takes place from autumn to early summer; for *N. dotilliformis* and *E. orientalis* the breeding season takes place between spring and summer, while for *M. messor* the breeding season is from late spring to early autumn and *M. depressus* between spring and summer. Although temperature is the most likely controlling factor (Orton, 1920; Gunter, 1957; Kinne, 1970). Ahmed (1980) has shown that for species which spawn throughout the year minimum breeding activity occurs during the SW monsoon season. This is explained in terms of food availability for crab larvae. A similar conclusion was also reached by Pillay and Nair (1973) studying the breeding biology of brachyuran crabs from the south - west coast of India. According to these authors the availability of food for the young during the planktotrophic life is the important factor controlling the breeding season. As larval duration is important, since the longer the planktonic phase , the higher the risk of predation both temperature and food supply are implicated in zoeal development and duration (Sulkin, 1975; Anger, 1983; Dawirs, 1985). In Kuwait seasons are very marked with a spring plankton bloom (Michel *et al.*, 1986b). This seasonality becomes less apparent further south in the Gulf (Dorgham and Moftah, 1989). However, further studies are required to correlate salinity, air and water temperatures as influencing factors on reproduction of present crab species. These studies should also include measurment of near shore productivity to see whether it is linked to brachyuran breeding cycles, as has been suggested (Pillay & Nair, 1971).

Table 31: Breeding and recruitment periodicity for several species from the Gulf.

Species	Locality	Breeding months	Breeding season	Recruitment	Source
Ocypodidae					
S. leachii	Qatar	7	Nov.-May	Oct.-Nov., Mar.	Present study
N. dotilliformis	Qatar	6	Feb.-Jul.	Sep-Oct & Mar	Present study
N. dotilliformis	Kuwait	5	Nov.-Mar.	Dec.- Mar,	Snowden & Clayton, (1995)
N. dotilliformis	Saudi Arabia	-	* Oct.	Nov.-Mar.	Apel (1994)
M. depressus	Qatar	11	** All year	Feb.- Jul.	Present study
M. depressus	Saudi Arabia	10	***All year	Mar.-Nov. & May	Apel (1994)
Grapsidae					
M. messor	Qatar	6	Apr.-Sep.	Oct.-APR..	Present study
Xanthidae					
E. orientalis	Qatar	7	Feb.-Aug.	Oct.- Nov & Apr.-Jun.	Present study

* Only 3 samples of ovegerus females were collected.

** All year except December. *** All year except November and January.

CHAPTER 5

THE FUNCTIONAL MORPHOLOGY OF THE MOUTHPARTS OF MANGROVE ASSOCIATED CRABS FROM QATAR.

INTRODUCTION

The distribution of brachyurans associated with the mangroves and salt marsh in Qatar (Chapter 2) shows that most ocypodid species are linked to the occurrence of special habitats. In contrast other genera such as the omnivorous *M. messor* have been shown to be ubiquitous, ranging over habitats as diverse as rocky shores, sandy beaches, salt marsh and mangroves (Apel, 1994; Jones, 1994) and the carnivorous xanthid *Eurycarcinus,* is found in muddy banks and muddy sand flats (Jones, 1986). The largest group, the ocypodids, are all deposit feeders and many have been shown to be characteristic inhabitants of mangroves (Jones, 1986, 1994). However, some have also been found on sand or mud flats and salt marshes in the absence of mangroves (Hartnoll, 1973; Jones and Clayton, 1983; Clayton, 1986; Jones, 1986, 1992; Vousden, 1989). For these deposit feeding species it may be that distribution is related to sediment characteristics.

Feeding in crabs, as in other decapods, consists of a complex, functionally integrated action by the six pairs of modified limbs located around the mouth. The third maxillipeds form an opercular cover over the second and first maxillipeds, maxilla, maxillule and finally the mandible arranged in sequence towards the buccal cavity (Skilleter & Anderson, 1986). The mandibles are overhung by dorsal fleshy lobes, the labrum and ventrally by the paragnath (Alexander, 1988). These lobes surround the entrance to oesophagus (Maitland, 1990).

Several authors have pointed out that ocypodid crabs are specialised for deposit feeding taking micro-organisms and organic materials which are sorted out of the soil mass by the mouthparts (Takahashi, 1932; Crane, 1941,1943; Altevogt, 1955,1957; Peters, 1955; Miller, 1961). The results of observations on the feeding behavior of ocypodid crabs are summarized by Ono (1965) and Icely and Jones (1978). Ono (1965) reported that 5 species, *Scopimera globosa* De Haan, *Uca lactea* (Milne Edwards), *Uca arcuata* (De Haan), *Ilyoplax pusilla* De Haan and *Macrophthalmus japonicus* (De Haan), show pellet-making behavior, while 2 ocypodids, *Paracleistostoma cristatum* (De Haan) and *Cleistostoma dilatatum* (De Haan), do not show this behavior. Such differences amongst species in feeding habit seem to be directly correlated with morphological differences in the mouthparts. Schembri (1982a) emphasized the need for further studies on the functional morphology of the cheliped and mouthparts of the brachyurans, indicating that texture of substratum is the main factor restricting the distribution of ocypodid crabs. Hartnoll (1973) reported that *Dotilla* and *Scopimera* prefer sandy shores where their specialised mouthparts enable them to sort the sand with a high efficiency in order to extract the low proportion of organic material (Tweedie, 1950; Ono, 1965). Some other ocypodid genera such as *Ocypode* and *Macrophthalmus* also extend on to sandy substrates, but with a few exceptions (e.g *Ocypode gaudichaudii* Milne Edwards & Lucas) these species are scavengers and predators rather than deposit sorters. *Uca* and most *Macrophthalmus* prefer finer substrates and cannot feed on clean sand with an efficiency comparable to *Dotilla* and *Scopimera* (Hartnoll, 1973).

The important relationship between feeding method and habitat preference of species is correlated with the specialization of the mouthparts. In species living in sandy areas, such as *S. globosa* and *U. lactea*, the spoon - shaped setae on the maxillipeds are highly developed, while they are less developed or replaced by "woolly" type hairs in species living in muddy areas, such as *M. japonicus* and *P. cristatum* (Ono, 1965). This author also demonstrated that the shape of spoon itself shows adaptive development; the spoon of species living on sandy substrata is large in size and stoutly serrated for scraping the surface of large particles, while that of species living on sandy - mud substrata is small and feebly serrated for scraping small particles. In deposit feeding crabs living on a muddy substratum, mouthpart morphology and the degree of sifting performed prior to ingestion is strongly correlated to the consistency of the the mud which tends to be very fine grained and rich in organic material (Ono, 1965; Brafield, 1978; Maitland, 1990). Crabs living in the richest of these habitats are able to ingest much of the mud directly, with little prior processing by the mouthparts (Ono, 1965).

In view of the literature that has been published on general ecology of deposit feeding crabs inhabiting soft substrate habitats in the Arabian Gulf (Basson *et al.*, 1977; Jones and Clayton, 1983; Jones, 1986; Vousden, 1987; Apel, 1994), it is surprising that there has been no detailed description of the functional morphology of the feeding mechanisms for any species. This is all the more surprising in view of the detailed studies that have been made of the mouthparts of other crab species and crustacean groups (Mauchline, 1967; Hartnoll, 1973; Jones, 1968, Fish, 1972; Icely & Jones 1978; Skilleter & Anderson, 1986: Maitland, 1990).

In this work, the functional morphology of the mouthparts and proventriculus are examined for 9 species of brachyurans found in mangroves and salt marshes in Qatar. The aim is to relate the functional morphology of the mouthparts to the distribution patterns observed in an attempt to explain the absence of some species from newly planted mangrove areas.

MATERIALS AND METHODS

Six species of the family Ocypodidae, 2 species of the family Grapsidae and 1 species of the family Xanthidae were selected for investigation in the present study. *Scopimera crabricauda* Alcock, *Nasima dotilliformis* (Alcock), *Serenella leachii* (Audouin), *Manningis arabicum* (Jones & Clayton), *Ilyoplax frater* Kemp, *Macrophthalmus depressus* Ruppell, *Metaplax indica* Milne Edwards, *Metopograpsus messor* (Forskål), and *Eurycarcinus orientalis* (Milne Edwards) were collected from the intertidal zone of saltmarsh, mangrove and open mudflats in Qatar.

Scopimera crabricauda is common on sheltered sand beaches and sand flats in the upper intertidal zone whereas *Nasima dotilliformis* digs burrows in salt-marshes and muddy sand flats around mean high water. *Serenella leachii* also digs burrows on mud flats around mean high water level.

Manningis arabicum digs burrows on sand / mud flats at a slightly lower level between mean high water to mean sea level, while *Ilyoplax frater* produces burrows in sand/mud flats towards the mid intertidal zone of mangrove areas. *Macrophthalmus depressus* is an extremely common intertidal species preferring lower levels of sand / mud flats around mean sea level where the water table reaches the surface (Jones 1986).

Crabs were preserved in 5 % formalin in sea water. The mouthparts were dissected under a wild M5 binocular microscope and drawn with the aid of camera lucida. During this operation the appendages were immersed in water to avoid air drying and no stains were used. The descriptions of the mouthparts relate to adult specimens only.

Types of setae:

The terminology employed in descriptions of the mouthparts is adapted from Fish (1972), Farmer (1974) and Maitland (1990) who produced a classification of setal types. In general, the setae of the species of Ocypodidae used in this study can be divided into seven basic types (Fig. 1):

1- Simple setae : Smooth shafts and without signs of serration or setules.

2- Spine setae : Strong but smooth and tapered seta, bearing paired spinules.

3- Spinose setae : Smooth, tapered seta bearing fine short spines along shaft.

4- Plumose setae : Seta bearing numerous setules in a row along each side of the setal shaft.

5- Pappose setae : Smooth shafts bearing setules on all sides of the shaft.

6- Serrate setae : These have rows of serrations or have a saw - toothed edge.

7- Spoon-tipped setae : morphologically, spoon-tipped setae vary with their position on the limb. Those on, and around, the palm of dactyl are short and stout with deep cups, while those extending from the distal edges of the palp are long and thin with shallow tapered cups, or without cups.

The above basic setal types were all found by observation with the light microscope and used to describe the setation of the various appendages of the mouthparts.

Detailed morphological studies were made on the proventriculus of each species using a Cambridge Scanning Electron Microscope (SEM). The proventriculus was removed and opened ventrally by means of a longitudinal incision. The dissected structures were then prepared for SEM examination by dehydration through graded concentrations of ethanol followed by critical point drying, replacing acetone with liquid CO_2. The dried tissue was mounted on the adhesive surface of aluminium tape and the latter attached to an aluminium specimen stub with colloidal silver. The mounted stubs were coated with gold in a polaron D.C. spluttering unit before examination in the SEM.

The small cheliped of each species was examined under a binocular microscope and drawings were prepared with the aid of camera lucida. Sediment samples were collected from the central area of the burrow of each species and were analysed using the same procedure as in chapter 2, sediment samples were also collected from feaces from around the burrows of each species and measured under a binocular microscope. For details of appendage terminology see Appenix 3.

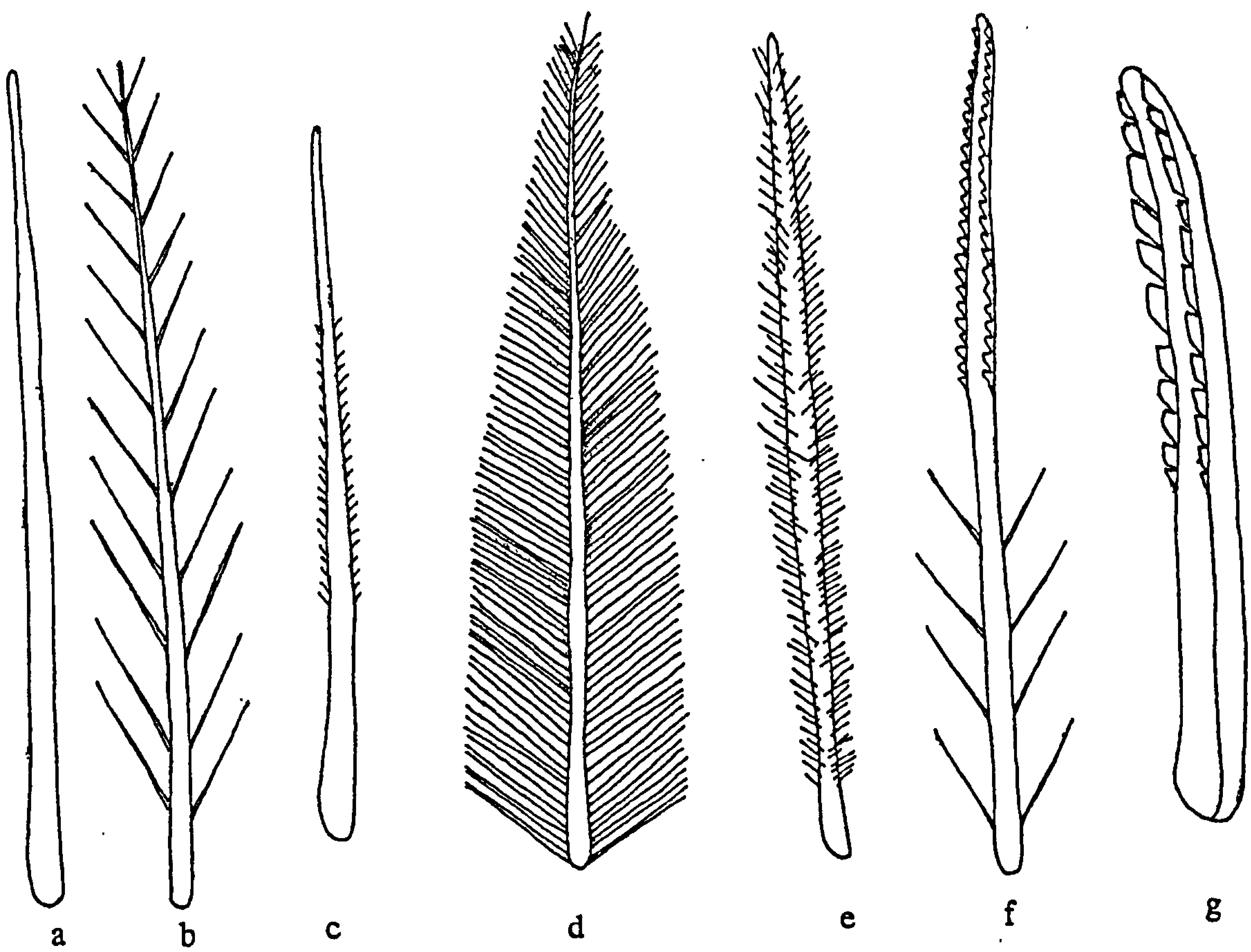


Figure 1: Type of setae found on the mouthparts as recognized by using the light microscope for 9 crab species: (a) simple setae, (b) spine setae, (c) spinose setae, (d) plumose setae, (e) pappose setae, (f) serrate setae, (g) spoon-tipped setae.

RESULTS

Sediment analysis

Substrate analyses made from the centre of the region occupied by each species investigated in this study are given in appendix 3 and summarised in Tab. 1. The results are briefly described separately for each species.

Scopimera crabricauda: Sediment samples from the burrows of this species have a median particle size falling with the range of 0.23±0.01 mm at natural mangrove sites and a range of 0.43±0.03 mm at planted mangrove sites, but a range of 0.37±0.05 mm at the salt marsh sites. The sorting parameters show that the sediments collected from different sites for this species are within the range of well sorted to poorly sorted, while the values for skewness range from very finely skewed to finely skewed. Levels of organic content in sediment samples with range of 2.6% at natural mangrove sites and a value of 2.57% at planted mangrove site, with a range of 2.52% at salt marsh sites.

Nasima dotilliformis: Sediments from burrows are with the range of 0.16±0.02 mm at natural mangrove sites and 0.18 mm at salt marsh sites. In terms of sorting they have very well sorted values, while skewness values range from strongly skewed to finely skewed. Organic content has a value of 3.12% at natural mangrove sites and a value of 2.20% at salt marshes.

Serenella leachii: The median particle size of sediment samples are in the range of 0.29±0.04 mm at planted mangrove sites and the sorting value within the range of well sorted to moderately well sorted, sediment is very finely skewed. The mean organic content of the sediment samples is 4.03%.

Ilyoplax frater: Sediment samples collected from natural mangrove sites only, reveal a range of 0.21±0.02 mm, very well sorted, and skeweness values between very finely skewed to fine skewed. The mean organic content was 4.03±0.64%.

Manningis arabicum: At natural mangrove sites the mean particle size is within the range of 0.19±0.02 mm, with a mean size of 0.41 mm at planted mangroves and 0.18 mm at salt marshes. The sorting value is within very well sorted to well sorted at natural mangrove and salt marsh sites, but moderately sorted at planted mangroves. The skewness values are very finely skewed at all sites. The mean organic content was 3.8% at natural mangrove sites, 4.39% at planted mangrove sites and 2.20% at salt marshes.

Macrophthalmus depressus: Burrow sediment samples collected from natural mangrove sites are 0.17±0.03 mm and at planted mangrove 0.30±0.04 mm, while at saltmarshes range is 0.16±0.05 mm. The sorting value is very well sorted at natural mangrove and well sorted at planted mangroves and salt marshes. Skewness values range from very finely skewed at the most sites to finely skewed at P1 and N1 sites. The mean organic content was 3.74% at natural mangroves, 3.46% at planted mangroves and 3.53% at saltmarshes.

Metaplax indica: Burrow sediment samples were collected only from the N5 site for this species and gave a median particle size of 0.19 mm and a sorting value of very well sorted finely skewed.

Eurycarcinus orientalis: The results of the median particle size for sediment samples are 0.18 mm at natural mangroves, 0.31 mm at planted mangroves and 0.22 mm at salt marshes. Skewness values fluctuated between finely skewed to very finely skewed.

Overall median particle size and mean organic content (Tab. 1) indicate that the highest particle size was recorded for *S. crabricauda* with a range of 0.37±0.06 mm and organic matter of 2.52%. The second species *S. leachii* had aparticle size of 0.29±0.06 mm and organic content of 3.76%. For *M. arabicum* the particle size was 0.26±0.07 mm and organic matter has 3.30%. *N. dotilliformis* has a range of 0.17±0.01 mm and organic matter of 2.66%. *M . depressus* was found with aparticle size of 0.21±0.01 mm and an organic content of 4.03%. For *I. frater* the range was 0.21±0.03 mm and organic content 3.30%. *E. orientalis* was found on mud 0.22±0.04 mm, while *M. indica* was in mud of 0.19 mm particle size.

Table 1: The relationship between percentage organic content and particle size for sediment samples taken from the centre of the region occupied by each species (N: natural mangrove; P: planted mangrove; S: salt marsh).

Species	Median particle size± SE			Average ± SE
	N	P	S	
Scopimera crabricauda	0.23±0.01	0.43±0.03	0.37±0.05	0.36±0.03
Serenella leachii	-	0.29±0.04	-	0.29±0.04
Ilyoplax frater	0.21±0.02	-	-	0.21±0.02
Manningis arabicum	0.19±0.02	0.40	0.18	0.23±0.04
Macrophthalmus depressus	0.17±0.03	0.30±0.04	0.16±0.00	0.21±0.05
Nasima dotilliformis	0.16±0.02	-	0.18±0.00	0.17±0.01
Eurycarcinus orientalis	0.18±0.01	0.31±0.04	0.18	0.22±0.04
Metaplax indica	0.19	-	-	0.19
Overall median particle size (mm)	0.19±0.01	0.36±0.02	0.22±0.03	

Species	Mean organic content ± SE			Average ± SE
	N	P	S	
Scopimera crabricauda	2.60±0.03	2.57±0.21	2.40±0.01	2.52±0.06
Serenella leachii	-	3.76±0.30	-	3.76±0.30
Ilyoplax frater	4.03±0.64	-	-	4.03±0.64
Manningis arabicum	3.81±0.50	4.39	2.20	3.30±1.10
Macrophthalmus depressus	3.74±0.22	3.46±0.32	3.60±0.21	3.53±0.07
Nasima dotilliformis	3.12±0.17	-	2.20	2.66±0.46
Eurycarcinus orientalis	2.40±0.40	3.45±0.04	2.16	2.67±0.40
Metaplax indica	3.50	-	-	3.50
Overall mean organic content (%)	3.38±0.18	3.22±0.20	2.77±0.26	

Particle size in faeces

The size distribution of soil particles (Fig. 2) containing faeces of crabs taken close to the burrows of *S. crabricauda, N. dotilliformis, M. arabicum, I. frater, S. leachii* and *M. depressus* were measured using a microscope to count 100 consequtive particles. The values of the mean diameter of soil particles for each species were 0.54, 0.28, 0.45, 0.45, 0.57, and 0.44 mm and are compared with those of the substrata taken from the centre of natural habitats for respective species also measured under the microscope (Tab. 2). From Tab. 2 it is clear that the particles size in faeces is smaller than that found in the centre of each natural habitat. Whilst this might be expected for *S. crabricauda* which sorts particles in the mouth and ejects larger sand grains in the form of Pseudofaeces, the same is not true of the other species. Hence the difference in particle size must be attributed to sampling methodology rather than crab feeding behaviour.

Table 2: Average mean and median () particle sizes taken at the centre of the population of each crab species at all sites, compared to mean and () median particle sizes in faeces of each species.

Species	Surface	Faeces	Difference in median size (mm)
	Mean particle diameter (mm)	Mean particle diameter (mm)	
Scopimera crabricauda	0.54 (0.36)	0.20 (0.25)	0.10
Ilyoplax frater	0.45 (0.21)	0.10 (0.11)	0.10
Manningis arabicum	0.45 (0.23)	0.10 (0.15)	0.07
Serenella leachii	0.57 (0.29)	0.15 (0.23)	0.06
Macrophthalmus depressus	0.44 (0.21)	0.10 (0.15)	0.06
Nasima dotilliformis	0.28 (0.17)	0.15 (0.23)	0.06

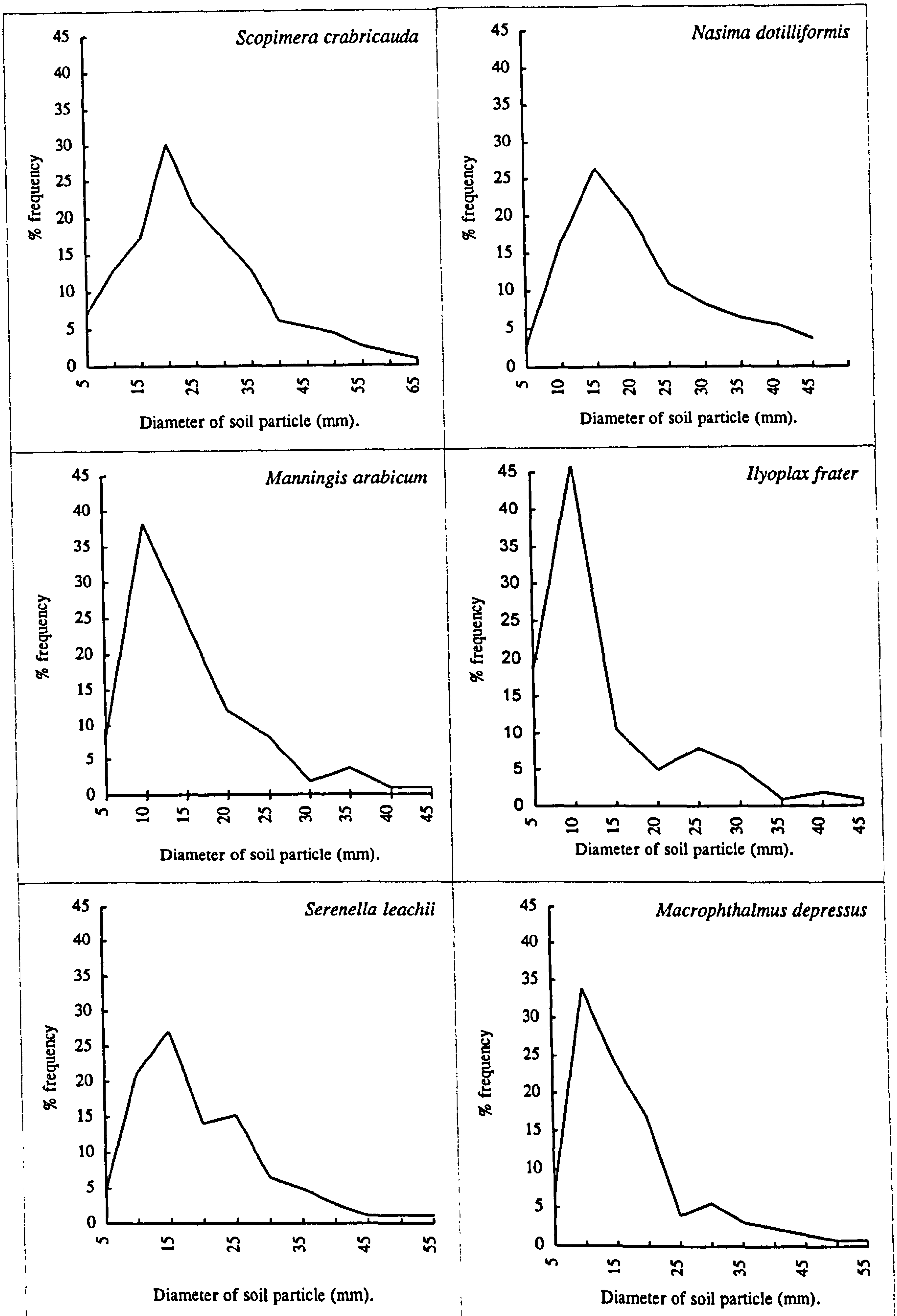


Figure 2: Particle size of feaces of 6 ocypodid species collected from Qatar.

Chelae morphology

The chelae of 9 crab species were examined (Fig. 3). The chelae of *N. dotilliformis, S. leachii* and *M. depressus*, have elongate dactyls with flattened spoon-like tips bearing simple setae on the upper and lower edge of the fingers, while in *S. crabricauda* the finger of the claw is shorter than the palm, is pointed and bears fine granulate serrations on the chela margins, and a distinct tooth on the finger. In *I. frater* the chelae are also pointed and glabrose with small serrations on the cutting edge of the finger. In *M. depressus* the chela have finely granulate margins and the inside surface and fingers are covered with dense setae. Fingers bear small teeth on the margins, and the shape of the chela is again more elongate. The chela of the *M. indica* are small with the palm nearly twice as long as the slender fingers which have a finely granulate edge to the margins of the fingers. The chela of *M. messor* is more robust as are the large teeth present on the cutting edge of the fingers. *E. orientalis* chelae are also robust, unequal, with hooked tips and teeth on the cutting edge of each finger.

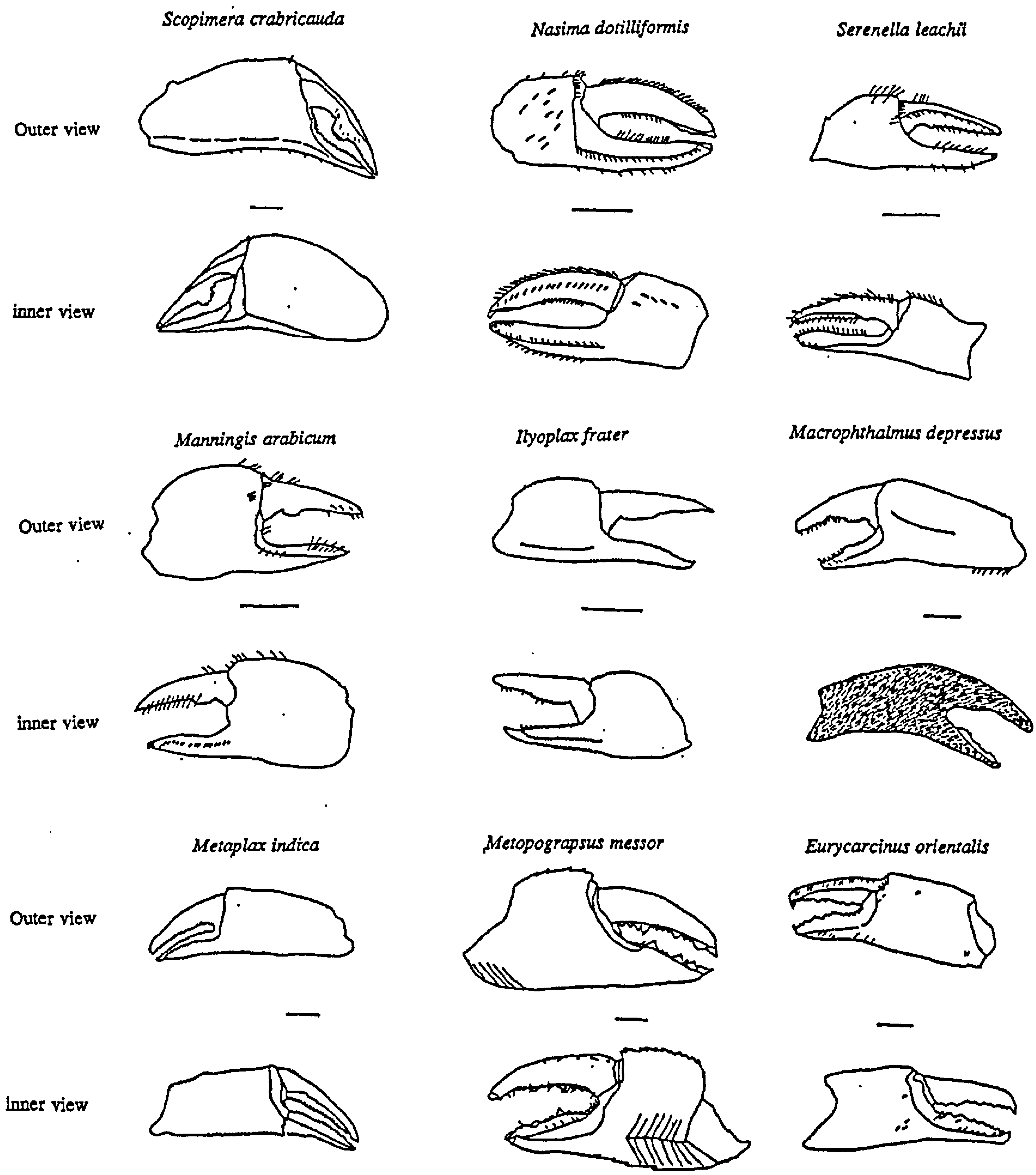


Figure 3: Dimorphic chelae of 9 brachyuran species. Scale lines represent 0.1 mm.

Mouth parts description

Scopimera crabricauda

Third maxilliped (Fig. 4a & b): The third maxillipeds are the largest and the most mobile of the various mouthparts. The ischium is larger and broader than the merus. The palp consists of 3 segments, the dactylus , propodus and carpus. The dactylus is narrow and elongate, the propodus is the shortest article, and carpus the longest article of the palp, all bearing long plumose setae. The medial margin of the ischium bears short plumose setae, which increase in size on the ventral margin, it also bears dense setae on the internal surface distally. The medial margin of the merus bears long plumose setae and a few setae on the inner surface.

Second maxilliped (Fig. 4c): The largest part of the second maxilliped is composed of the merus and carpus which form a functional unit. The merus is longer than it is broad, and it bears dense fringe of spoon-tipped setae on the outer margin. The ischium is smaller than the merus and bears short plumose setae. The coxapodite bears long plumose setae, while the basipodite bears long plumose setae on the lateral margin and short plumose setae on the outer margin. The exopod is elongate bearing plumose setae and the flagellum is heavily setose along the medial margin.

First maxilliped (Fig. 4d): As in other crabs, the first maxilliped differs from other maxillipeds in that large medially projecting lobes or endites, extend from the coxopodite and basipodite of the limb. The basal endite is larger than the coxal endite and bears short plumose setae on the medial margin, while the coxal endite is flattened and bears a dense row of spoon-tipped setae on the medial margin. The tip of the endopod is flattened and bears long plumose setae which extend along the rest of the medial margin. The terminal article of the exopod bears plumose setae on the lateral margin.

Maxilla (Fig. 4e): The coxal endite of the second maxilla is fringed with plumose setae on the lateral margin. The bilobed basal endite bears spoon-tipped setae on the outer margin and long plumose setae on the medial margin of the proximal lobe. The scaphognathite is formed as a lateral muscular blade which extends from the expodite of the limb and bears simple setae.

Maxillule (Fig. 4f): The first maxilla is the smallest of the mouthparts with a coxal endite consisting of a fleshy lobe whose outer surface is covered by simple setae. The basal endite of the first maxilla bears slender plumose setae on the dorsal margin. The endopodite is short and bears small plumose setae along distal medial margin.

Mandible (Fig. 4g): The mandible is compact and calcified. The none - biting surface bears plumose setae. The mandibular palp lies behind the mandible and projects above it, consisting of two segments, which have different setal types. The distal segment bears spoon - tipped setae, while the proximal segment is covered by very long plumose setae.

Figure 4: *Scopimera crabricauda*: (A&B) third maxilliped; (C) second maxilliped; (D) first maxilliped; (E) maxilla; (F) maxillule; (G) mandible. Scale lines represent 0.1 mm.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Nasima dotilliformis

Third maxilliped (Fig. 5a & b): The outer third maxilliped has the ischium slightly larger than the merus and the inner surface of both the merus and ischium are smooth and covered by a rows of fine simple plumose setae. The medial margins of merus and ischium bear a dense row of long plumose setae. The lateral margin of the palp (carpus, propodus, dactylus) and the medial margin of dactylus are also fringed with long plumose setae.

Second maxilliped (Fig. 5c): The merus of the second maxilliped is longer than it is broad with the medial margin bearing several thick rows of long plumose setae. The carpus and propodus also bear plumose setae while the dactylus is armed with serrate setae. The ischium is covered with plumose setae and the basopodite is naked. The exopod is relatively large and has a long basal segment, which carries several plumose setae on its lateral margin, and a few setae on its upper medial margin. The terminal segments of the flagellum are armed with long plumose setae born on the lateral margin. The epipodite is relatively long and bears simple setae on its surface.

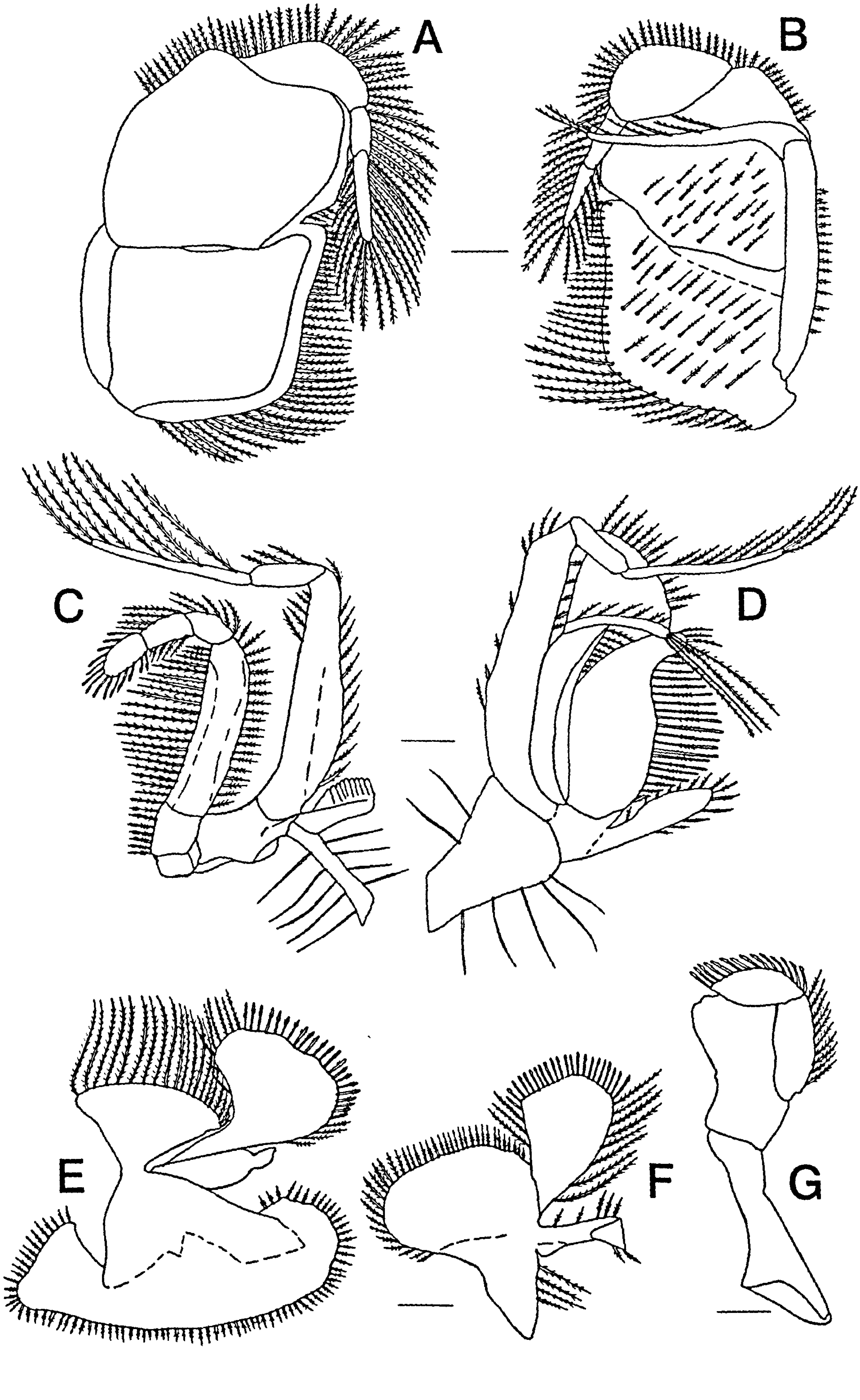
First maxilliped (Fig. 5d): The basal endite is larger than the coxal endite and consists of a large medially projecting lobe. The apex of the endopod is flattened into a horizontal flange and bears plumose setae. This flange functions to guide water over the outer mouthparts as it leaves the exhalant aperture, and to prevent water from entering via this route, into the inner mouthparts. The medial edge of the endopod bears a row of plumose setae. The coxal endite bears a dense row of serrate setae. The exopodite is elongate and bears a few fine small setae on the lateral margins. The flagellum of the exopodite is also elongate and bears long plumose setae. The epipodite is also long and bears long simple setae along its edge.

Maxilla (Fig. 5e):The basal endite of the second maxilla has a fleshy convex outer surface bearing dense spoon-tipped setae along the lateral edge and plumose setae along its medial margin. The coxal endite is shorter than the basal endite and bears long plumose setae on its distal margin. The scaphognathite is fringed with simple setae, with those on the lateral and medial margins longest.

Maxillule (Fig. 5f): The maxillule is the smallest of the mouthparts. The basal endite forms fleshy lobe whose distal surface is covered by spoon - tipped setae, while the lateral margin bears curved plumose setae. The coxal endite is axe - shaped and bears short plumose setae.

Mandible (Fig. 4g): The mandible consists of calcified material, and although sharp, is not toothed, and is without setae on both surfaces. A mandibular palp arises dorsally from the apophysis of each mandible and lies in a depression in the posterior surface of the jaws. The proximal palp segment bears short plumose setae, while the distal article is covered with spoon - tipped setae.

Figure 5: *Nasima dotilliformis*: (A&B) third maxilliped; (C) second maxilliped; (D) first maxilliped; (E) maxilla; (F) maxillule; (G) mandible. Scale lines represent 0.1 mm.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Serenella leachii

Third maxilliped (Fig. 6a & b): The third maxilliped is the largest and the most mobile of the various pairs of the mouthparts. The ischium is larger than the merus. The palp (carpus, propodus, dactylus) and medial edge of the merus and ischium are fringed with long plumose setae. The inner surface of the merus and ischium has a scattering of simple setae.

Second maxilliped (Fig. 6c): The merus is longer than it is broad and carries long plumose setae on the medial margin. The dactyl is short and bears both spoon - tipped and long plumose setae. The carpus and much of the propodus are covered with long plumose setae. The exopod is large and has plumose setae on its lateral margin and a few proximal setae. The terminal segment of the flagellum has long plumose setae.

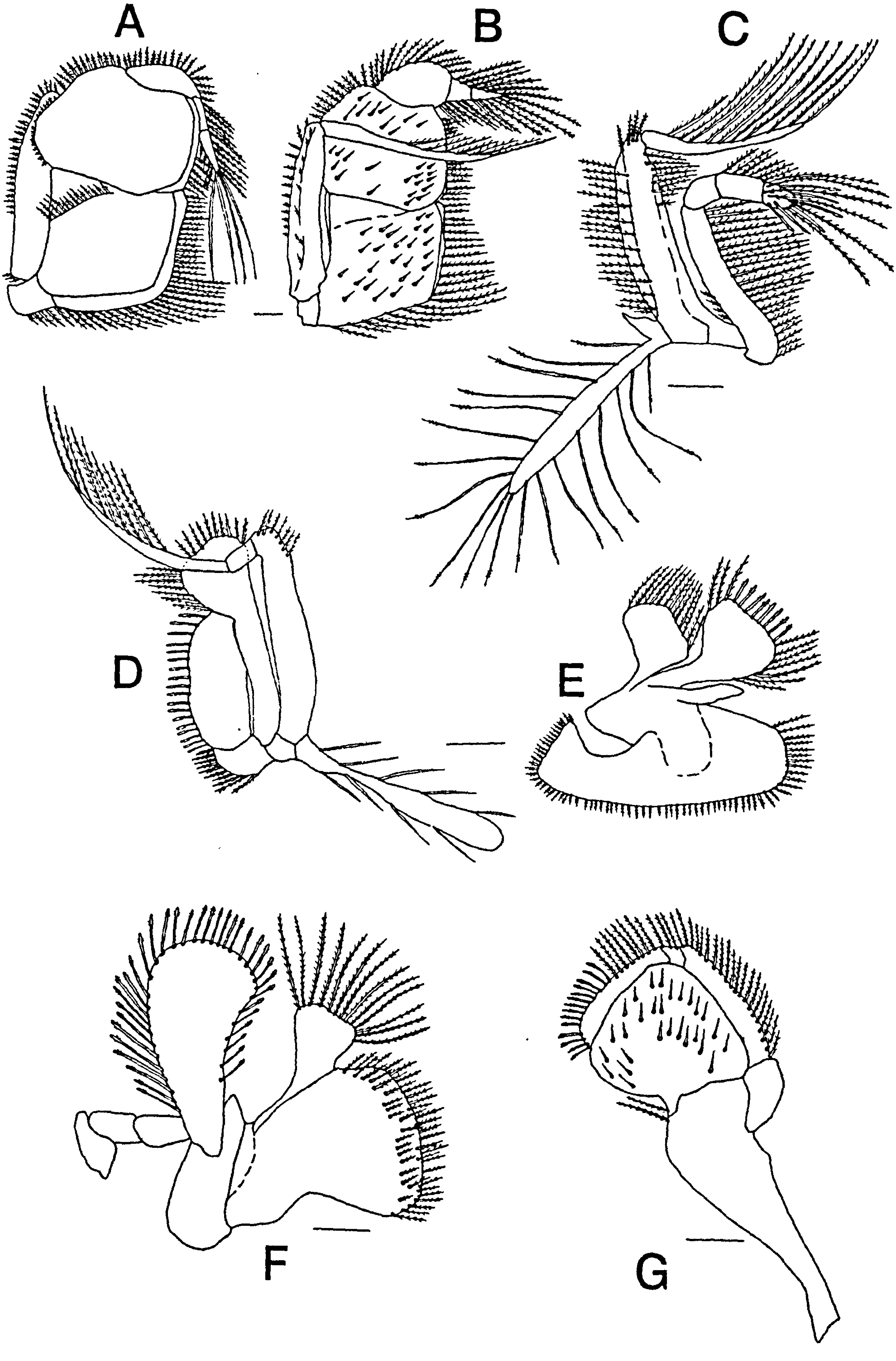
First maxilliped (Fig. 6d): The first maxilliped forms large inwardly projecting lobes. The basal endite is larger than the coxal endite. The apex of the endopod is flattened into a horizontal flange which is fringed with plumose setae. The basal endite is covered with numerous spoon - tipped setae which are longer proximally and the coxal endite is shorter and bears serrate setae along medial margin. The exopodite has a few distal setae; and a flagellum with long plumose setae. The epipodite is long and bears simple setae on its upper margin.

Maxilla (Fig. 6e): The coxal endite is fringed with long setae. The outer surface of the coxal endite fits into, and behind, the posterior surface of the basal endite of the first maxilliped. The basal endite of the maxilla forms an enlarged axe - shaped fleshy lobe which bears numerous setae of two types. Long plumose setae surround the margins of most edges of the article, while spoon - tipped setae are present on the distal margin of the endite. The basal endite is behind the endopodite of the first maxilliped. The scaphognathite forms the largest part of this appendage and consists of an elongate, round - ended blade fringed with setae.

Maxillule (Fig. 6f): The apex and proximal face of the basal endite is covered with serrate setae. The coxal endite consists of two lobes, both of which have different types of setae. The proximal lobe is covered with dense short plumose setae, while the outer surface of the distal lobe bears long plumose setae.

Mandible (Fig. 6g):The mandible is large, heavily scelerotised and with a sharp none toothed cutting edge. The mandibular surface bears stiff peg - like spines on the distal segment. The palp is fringed with plumose setae except for the laterodistal margin of the terminal article which has spoon-tipped setae.

Figure 6: *Serenella leachii*: (A&B) third maxilliped; (C) second maxilliped; (D) first maxilliped; (E) maxilla; (F) maxillule; (G) mandible. Scale lines represent 0.1 mm.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Manningis arabicum

Third maxilliped (Fig. 7a & b): The third maxilliped forms an opercular covering over the buccal mass. The ischium is longer than the merus. The palp (carpus, propodus, dactylus) and the margins of the merus are fringed with plumose setae. The inner surface of the merus and ischium is covered by simple and plumose setae.

Second maxilliped (Fig. 7c): The merus is longer than it is broad. The dactyl is armed with long plumose setae which bear slender tooth like spines on the shafts. The rest of the palp (carpus, and much of the propodus) is covered with long plumose marginal setae. The medial margin of the merus and ischium of the second maxilliped also bears long plumose setae. The epipodite is covered with relatively long simple setae each encircled by fine lateral hairs. The exopodite is large and bears long plumose setae on the lateral margin. The lateral margin of flagellum is also heavily setose.

First maxilliped (Fig. 7d): The basal endite is larger than the coxal endite and it is covered with serrate setae bearing tooth like spines. The coxal endite has long serrate setae on the upper half and plumose setae on the lower half of the medial margin. The endopodite is elongate and covered with long plumose setae. The epipodite of the first maxilliped is characteristically the longest structure and consists of a flattened strip bearing long setae on its lateral margins. The exopodite forms a large basal segment which carries a row of long plumose setae on the lateral margin; the flagellum also has long plumose setae along the lateral margin surface.

Maxilla (Fig. 7e): The coxal endite of the maxilla has a smooth convex outer surface bearing relatively long plumose setae, which fits into and behind the concave posterior surface of the basal endite of the first maxilliped. The basal endite forms a large fleshy lobe which bears numerous setae of two types. The laterodistal margin bears long plumose setae, whilst the distal margin carries spoon-tipped setae. The basal endite fits behind the endopodite of the first maxilliped. The scaphognathite is shaped like a muscular blade and extends from the exopodite of the limb as in all crabs, and is fringed with plumose setae.

Maxillule (Fig. 7f):The coxal endite is broader than the basal endite and consists of a fleshy lobe with a dense fringe of fine curved setae. The basal endite is fringed by setae of different lengths. The setae on the proximal margin bear short serrate setae, while those on the lateral margin are more slender and slightly plumose.

Mandible (Fig. 7g): The mandible forms a heavy setose structure; the inner most medial margin is chitinised and, although sharp, is not toothed. A mandibular palp arises dorsally from the apophysis of each mandible and lies in a depression in the posterior surface of the jaws. The mandibular palp bears a variety of setal types. Distally the mandibular palp is covered by spoon-tipped setae, while those on the upper surface of the second segment of the mandibular palp are slightly curved and plumose.

Figure 7: *Manningis arabicum*: (A&B) third maxilliped; (C) second maxilliped;(D) first maxilliped; (E) maxilla; (F) maxillule; (G) mandible. Scale lines represent 0.1 mm.


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Ilyoplax frater

Third maxilliped (Fig. 8a & b): The third maxilliped has a broad ischium and merus fringed with long plumose setae, while the inner surface is smooth and covered by simple setae. The carpus bears long plumose setae, as does the propodus, while the dactylus bears simple long setae.

Second maxilliped (Fig. 8c): The merus is longer than it is broad and bears dense long plumose setae on the medial margin, and a few and short on the lateral margin. The carpus is recurved, with short spoon setae on the medial margin. The propodus articulates with the carpus, and has spoon-tipped setae on the medial margin and long curved plumose setae on the lateral margin. The dactylus is small and covered with numerous stout serrate setae on the medial margin. The exopodite has a terminal flagellum bearing rows of plumose setae.

First maxilliped (Fig. 8d): The basal endite of the first maxilliped is larger than the coxal endite. The apex of the endopod is flattened into a horizontal flange which is fringed with long plumose setae. The medial margin of the endopod bears a row of long spinose setae. The coxal endite is consists of fleshy lobe whose distal margin is covered by stout serrate setae with plumose setae on the lateral margin. The exopodite is long with plumose setae dorsally. The flagellum is not segmented, with short plumose setae proximally and long plumose setae distally.

Maxilla (Fig. 8e): The coxal endite of the maxilla is extended laterally into two lobes, both of which have terminal plumose setae. The basal endite forms large axe-shaped fleshy lobe which bears numerous setae of different types. The apex of the basal endite is covered by spoon-tipped setae, while the rest of outer margin bears long plumose setae. The scaphognathite is blade-shaped and bears short plumose setae.

Maxillule (Fig. 8f): The basal endite is larger than the coxal endite and forms a fleshy lobe, whose outside surface is covered by two types of setae. The distal margin of the endite bears spoon - tipped setae and the rest of the proximal margin long plumose setae. The coxal endite consists of a broad lobe and bears short plumose setae on the dorsal and medial margin.

Mandible (Fig. 8g): The mandible is large and heavily chitinised with a sharp serrate toothed cutting edge. The mandibular palp consists of three segments. The distal segment bears two types of setae. Those on the lateral margin are spoon-tipped, while the rest are long plumose setae.

Figure 8: *Ilyoplax frater*: (A&B) third maxilliped; (C) second maxilliped; (D) first maxilliped; (E) maxilla; (F) maxillule;(G) mandible. Scale lines represent 0.1 mm.


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Macrophthalmus depressus

Third maxilliped (Fig. 9a & b): The ischium is larger than the merus and both are covered on the inner surface with a few rows of simple setae. The outer surface of the merus is smooth, whilst the outer surface of the ischium bears a few long simple setae. The carpus and propodus are covered with dense plumose setae. The dactylus is the smallest segment of the palp, with long plumose setae on the lateral margins and spoon - tipped setae on the distal margin.

Second maxilliped (Fig. 9c): The second maxillipeds are markedly smaller than the third maxillipeds and longer than broad. The medial margin of the merus bears long plumose setae and the lateral margin bears a few short simple setae. The carpus is naked, but the rest of palp (propodus and dactylus) is covered with dense long spoon-tipped setae especially the dactylus. The ischium bears serrate setae while the basopodite bears simple setae on the medial margin. The exopod bears several plumose setae on the lateral margin and the flagellum bears rows of plumose setae. The epipodite is enlarged and the merus bears long serrate setae and carries the usual curled simple tipped setae on its margin.

First maxilliped (Fig. 9d): The basal endite of the first maxilliped is larger than the coxal endite. Its fleshy lobes bear spoon-tipped setae along medial margins. The coxal endite bears an assemblage of serrate setae on the medial margin. The exopodite bears fine simple setae on its outer and inner surfaces, together with a small group of short serrate setae at the distal end close to the articulation with the flexible flagellum. The flagellum bears long plumose setae along the lateral margin. The epipodite of the first maxilliped is larger than that of the second maxilliped. Its carries curled simple tipped marginal setae.

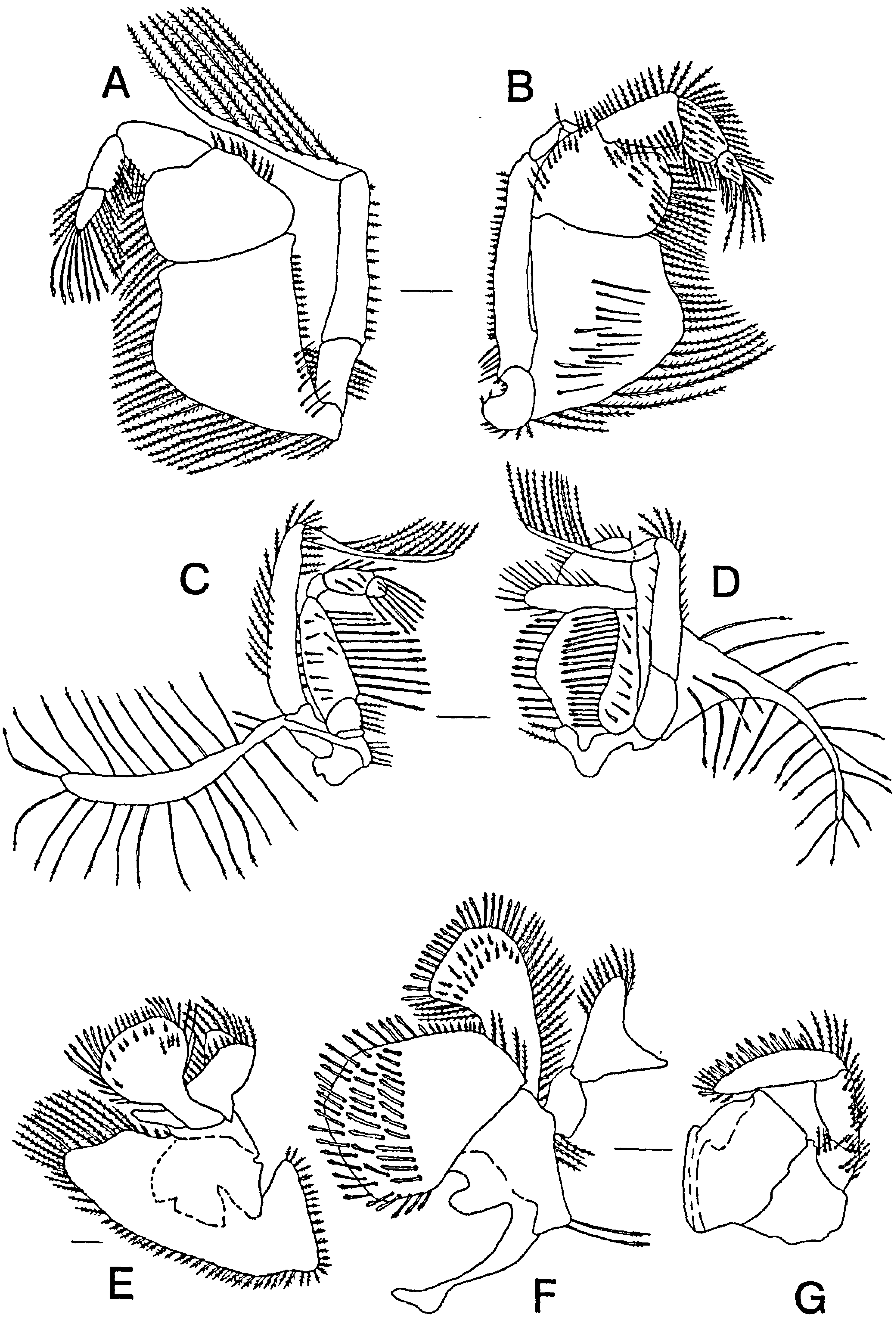
Maxilla (Fig. 9e): The coxal endite has a smooth convex outer surface bearing small plumose setae on the proximal lobe and long plumose setae on the distal lobe. The basal endite of the maxilla is an enlarged axe-shaped fleshy lobe which covered with dense of spoon-tipped setae and few small stout serrate setae on the inner surface.

The scaphognathite is the largest part of this appendage and has the medial margin fringed with long plumose setae, and other margin fringed with stout setae.

Maxillule (Fig. 9f): The coxal endite consists of a fleshy lobe whose inner surface is covered by small plumose setae, the distal margin with of spoon-tipped setae and the medial margin bears long plumose setae. The basal endite bears strong spoon-tipped setae on the outer and inner surfaces.

Mandible (Fig. 9g): The mandible is well developed and heavily chitinised, with a sharp none-toothed cutting edge. The mandibular palp consists of 3 segments. The distal segment bears spoon and short stout setae on the disto-lateral margin, the rest of lateral margin bears plumose setae. The rest of the segments bear plumose setae on the inner and lateral surfaces.

Figure 9: *Macrophthalmus depressus*: (A&B) third maxilliped; (C) second maxilliped; (D) first maxilliped; (E) maxilla; (F) maxillule; (G) mandible. Scale lines represent 0.1 mm.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Metaplax indica

Third maxilliped (Fig. 10a & b): The third maxilliped has an elongate merus and ischium fringed with long plumose setae, while the lateral surface is smooth and naked. The inner surface of the merus is smooth and covered by a few spine setae on the distal margin. The carpus bears plumose setae on the dorsal and ventral margins. The propodus is covered by dense long and short plumose setae, while the dactylus bears long spoon-tipped setae.

Second maxilliped (Fig. 10c): The merus is longer than it is broad and bears dense serrate setae on the medial margin. The palp (carpus, propodus and dactylus) is covered with spoon-tipped setae on the medial and lateral margin. The exopod is relatively large and bears plumose setae along the lateral and medial margin, the flagellum bears long plumose setae on the lateral margin. The epipodite is elongate and bears long simple setae along its edge.

First maxilliped (Fig. 10d): The basal endite of the first maxilliped is larger than coxal endite and the medial margin bears a row of serrate setae. The endopodite has a horizontal flange and bears serrate setae, while the medial margin bears a row of plumose setae. The exopodite is covered with long serrate setae on the lateral margin and a few distally on the medial margin, the flagellum consists of 2 segments the proximal segment naked, while the distal segment bears long plumose setae on the lateral margin. The epipodite is broad and long bearing simple setae on its lateral margin.

Maxilla (Fig. 10e): The coxal endite of the second maxilla is fringed by long setae. The outer surface of the coxal endite fits into, and behind, the posterior surface of the basal endite of the first maxilliped. The basal endite of the maxilla forms an enlarged axe-shaped fleshy lobe which bears numerous setae of various types. The most peripheral edges of the limb bear spoon-tipped setae. Plumose setae are present on the lateral margin of the endite. The scaphognathite is shaped like a laterally expanded blade which extends from the exopodite of the limb, and is fringed with short plumose setae.

Maxillule (Fig. 10f): The coxal endite is broader than the basal endite and consists of a fleshy lobe which is covered by plumose setae along the distal margin. The basal endite of the maxillule bears short spoon-tipped setae along its distal and proximal margin.

Mandible (Fig. 10g): The mandibles are large, heavily scelerotised and with a sharp none toothed cutting edge. The small mandibular palp consists of 4 segments. Distally, first and second segments bear short spoon-tipped setae, while the other segments bear short stout setae on the disto-lateral margin.

Figure 10: *Metaplax indica*: (A&B) third maxilliped; (C) second maxilliped; (D) first maxilliped; (E) maxilla; (F) maxillule; (G) mandible. Scale lines represent 0.1 mm.

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Metopograpsus messor

Third maxilliped (Fig. 11a & b): In *M. messor*, the ischium is elongate dorsoventrally and the third maxillipeds form a complete cover to the more internal mouthparts. The medial margin of the ischium bears plumose setae and the outer surface bears 2 sharp spines, 1 on the distal margin and 1 on the proximal margin, while the inner surface is naked. The merus is shorter and broader than the ischium and bears plumose setae on the lateral edge. The outer surface of merus is naked, while the inner surface bears a few distal spine setae. The carpus of the palp bears long plumose setae, while the propodus and dactylus are covered with two types of long and short serrate setae. The exopodite is robust, half width of ischium long and bears a few fine setae on the distal and proximal margins.

Second maxilliped (Fig. 11c): The merus is longer than it is broad, and carries long serrate setae on the medial margin. The inner surface of merus bears small spines surrounding the inner edge. The palp (carpus, propodus and dactylus) is covered by serrate setae along the lateral margin. The exopod is large and has fine setae on lateral margin and dense fine setae distally on the medial margin. The terminal segment of the flagellum has long plumose setae.

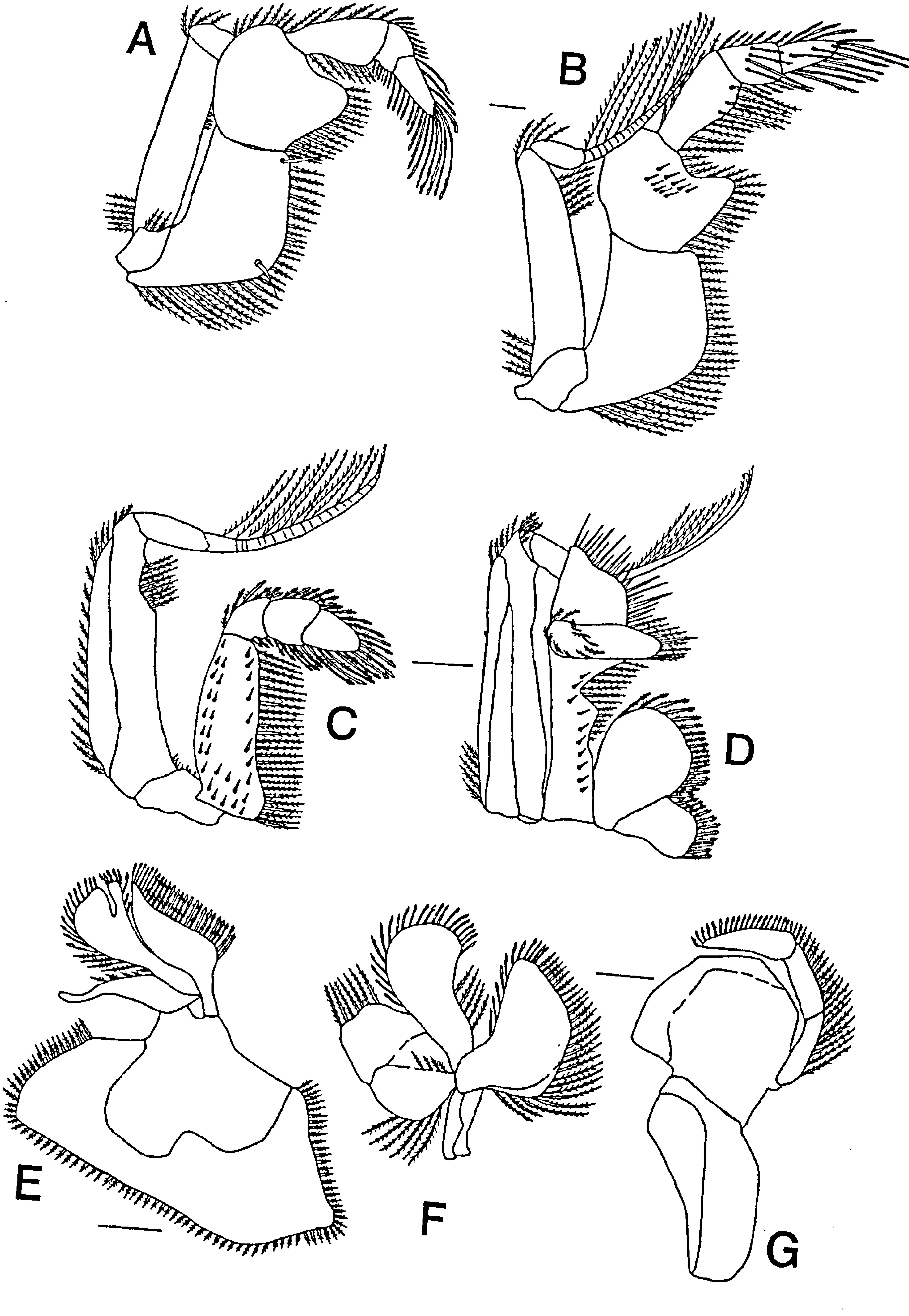
First maxilliped (Fig. 11d): This consists of a large inwardly projecting lobe. The basal endite is larger than the coxal endite and the apex of the endopod is flattened into a horizontal flange which is fringed with long plumose setae and long sharp setae, along the inner surface there is a row of short spine setae. The medial margin of the basal endite bears serrate setae and the coxal endite is also covered with serrate setae which are longer toward the distal margin.,

Maxilla (Fig. 11e): The coxal endite of the maxilla is elongate and fringed by long serrate setae. The basal endite forms an enlarged axe-shape fleshy lobe which bears two types of setae. Spoon-tipped setae surround the lateral margins of the limb, while plumose setae are present on the medial margin. The scaphognathite forms the largest part of the appendage and bears short setae.

Maxillule (Fig. 11f): The basal endite of the first maxillae is covered with spoon-tipped setae on the apex and long plumose setae on the medial margin. The coxal endite bears two types of setae, proximally most of the lobe covered with serrate setae, while the lateral margin is covered with spoon-tipped setae.

Mandible (Fig. 11g): The mandible is large and heavily chitinised with a sharp none toothed cutting edge. The small mandibular palp consists of 3 segments, distal segment bearing short spoon-tipped setae, while other segments bear long serrate setae on the lateral margin.

Figure 11: *Metopograpsus messor*: (A&B) third maxilliped; (C) second maxilliped; (D) first maxilliped; (E) maxilla; (F) maxillule; (G) mandible. Scale lines represent 0.1 mm.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Eurycarcinus orientalis

Third maxilliped (Fig. 12a & b): The ischium is flattened dorsoventrally and forms a complete cover to the internal mouthparts. The medial margin of the ischium is serrated (saw-toothed), more visible from inner view of the third maxilliped. A dense row of short spine setae occur along the medial margin of the ischium. The outer surface of the ischium bears a row of short spine setae, while the inner surface is covered with several rows of short spine setae. The merus is short and bears short spine setae on the medial margin and a few spine setae on the outer surface. The palp consists of 3 segments, with the dactylus as the longest segment, all palp segments bear serrate setae along lateral margins.

Second maxilliped (Fig. 12c): The merus is longer than it broad, and bears a few spine setae on the medial margin and a few setae distally on the lateral margin. The carpus, propodus and dactylus are covered with short spoon-tipped setae on the medial margin. The exopod is relatively large, and bears a row of short simple setae on the medial margin and dense plumose setae distally and proximally on the lateral margin. The terminal segment of the flagellum has plumose setae. The epipodite is relatively elongate and bears simple setae on its surface.

First maxilliped (Fig. 12d): The basal endite of the first maxilliped is larger than the coxal endite and both are covered with serrate setae along the lateral and medial margins. The endopodite consists of 2 segments and bears an assemblage of serrate setae on the medial margins. The exopodite bears fine simple setae on the medio-lateral margins and a row of small spine setae proximally on the inner margin. The apex of the endopod is flattened into horizontal flange which is fringed with simple spine setae. The medial margin of the endopod bears a row of plumose setae. The flagellum bears short simple setae along the lateral margin. The epipodite of the first maxilliped is larger than that of the second maxilliped. Its carries curled simple tipped marginal setae.

Maxilla (Fig. 12e): The coxal endite of themaxilla consists of 2 small elongate lobes bearing serrate setae on the medial margin. The basal endite is an enlarged axe-shaped fleshy lobe which bears dense serrate setae on the distal margin and plumose setae on the proximal margin. The scaphognathite is the largest part of the appendage and bears short setae.

Maxillule (Fig. 12f): The coxal endite is smaller than the basal endite and forms a fleshy lobe whose outer surface is covered by long plumose setae. The basal endite consists of a long lobe and its lateral margin is surrounded by spoon-tipped setae, while the endopodite is covered with long spinose setae.

Mandible (Fig. 12g): The mandible is well developed with a sharp none-toothed cutting edge. The none-biting surface is without setae. The distal segment of the small mandibular palp is covered with spoon-tipped setae, while long plumose setae are borne on the rest of the segments.

Figure 12: *Eurycarcinus orientalis*: (A&B) third maxilliped; (C) second maxilliped; (D) first maxilliped; (E) maxilla; (F) maxillule; (G) mandible. Scale lines represent 0.1 mm.


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Comparisons of mouthpart morphology for different species

Morphometric comparisons of the mouthparts of the 9 species of crab were made as follows: (1) the relative size of the third maxilliped to body size; (2) a comparison between the shapes of cephaic and thoracic appendages; and (3) a comparison between the shapes of attached setae of the second and first maxillipeds.

(1) Comparison of the relative size of the third maxilliped to body size.

The relative size of external maxilliped to the body size (C) was calculated for 9 species by using the following formula (Ono, 1965):

$$C = \frac{\text{max. length} \times \text{max. width of 3rd maxilliped}}{\text{max. length} \times \text{max. width of carapace}}$$

The values of C together with standard deviation (SD) are given in (Tab. 3). From this table it is evident that the sand deposit feeder *S. crabricauda* has the largest third maxilliped relative to body size followed by *I. frater* which is also found in areas of sandy mud high on the shore. *M. arabicum, N. dotilliformis, S. leachii* and *M. depressus* are all closely grouped at 0.07-0.06 and found deposit feeding on wet muddy substrates. The omnivorous or carnivorous species *M. indica, M. messor* and *E. orientalis* show the smallest third maxillipeds relative to body size.

Table 3: Comparison of the relative size of third maxillipeds to crab body size.

Species	C ± SD
Scopimera crabricauda	0.29 ± 0.02
Ilyoplax frater	0.13 ± 0.02
Manningis arabicum	0.07 ± 0.03
Nasima dotilliformis	0.06 ± 0.01
Serenella leachii	0.06 ± 0.01
Macrophthalmus depressus	0.06 ± 0.01
Metaplax indica	0.04 ± 0.01
Eurycarcinus orientalis	0.03 ± 0.00
Metopograpsus messor	0.02 ± 0.00

(2) Comparison between the shapes of cepharic and thoracic appendages.

Typically in crabs the mouthparts consist of 3 thoracic appendages (third, second and first maxillipeds), while the cepharic appendages are the second and first maxillae and mandible. As can be seen from Figs. 4-12, summarised in table 4 all ocypodid species have poorly defined cutting edges and medium to large mandibular palps, many of which are moderately or densely setose. In contrast the grapsid and xanthid species have robust mandibles, often heavily calcified, with small naked mandibular palps.

Similarly the endopodite of the maxillule is reduced in most deposit feeding species, but robust in omnivorous or carnivorous species, while the coxa and basis are expanded in the former but moderate in the latter species (Tab. 4, Figs. 4-12). The articles of the maxillule and maxilla are moderately or heavily setose in all ocypodid species, but glabrose in *M. indica* and *E. orientalis*. The maxilla and first maxilliped are of a moderate or large size in deposit feeders, but small in *M. indica*, *M. messor* and *E. orientalis*. Relative size of the second maxilliped is similar for most species with only *S. crabricauda* and *S. leachii* possessing enlarged endopodites (Figs. 4-12).

Table 4: Comparison between the shapes of cepharic and thoracic appendages (S: small; M: medium; L: large).

Species	Mandible	Palp	Maxillule			Maxilla		Maxilliped 1	Maxilliped 2	
			Endopod	Coxa	Basis	Basis	Coxa	Basis/Coxa	Endopod	Exopod
Scopimera crabricauda	Weak	Large	S	L	L	L	L	L	L	S
Ilyoplax frater	Weak	Medium	S	L	L	L	L	L	S	S
Manningis arabicum	Weak	Medium	S	L	L	M	M	L	S	S
Nasima dotilliformis	Weak	Medium	S	L	L	L	L	L	S	S
Serenella leachii	Weak	Medium	S	L	L	L	L	L	L	S
Macrophthalmus depressus	Weak	Large	M	L	L	L	L	L	S	S
Metaplax indica	Robust	Small	L	M	M	S	S	S	S	S
Eurycarcinus orientalis	Robust	Small	L	M	M	L	L	S	S	S
Metopograpsus messor	Robust	Small	L	M	M	L	L	S	S	S

(3) Comparison of the setae on the second and first maxillipeds.

The setal type and distribution of the setae growing on the inner side of the merus of second maxilliped and on the outer side of the coxal endite and basal endite of the first maxilliped differ between the species investigated in this study (Tab. 5). The merus of the second maxilliped of *S. crabricauda* (Fig.4c) is broad and fringed with spoon-tipped setae reaching the highest density distally. The first maxilliped bears 2 types of setae, those on the coxal endite are spoon-tipped setae and those on the basal endite are plumose setae.

Spoon-tipped setae are replaced by plumose setae on the merus of the second maxilliped of the other 5 ocypodid species (Figs. 5c, 6c, 7c, 8c, 9c). The plumose setae on the basal endite of the first maxilliped are replaced by serrate setae in all other species (Figs. 5d, 6d, 7d, 8d) except for *M. depressus* which has spoon-tipped setae (Fig. 9d). Serrate setae occur on the coxal endite of all other species with the exception of *S. leachii* and *M. depressus* which have plumose setae. The merus of the second maxilliped of *M. indica* is covered with serrate setae as are the coxal and basal endite of the first maxilliped (Fig. 10c). In *M. messor* and *E. orientalis* the merus is covered with spinose setae, although the latter species has a lower abundance of setae, while the coxal and basal endite of the first maxilliped are covered with serrate setae with highest densities on the medial edges.

Distributions and densities of the setae found on the merus of the second maxilliped and on the coxal endite and basal endite of the first maxilliped were estimated under a compound microscope in area of 500 X 500 μm for the 9 species. The setae were counted in upper, median and lower regions of the merus of the second maxilliped and on the coxal and basal endites of the first maxilliped. Estimated densities of setae are presented in Tab. 5 which shows there are variations between upper and lower regions in terms of setal numbers and types.

In general, the densities of setae reduce with an omnivorous or carnivourous habit, both on the first and second maxillipeds. Setal type also changes with feeding type, so that spoon-tipped are more commonly associated with sand deposit feeding and plumose setae with mud feeding (Tab. 5). Serrate or spinose setae are typical of omnivorous or carnivourous species.

Table 5: Distribution and densities of setae types on the inner merus of the second maxillipeds and basal and coxal endites of the first maxillipeds for the 9 crab species (setal represented as the mean number/ 500 X 500 μm area).

Species	Portion	2nd maxilliped		1st maxilliped			
		setae no.	Setal type on merus	setae no.	Coxal setal type	Setae no.	Basal setal type
S. crabricauda	Upper	8	Spoon tipped	18	Spoon tipped	17	Plumose
	Median	8		20		20	
	Lowest	15		22		24	
N. dotilliformis	Upper	10	Plumose	11	Serrate	14	serrate
	Median	8		15		121	
	Lowest	8		14		12	
S. leachii	Upper	4	Plumose	10	Spoon tipped	8	Serrate
	Median	6		10		10	
	Lowest	8		14		10	
M. arabicum	Upper	7	Long Plumose	16	Serrate	13	Serrate
	Median	4		18		18	
	Lowest	6		20		24	
I. frater	Upper	8	Plumose	16	Stout serrate	17	Serrate
	Median	9		20		17	
	Lowest	14		16		16	
M. depressus	Upper	7	Plumose	9	Plumose	7	Spoon tipped
	Median	6		7		7	
	Lowest	5		10		10	
M. indica	Upper	6	Serrate	12	Serrate	9	Serrate
	Median	5		15		9	
	Lowest	8		15		13	
M. messor	Upper	8	Spinose	9	Serrate	7	Serrate
	Median	7		9		8	
	Lowest	6		12		10	
E. orientalis	Upper	2	Spinose	4	Serrate	6	Serrate
	Median	2		4		8	
	Lowest	1		5		8	

Functional morphology of the proventriculus

Essentially food enters the cardiac portion of the stomach through the oesophagus and is churned by peristaltic waves created by muscle contraction and by the posteriorly inclined setae lining the walls of the stomach. Within the proventriculus digestion commences with the the secretion of enzymes from the hepatopancreas (Icely and Jones, 1978). Fine particles of food and chyme passes along the food groove to the hepatopancreas for absorption, while larger particles are carried dorsally to the masticating ossicles where they are ground and scraped by the medially moving lateral teeth and the ventrally moving median tooth complex. Undigested material finally passes via the cardio-pyloric valve into the pyloric chamber and then to the mid gut. The structure of the ossicles takes the form of a large median tooth complex and lateral teeth bearing a varying number of transverse ridges. During mastication the median tooth moves ventrally to interdigitate with the lateral teeth which move medially. The vertical ridges of the latteral teeth are brought into contact with and scraped across the transverse ridges of the median tooth. The morphology of these surfaces may reflect diet and have been examined using SEM microscopy. The ventral surface of each lateral tooth is flattened and smooth.

In *S. crabricauda* the median tooth consists of 2 oval transverse ridges placed one behind the other leaving a gap. The lateral edges are curved upwards and rounded (Plate 1a). The 4-5 setal rows borne on each of the 18 vertical ridges on the lateral teeth are composed of short stiff setae (Plate 1b). The ventral edge of each lateral tooth is relatively smooth and flattened.

In *S. leachii* the urocardiac ossicle (Plat 2a) is an elongated thick flattened plate with a smooth surface and the median tooth consists of 2 closely spaced transverse ridges. The 6-8 setal rows borne on the 16 vertical ridges of the lateral teeth are slightly longer and more flexible (Plate 2b) than those in *S. crabricauda*. The terminal setae are plumose. In *M. arabicum* the median tooth is composed of 2 large transverse ridges either side of a smaller transverse ridge. The 8-10 setal rows, borne on 11 vertical ridges on the lateral teeth, are plumose longer and more flexible (Plate 3b) and extend further towards the base of the ridge. The ventral edge of each lateral tooth is smooth and flattened.

The median tooth in *N. dotilliformis* consists of 2 widely spaced transverse ridges (Plate 4a), similar to those of *S. crabricauda* (Plate 1a). The 8 setal rows borne on the 14 vertical ridges of each lateral tooth (Plate 4b) are elongate but stout and short and stiff towards the base of the ridge. The ventral edge of each lateral tooth is smooth and flattened.

In *I. frater* the median tooth consists of a single large transverse ridge (Plate 5a). The 10 setal rows borne on the 11 vertical ridges of each lateral tooth are elongate and flexible with terminal tufts of flattened setae. These become short and blunt towards the base of each ridge. The vertical edge of each lateral tooth is smooth and flattened (Plate 5b).

In *M. depressus* (Plate 6a) the 4 transverse ridges on the median tooth form a closely fitting fan shape. The 8 setal rows born on the 16-18 vertical ridges on each lateral tooth are composed of long flexible plumose setae which extend from the base to the tip on the anterior edge of each ridge. Posteriorly there are sharp teeth and grooves (Pate 6b). The ventral edge of each lateral tooth contains a central raised ridge, but is otherwise smooth.

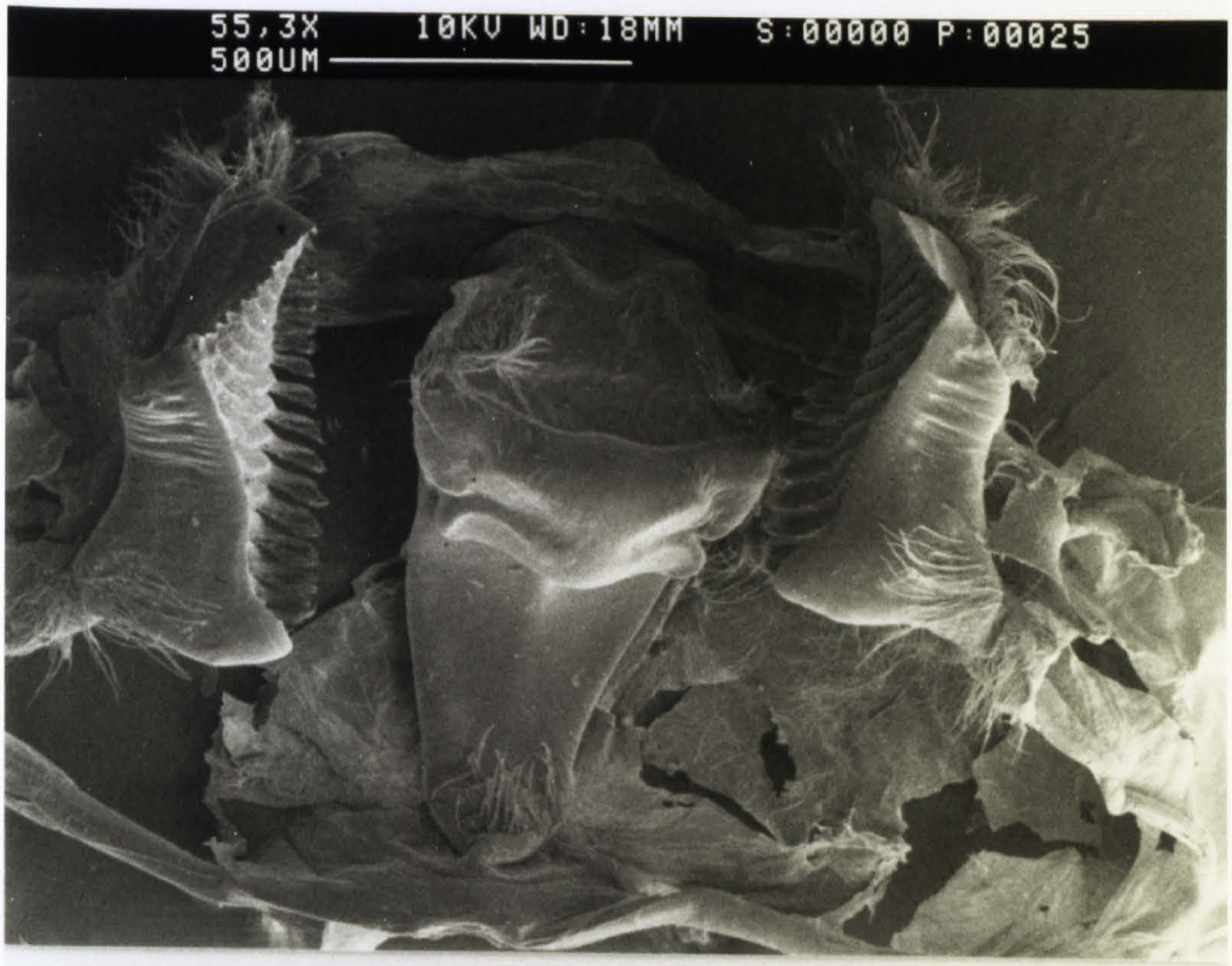
In *M. messor* the median tooth consists of 3 transverse ridges with a row of spines on the dorsolateral margins (Plate 7a). The 18 vertical ridges on each lateral tooth are devoid of terminal setae, but have short blunt teeth on the proximal part of each ridge (Plate 7b). The ventral edge of each lateral tooth is raised to form a series of rounded teeth decreasing in size posteriorly.

The median tooth in *M. indica* (Plate 8a) consists of 2 simple rectangular ridges, each of the 12 vertical ridges on the lateral tooth bears 3 rows of short blunt spines which become longer distally (Plate 8b). The ventral edge of each median tooth is convoluted to form a series of pointed teeth which decrease in size posteriorly.

In *E. orientalis* the median tooth bears a single peg like rounded ridge (Plate 9a) and the posterolateral edges of the tooth are curved with 10 long rigid spines (Plate 9b). Each lateral tooth bears 9 strong glabrose vertical ridges (Plate 9c). The vertical edge of each lateral tooth is developed into large pointed teeth which decrease in size posteriorly (Plate 9c).

Plate 1: *Scopimera crabricauda*: (a) proventriculus; (b) rows of setae on the lateral teeth.

a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500UM

b

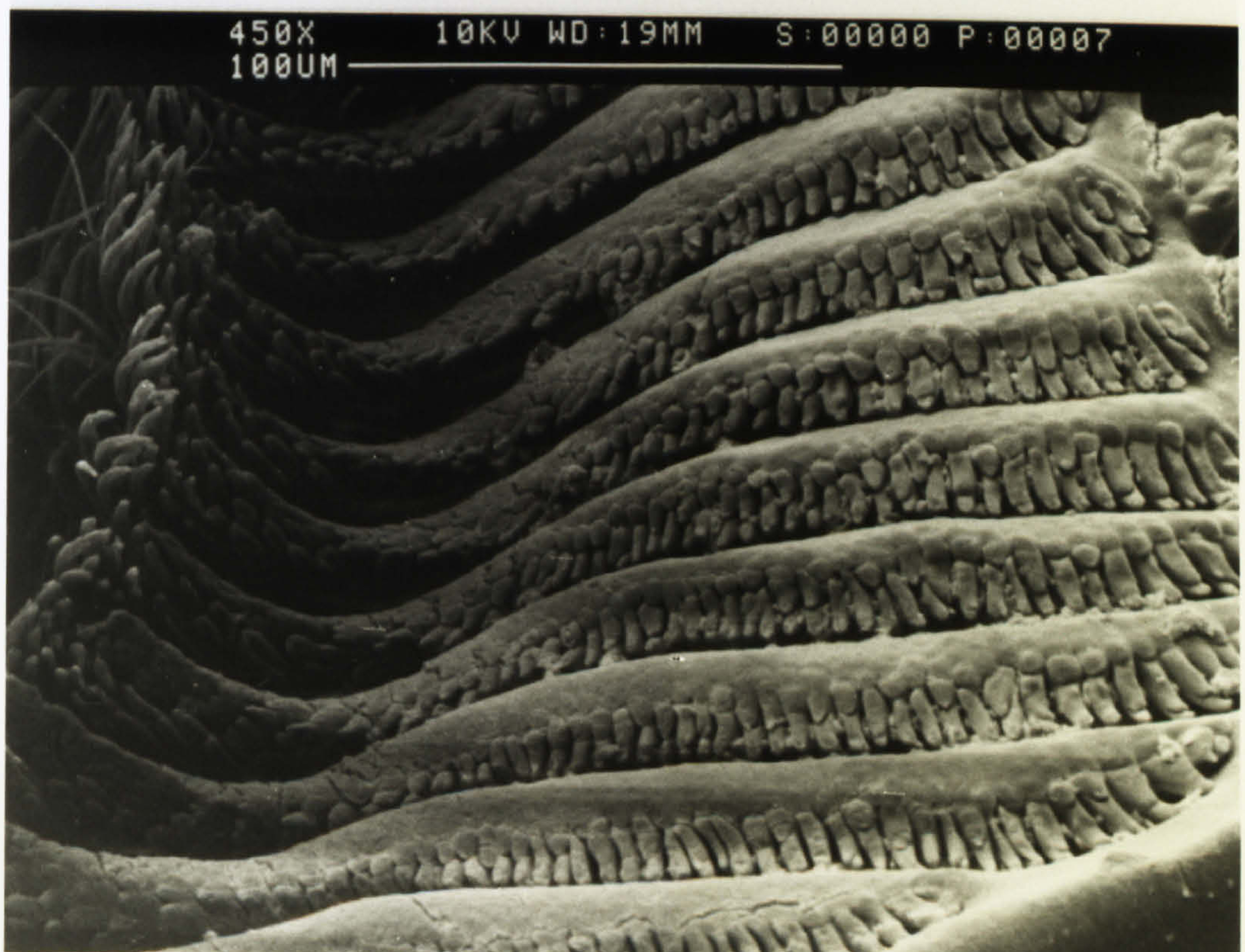

450X 10KV WD:19MM S:00000 P:00007
100UM

Plate 2: *Serenella leachii*: (a) proventriculus; (b) rows of setae on the lateral teeth.

a


55,3X 10KV WD:18MM S:00000 P:00039
500UM

b

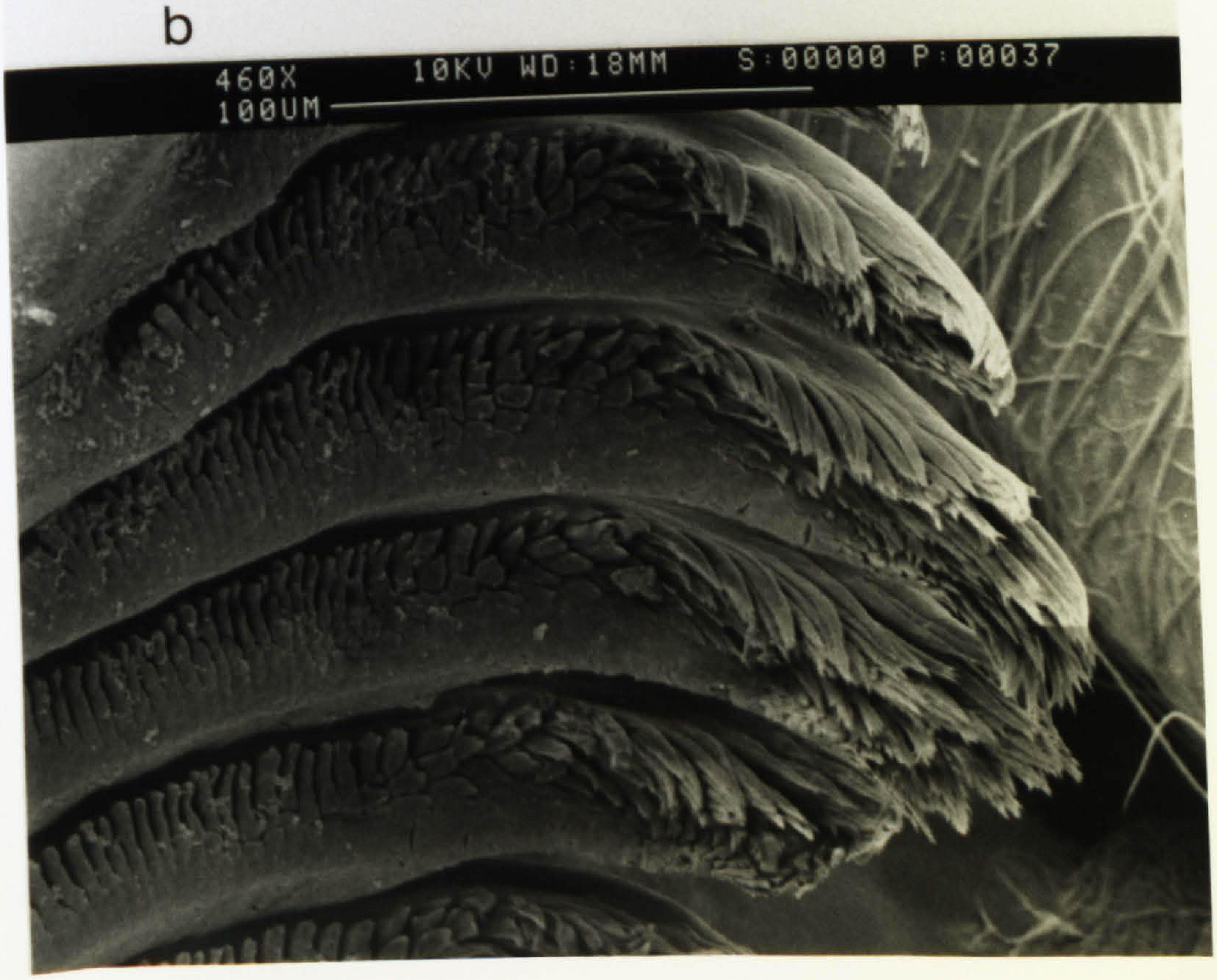

460X 10KV WD:18MM S:00000 P:00037
100UM

Plate 3: *Manningis arabicum*: (a) proventriculus; (b) rows of setae on the lateral teeth.

a


65,5X 10KV WD:24MM S:00000 P:00006
500UM

b


338X 10KV WD:8MM S:00000 P:00017
100UM

Plate 4: *Nasima dotilliformis*: (a) proventriculus; (b) rows of setae on the lateral teeth.

a


55,3X 10KV WD:18MM S:00000 P:00004
500UM

b

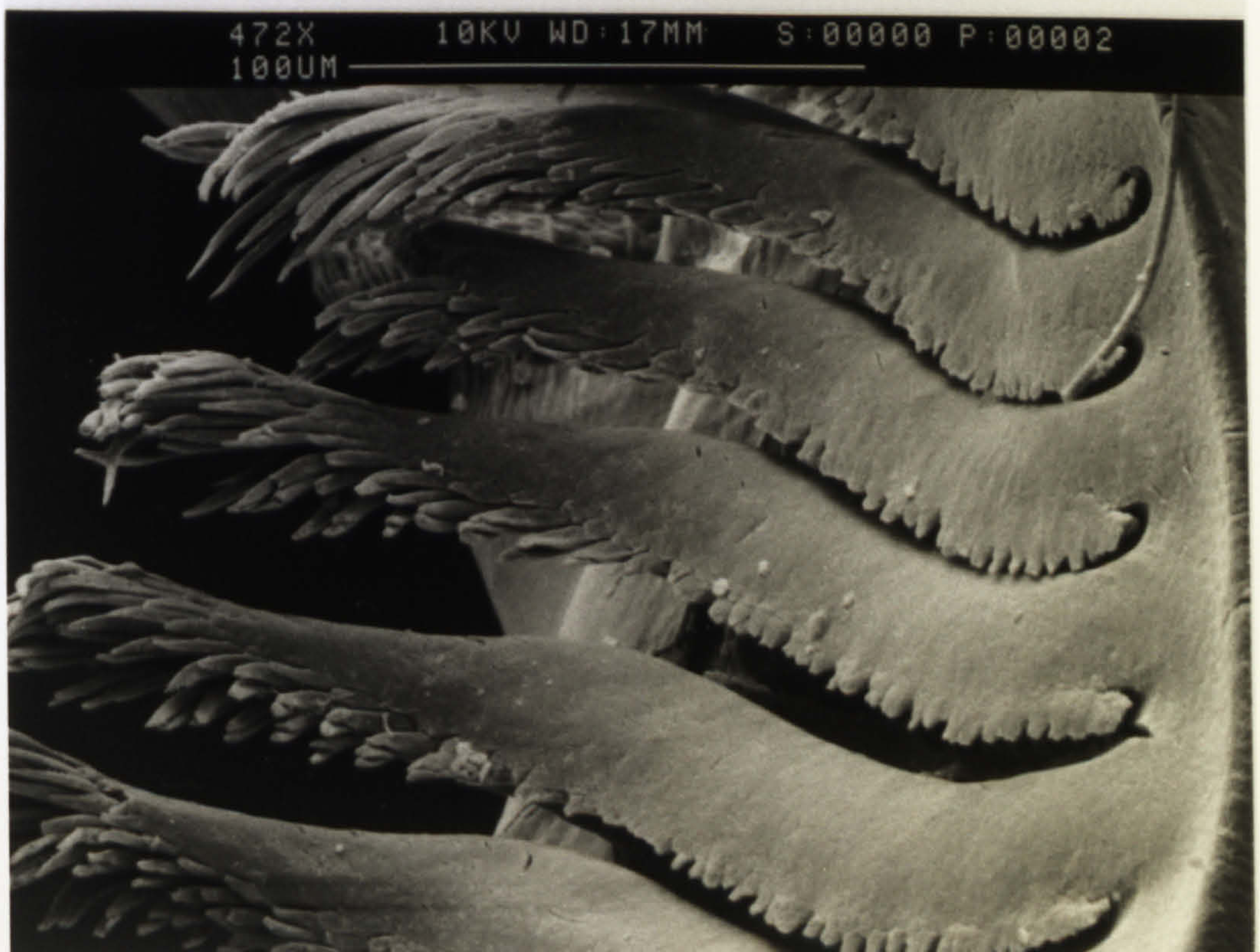

472X 10KV WD:17MM S:00000 P:00002
100UM

Plate 5: *Ilyoplax frater*: (a) proventriculus; (b) rows of setae on the lateral teeth.

a


54,1X 10KV WD:19MM S:00000 P:00009
500UM

b


344X 10KV WD:8MM S:00000 P:00008
100UM

Plate 6: *Macrophthalmus depressus*: (a) proventriculus; (b) rows of setae on the lateral teeth.

a


28,8X 10KV WD:16MM S:00000 P:00009
1MM

b

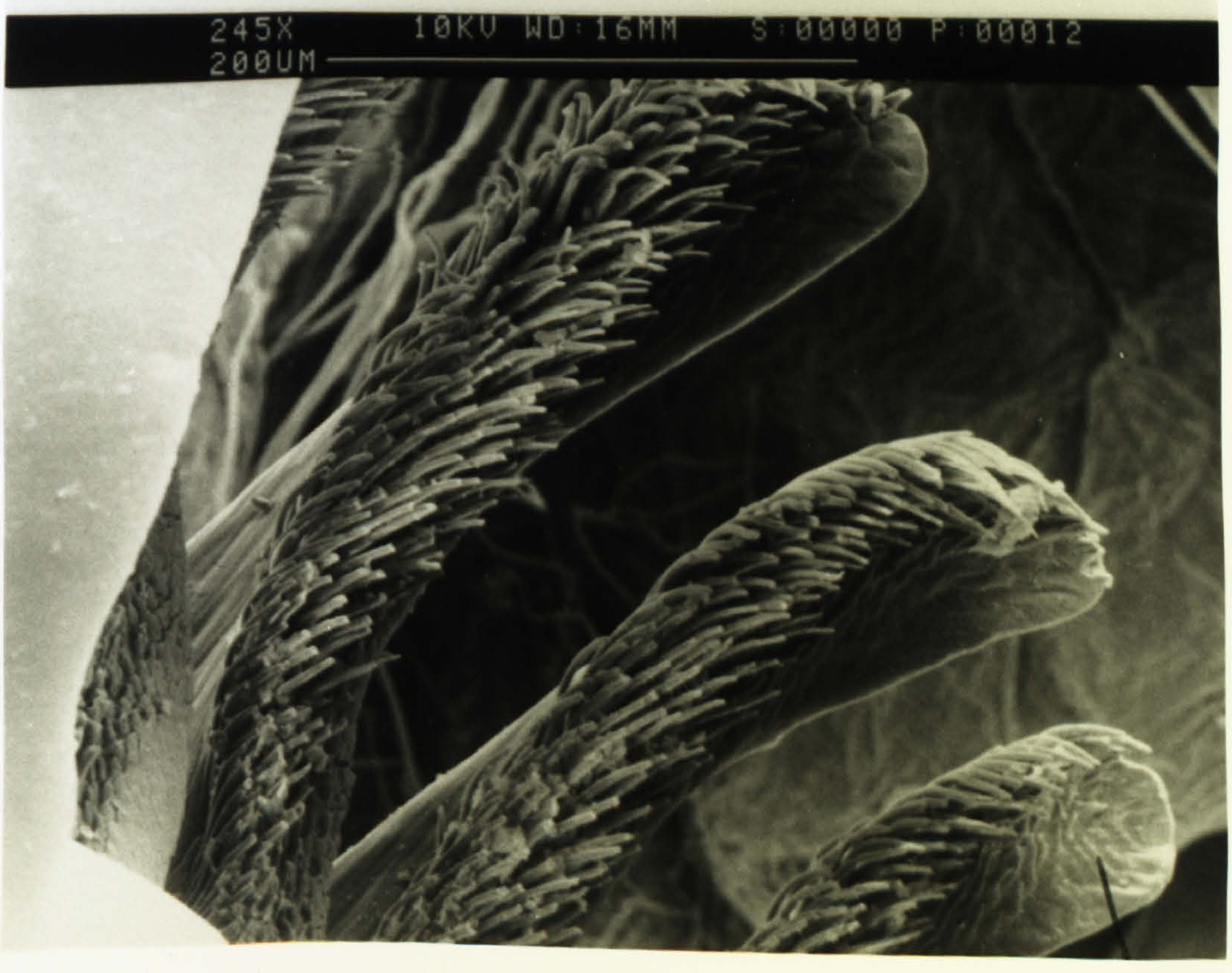

245X 10KV WD:16MM S:00000 P:00012
200UM

Plate 7: *Metaplax indica*: (a) proventriculus; (b) rows of setae on the lateral teeth.

a

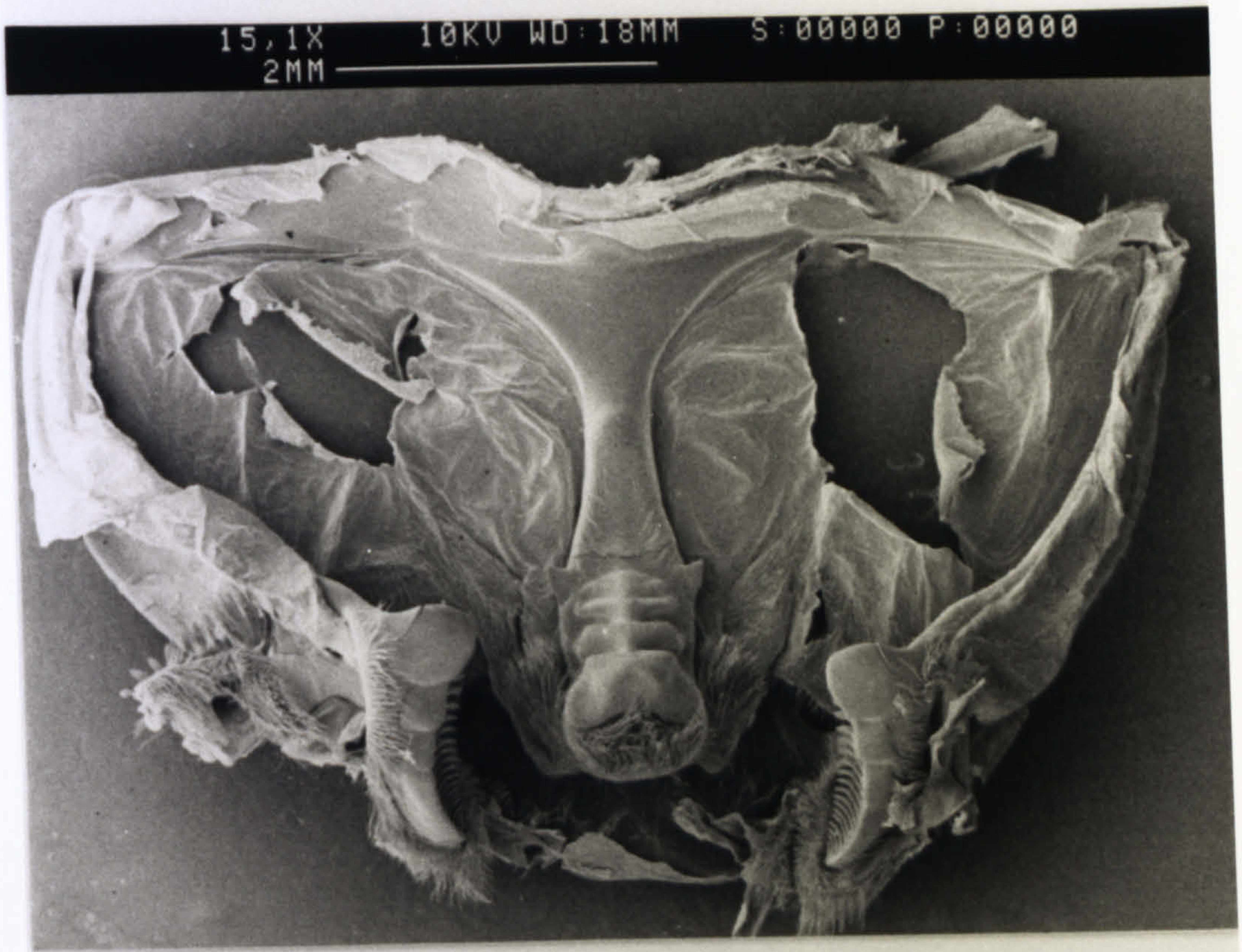

55,3X 10KV WD:18MM S:00000 P:00007
500UM

b


900X 10KV WD:19MM S:00000 P:00006
50UM

Plate 8: *Metopograpsus messor*: (a) proventriculus; (b) lateral teeth.

a


15,1X 10KV WD:18MM S:00000 P:00000
2MM

b

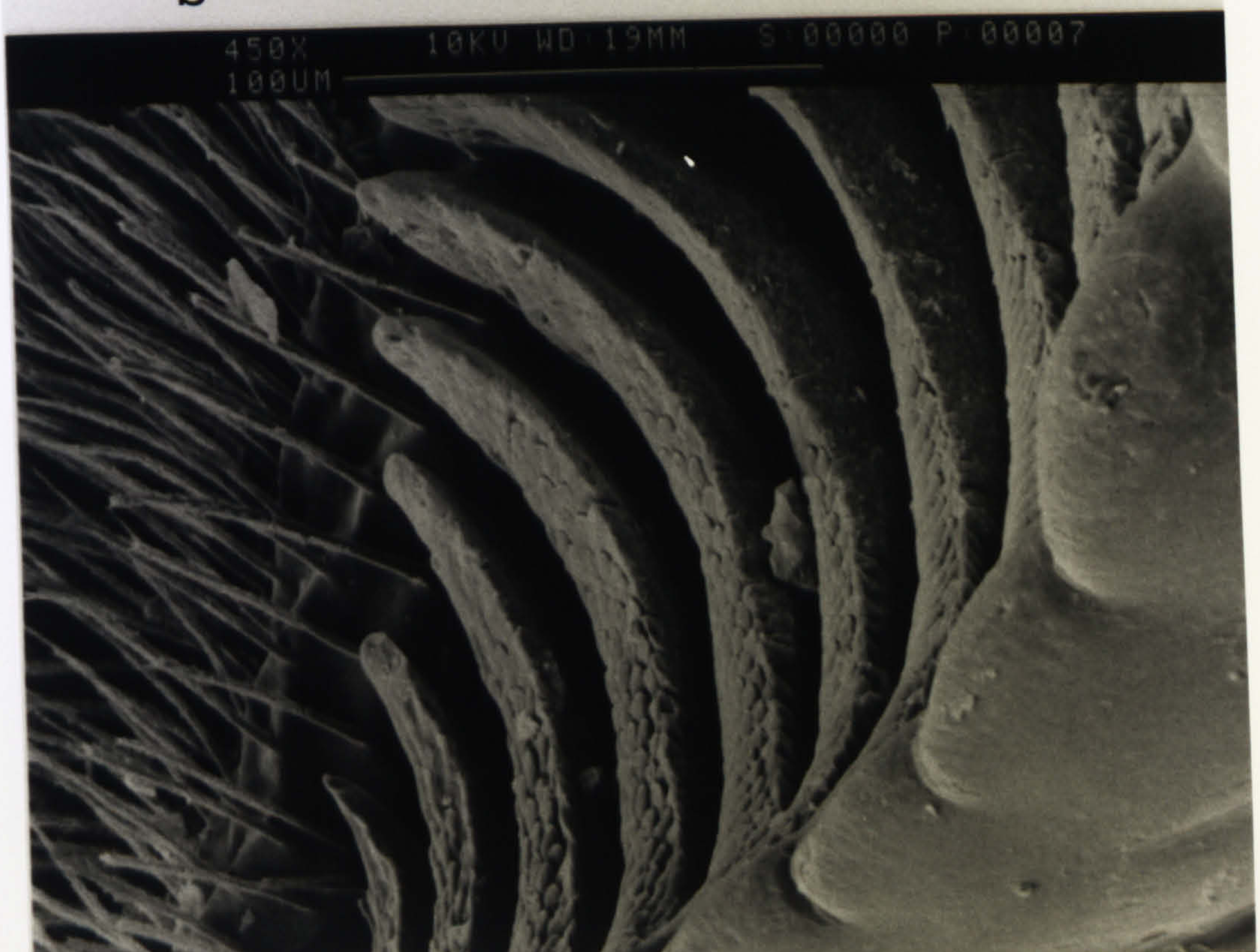

450X 10KV WD:19MM S:00000 P:00007
100UM

Plate 9: *Eurycarcinus orientalis*: (a) proventriculus; (b) lateral teeth; (c) vertical edge of lateral tooth.

a

b

c


28,8X 10KV WD:16MM S:00000 P:00011
1MM
228X 10KV WD:18MM S:00000 P:00022
200UM
460X 10KV WD:18MM S:00000 P:00017
100UM

DISCUSSION

Substrate preference

The distribution of ocypodid crab species populations are known to affected by several factors. Substrate characteristics such as grain composition, organic matter and moisture content are of primary importance (Ono, 1965; Hartnoll, 1973; Frith *et al*, 1976; Frith and Frith, 1977b; Icely and Jones, 1978; Frith and Brunenmeister, 1980). Ocypodid mouthparts are highly specialised for certain substrate particle sizes (Altevogt, 1955; Miller, 1961; Ono, 1965; MacNae, 1968; Von Hagen, 1970).
The organic matter sediment content was usually high in natural mangroves during the present study with an overall mean of 3.38% and was lower in planted mangroves (3.22%) and saltmarshes (2.77%). The highest organic content in natural mangroves was correlated to the sediment with the lowest particle size. The overall mean particle size distribution indicates that the natural mangrove has the lowest value of 0.19 ± 0.01 mm and planted mangroves a higher particle size of 0.22 ± 0.01 mm (Tab. 1).

The crabs *S. crabricauda, I. frater, S. leachii, M. arabicum, N, dotilliformis* and *M. depressus* are selective deposit feeders. Soil is scooped up by the mouthparts which partially select out the organic fraction and unwanted sand is returned to the substrate. Differences in feeding and masticatory structures were found between the 6 crab species which appear to reflect the sediment type upon which they feed. *Scopimera crabricauda* and *Ilyoplax frater* are specialised for feeding on sand rather than mud. Ono (1965) determined that *S. globosa* was able to sort the organic content from sand with 61% efficiency, whilst various mud living ocypodids sorted at an efficiency of less than 10%. These high sorting efficiencies in coarse grained deposits are essential in view of their low organic content (Hartnoll, 1973).

The other ocypodid species such as *M. arabicum, N. dotilliformis, S. leachii* and *M. depressus* prefer muddy substrates which have low particle size and high organic content and cannot feed on cleaner sand. Thus Hartnoll (1973) reported that *Uca* and *Macrophthalmus* feed on finer substrates with an efficiency comparable to *Dotilla* and *Scopimera*.

Chelae and mouthpart structure

Most crabs collected during this study are primarily deposit feeders, picking surface mud from the substrate with chelae. Modification in form and armature of chelae, mouthparts and proventriculus have occurred in relation to type of substratum utilised during feeding (Jones, 1984). This suggests some degree of ecological separation based upon the ability to sort and ingest sediment particles. Distribution correlates most closely with the percentage of organic content, *S. crabricauda, I, frater* and *M. arabicum* presumably being better able to extract lower organic concentrations of material found in coarse sediments. Hence these species have specialised chelae in form of fine forceps to pick organic materials from coarse sand. The muddy substrate feeders *S. leachii, N. dotilliformis* and *M. depressus* chelae with large flattened spoon-shaped tips and in addition the latter species has very dense hair on the outer cheliped surfaces used for sweeping the mud surface. The progressive development of spoon-tip chelae is associated with scooping up finer sediments (Icely and Jones, 1978). Jones and Clayton (1983) report that the chela of *M. arabicum* is forceps-like and used to pick up organic material from between sand grains which form a large proportion of the sediment. *N. dotilliformis* and *L. kuwaitense* have spatulate chelae bearing rows of long fine setae use to sweep up and retain finer particles from the mudflats. In contrast, the omnivorous and carnivorous species such as *M. messor* and *E. orientalis* have strong chelae, sharply toothed with a wide gape for seizing and tearing prey (Fig. 3).

A further relationship between feeding habit and habitat preference is demonstrated by the specialisation of mouthparts and their setae. A comparison of the relative size of the third maxilliped to crab body size (Tab. 3) shows a direct relationship between buccal cavity size used for sorting and substrate particle size. This very obvious for sand feeding *Scopimera crabricauda* and *I. frater* which have the largest maxilliped relative to body size in contrast to mud feeders *M. arabicum, N, dotilliformis, S. leachii* and *M. depressus*. The smallest maxilliped ratio to body size is found in *M. indica, M. messor* and *E. orientalis* which indicates the absence of sediment capacity.

The first and second maxillipeds in deposit feeding crab species are particularly important in performing sediment separation processes and are usually equipped with a variety of specialised setae. In *S. crabricauda*, feeding off sandy substrates, spoon-tipped setae occur on the merus and carpus of the second maxilliped while the propodus and dactylus are completely reduced. Miller (1961) reported that the spoon-tipped setae of the second maxilliped provide a rigid surface to provide an efficient scouring action on the sand grains as they are carried across the first maxillipeds. Spoon-tipped setae are replaced by plumose setae in muddy substrate feeders such as *N, dotilliformis, S. leachii* and *M. depressus* (Tab. 5). These are replaced by serrate setae in *M. indica* and spinose setae in omnivorous and carnivorous species such as *M. messor* and *E. orientalis*. Similarly, Miller (1961) and Ono (1965), working with *Uca* and *Scopimera*, found that sand-dwelling species under poor nutritive conditions possess more refined spoon-tipped setae than mud-dwellers where substrates are richer in organic content. The high density of spoon-tipped setae in *S. crabricauda* on the merus of second maxilliped (8-15 setae) and on coxa of first maxilliped (18-22 setae) is also a feeding adaptation. Carne, 1941; Altevogt, 1957; Miller, 1961 regard the second maxilliped as important in the sorting mechanism. This was verified by the occurrence of dense spoon-setae on the second maxilliped of *Uca* (Ono, 1965). In *S. crabricauda* these setae extend at high density onto the to coxal endite of the first maxilliped which suggests a high sorting ability .

The setal density on second and first maxillipeds of other sediment feeding is ocypodid are relatively higher than those of omnivorous and carnivorous species examined. The abundance of setae and their type appears to correlate with the relative abundance of sand in the foraged sediment (Miller, 1961; Ono, 1965; Icely and Jones, 1978). The plumose setae in ocypodid species grow most densely over almost the whole surface of the second maxilliped, appear to act as a sieve for feeding on muddy tidal flats. The serrate setae on the coxal and basal endite of the first maxilliped are expected as their function is concerned with gripping and cleaning. In *M. indica* the plumose setal and spoon types are replaced by serrate setae on the first and second maxillipeds with a high density on the coxal endite of the first maxilliped. Similarly, in *M. messor* and *E. orientalis* the setal density is reduced and replaced by only a few spinose setae on the second maxilliped as these species are predators.

Modification of the mandible can also be recognised between present species examined. In deposit feeders a weak mandible contrasts with a robust mandible used for tearing prey in omnivorous and carnivorous species. The palps are medium to large size in ocypodid species but small in predatory species. The larger size of palps further supplements the manipulation of material to be discarded from the buccal cavity, as well as carrying food material to the maxilla for passage to the mouth. The maxilla has a large basis and coxal endite in all ocypodids except *N. dotilliformis* which has a medium size, while the smallest basis and coxal endites are present in predatory species (Tab. 4). The larger size of basal and coxal endite is thought to increase the efficiency of the mouthparts in handling sediment, as well as providing another surface on which fine sediment particles may accumulate (Ono, 1965).

Ilyoplax frater, *S. leachii* and *M. depressus* possess only spoon tipped setae on the second maxilliped palp which may permit feeding on wet sandy or muddy substrates. The palp also aids in the manipulation of particles within the buccal cavity (Miller, 1961). A similar modification occurs with the long endopod of the second maxilliped of *S. crabricauda* and *S. leachii* which may increase the efficiency of the sorting process by spreading the material across the first maxilliped endopodite. Miller (1961) suggests that the enlarged setae projecting perpendicular from the endites offer a brush-like surface against which sand grains may be scoured and food material removed as the second maxillipeds sweep grains across the endite.

Proventriculus

After the process of sorting and ingestion particles pass to proventriculus where further adaptations in relation to diet have occurred. The median ridges with a wide gap together with lateral teeth bearing stiff setae in the proventriculus of *S. crabricauda* present a coarse abrasive surface for scraping organic material from the surface of large sand particles. In *I. frater*, *S. leachii* and *M. arabicum* more closely spaced median ridges and lateral teeth with blunt setal tufts offer a flattened abrasive surface for scouring organic matter from the surface of smaller sand grains. *Nasima dotilliformis* has a widely spaced ridges and longer setae which suggested that whilst a scraping surface for large sand particles is retained the longer setae of the lateral teeth assist in the breakdown and retention of the filamentous cynobacteria now present in the diet. In *M. depressus* the transverse ridges of the median tooth are expanded and the lateral teeth are furnished with brush-like setae to assist in breakdown and retention of very fine particles. In contrast omnivorous and carnivorous species such as *M. indica*, *M. messor* and *E. orientalis* have the transverse ridges of the median tooth furnished with short blunt teeth and large spines on the lateral teeth with setae absent or small and flattened.

It is apparent that *S. crabricauda* is adapted to extract its nutrition from sandy areas with a low organic content while other ocypodid species studied here are adapted to extract food from areas with a high organic content. Omnivorous and carnivorous species show no adaptation to substrate and can be found any where. Similarly, Icely and Jones (1978) report that *U. lactea* is well adapted to cope with the high proportion of sand grains and large particles associated with its habitat, while *Uca chlorophthalmus chlorophthalmus* (Milne Edwards) is modified to feed on rich mud and is unlikely to be able to extract sufficient nourishment from sediments with lower organic content.

Distribution

The 6 ocypodid crabs considered in this study show specialisations in the form of their mouthparts and proventriculus which adapt them for feeding from either sandy or muddy substrata. Thus each crab is distributed on shores broadly in relation to the occurrence of suitable sediment grades. Omnivorous and carnivorous species such as *M. indica, M. messor* and *E. orientalis* were present in all habitats surveyed (natural mangrove, planted mangrove and saltmarsh areas) except for *M. indica* which prefers the lower shore which was not sampled at the salt marsh site. *Macrophthalmus depressus* was also found on the lower muddy shore at all sites below the mangrove zone which indicating that this species does not rely on mangrove. *Nasima dotilliformis* was not recorded from planted mangroves as this species needs very soft high shore mud to feed on and this habitat was absent at these sites. *Ilyoplax frater* is a sand-dweller but also inhabits soils with an appreciable admixture of mud. It was found at all sites except 2 planted mangrove sites on the east coast (P1 and P4) and the absence of this species from these sites may be related to the presence and competion with *S. leachii*. The latter species is also a sandy -mud dweller but was absent from all natural mangroves and this may related to the above reason. In Oman mangal, *Serenella leachii* was recorded on the upper shore and extended into the lower shore in smaller densities (Hywel-Davies, 1994).

GENERAL DISCUSSION AND CONCLUSION

GENERAL DISCUSSION AND CONCLUSIONS

The effect of physical environment

Physical and biological processes profoundly influence the occurrence and distribution of intertidal fauna in Qatar and other parts of the Gulf region. Seasonal changes in air temperature are considerable causing dramatic differences between winter, with an average of 12°C, and summer with an average of 38°C in August. This high range in air temperature naturally influences the extreme range of water temperatures especially in shallow water. High evaporation rates are mainly responsible for elevated salinities in Qatar and the rest of the region (40-70‰). Both high salinities and extreme temperatures limit the occurrence of many of the biota. Salinities range from 38-41‰ and reach 60-70‰ in the Gulf of Salwah, while in hypersaline embayments salinities exceed 200‰ (Basson *et al.*, 1977; Jones *et al.*, 1978). The high salinity on the west coast of Qatar is reflected in a poor growth of *A. marina* so that at Zekrit (P5) at 60-90‰ salinity 8.5 year old trees reach only 45 cm in height. Salinity is also a major limiting factor on the distribution of brachyuran fauna at this site where only 2 species (*S. crabricauda* and *M. messor*) were found. In contrast, most planted mangrove on the east coast at a salinity of 45‰ grew to 2m during the same period with a much higher macrofaunal species diversity. Observation elsewhere suggests that climate may also affect *Avicennia marina* size (Lear and Turner, 1977). Clough (1993) suggests that aridity is the main factor influencing mangrove growth, although other factors such as humidity and solar radiation are important.

The main trend in sediment characteristics observed between different mangrove and salt marsh sites was that of decreasing grain size from the upper shore to the lower shore. Natural mangrove sites contain a smaller grain size compared to that of planted mangrove sites. This decrease in particle size is probably related to the extensive pneumatophore system of mangroves which acts to slow water motion and cause settlement over time of fine sediment particles in established mangrove areas. Accordingly, the proportion of silt and clay is higher in natural mangrove sites than those of the newly planted mangrove sites which will require a longer period of time to reach similar levels of silt and clay. This higher level of sand and clay with a smaller grain size results in increased substrate moisture and organic content in natural mangrove areas in comparison to planted mangrove areas.

Substrate particle size was fairly uniform throughout natural mangroves, with very fine sands dominating. The particle size is higher and organic content lower than for mangroves else where (Chapman. 1976). Hence at most natural, planted mangrove and salt marsh sites soil oxygen content was high and no relation between crab burrows and tree abundance or height was evident as seen elsewhere when anoxic conditions prevail (Wada and Takagi, 1988).

The difference in temperature regimes between the northern Gulf and central Gulf (Qatar, Saudi Arabia and Bahrain) (Vousden, 1989; Jones, 1986) may explain some of the quantitative and qualitative differences in biota character especially in view of seasonal maxima and minima (Vousden, 1989). The contrast in salinity regimes between the two areas must also definitely play a part (Jones, 1986). Almost all the mangrove and salt marsh crabs construct burrows which protect them from high evaporation and temperature stresses. The highest burrow temperature (36°C) was recorded for *S. crabricauda* in June at an air of 40°C. However, as Jones (1986) records air temperatures of 0°C in Kuwait which has a higher biodiversity of tropical mudflat ocypodids (Clayton, 1983) it is unlikely that temperature is the controlling factor on distribution in the Arabian Gulf. As maximum salinities reach only 39‰ in Kuwait it is probable that lower brachyuran biodiversity in Qatar is due to elevated salinity.

The relation of substrata on population distribution and abundance of fauna.

The soft substrate crab faunal distribution in Qatar is mainly governed by the nature of substrate. *Scopimera crabricauda* inhabits sandy areas of the upper shore at the same abundance at all sites. When this substrate contain a high proportion of mud and silt *N. dotilliformis* is present with range of between 4-7 individuals 0.25 m^2 at natural mangrove and salt marsh sites, but is absent from planted mangrove where this habitat is not available. *Ilyoplax frater* was only found at one planted mangrove site (P3), but was very abundant in natural mangroves with an average of 18 individuals 0.25 m^2 . The absence of this species from planted mangrove may also be related to the absence of suitable substrate. The muddy substrata below the mangroves was similar at all sites and *M. depressus* occurred on the lower shore with 4-5 individuals 0.25 m^2 while *M. indica* was also present but at lower numbers at all sites. *Serenella leachii* was absent from all natural mangrove sites and planted mangrove sites (P3, P4, P5) but present at sites P1 and P2 and salt marsh. This species is only found on mud banks and its absence from other sites may related to competition with *I. frater*.

The composition of the substrate has a close relationship with the degree of rejected material for deposit feeding crabs. Hence *S. crabricauda* and *I. frater* living on sandy soil scoop larger amounts of soil but reject a higher number of coarser particles than muddy deposit feeder crabs such as *M. depressus* and *M. indica* living in muddy soils with a high organic content. Substrate structure also appears to control the distribution of mudskipper *Boleophthalmus boddarti* which was found in muddy substrates in the upper intertidal zone at natural mangrove sites and salt marshes, but was absent from all planted mangrove sites where this muddy substrate is still absent.

Other associations with mangroves

Many species of fish and prawns utilize mangrove areas as feeding or nursery sites (Macnae, 1974; Macintosh, 1983; Leh and Sasekumar, 1984). They may enter and leave the mangrove during a single tidal cycle or, as in the case of several important penaeid species, spend up to several months in the mangrove before emigrating offshore to spawn (Macintosh, 1988). Within intertidal mangrove habitats most fish species seek shelter, protection from predation and a food source. In present work natural mangrove contained the highest fish species diversity and abundance. The fish survey by using hand net revealed that the pneumatophores of *A. marina* contained 10 species of juvenile fish in natural mangroves, 8 at planted mangrove but few species on sandy shores or salt marshes. Most juvenile and adult *Liza* sp were found in their highest abundance at mangrove sites where they feed on the rich nutrient bottoms.

Taxonomy and larval description:

During the last 30 years there have been few systematic investigations and fewer reports on Arabian Gulf Brachyura (Stephensen, 1945). Tirmizi (1980a , 1980b), Tirmizi and Kazmi (1979, 1984), Tirmizi and Ghany (1982, 1988) and Tirmizi *et al.*, (1985) have made taxonomic studies on crabs in the Gulf region, but the Ocypodidae have received less attention.

In present work new generic diagnoses are given for *Paracleistostoma arabicum* and *Cleistostoma kuwaitense*. Neither of these crabs belong to *Cleistostoma* or *Paracleistostoma*as as restricted by Manning and Holthuis (1991). Both *P. arabicum* and *C. kuwaitense* have all somites of the male abdomen free which distinguishes them from *Paracleistostoma* and *Serenella*, where the third to fifth somites of the male abdomen are fused (Manning, 1991). Thus, these 2 species are referred to the new genera *Manningis* and *Leptochryseus* respectively.

Apart from the family Penaeidae there has been no attempt to identify the larvae of Arabian Gulf decapods beyond the generic level, although in recent surveys of the planktonic Decapoda of the western Gulf (Al-Aidaroos, 1993) brachyuran larvae formed the most dominant component of decapod larvae recorded. The prezoea and zoea of 6 species of common intertidal crabs were reared from eggs in the laboratory and are described.

Crab biology and population dynamics

Studies on the population dynamic of *M. messor, N. dotilliformis, S. leachii, M. depressus* and *E. orientalis* has revealed detailed information on their population dynamics in Qatar waters, including carapace width weight relationship, sex ratio, size composition and reproductive seasons. For ocypodid species there is little difference between slope value indicating that there is little sexual dimorphism. For predatory species (*M. messor* and *E. orientalis*) the slope value for males is higher than for females due to positive allometery of the chelae (Hartnoll, 1982).

The carapace width - weight measurements reveal that males of all species are heavier than females and seasonal changes in weight for crabs of the same carapace width occurred with highest weights in winter and lowest in summer. Female *M. messor* follow the male pattern, while females of all other species show greatest seasonal weight during autumn (*N. dotilliformis* and *S. leachii*) or summer (*E. orientalis* and *M. depressus*). The sex ratio in the most species is in favor of males except for *S. leachii* where females are more abundant than males.

Size at maturity for females of the 5 crab species occur at small size classes and male maturity appears to be earlier than females possibly due to the fast growth of males which predominate in larger size classes. A large part of the adults of all species appear to be lost within one year. The breeding season for *S. leachii* takes place in autumn and early summer; *N. dotilliformis* and *E. orientalis* spring and summer; *M. messor* between early autumn - spring and *M. depressus* spring - summer. Whilst this is similar to the breeding season seen in Saudi Arabia for some species (Apel, 1944) in Kuwait winter appears to be the breeding season (Snowden *et al.*, 1991;

Snowden *et al.*, 1994; Snowden and Clayton, 1995) perhaps due to higher summer temperatures.

The relation between the feeding and specialisation of mouthparts

Examination of the mouthparts of 6 species of Ocypodidae, 2 species of Grapsidae and 1 species of Xanthidae has confirmed the apparent relationship between the distribution of these crabs and feeding habit. Deposit feeding mangrove ocypodids show similar mechanisms for partially extracting organic matter from coarse and fine mangrove sediments. Specialisations of mouthparts include broadening of merus or propus of the second maxilliped and development of spoon-tipped setae on the maxillipeds for species inhabiting more sandy sediments. *Scopimera crabricauda,* adapted to sandy sediments, has a high proportion of spoon-tipped setae that assist in scouring food material bound to sand particles. Ono (1965) suggested that broadening of the second maxilliped and development of spoon-shaped setae in species living in sandy areas are closely correlated with a high sorting ability, these specialisations are present in *S. crabricauda.* In contrast muddy sandflat species such as *M. depressus, N. dotilliformis, S. Leachii,* and *M. indica* have predominately plumose setae on the second maxilliped which provide a large surface area to brush fine sediment particles and trap food material from the substrate (Ono, 1965; Hartnoll, 1973; Icely and Jones, 1978). The deposit feeder species collected during this study revealed predominately spoon-tipped setae for sandy dwellers and plumose setae in muddy habitat crabs. Hence the distribution of these species between mangroves and salt marshes is probably determined not only by their tolerance of exposure to air, but also by their adaptation to feeding specific substrates of certain particle size and organic content.

The omnivorous and carnivorous species *M. indica, E. orientalis* and *M. messor* were present in all habitats available and have mouthparts differing from those of ocypodids. Their second maxilliped is armed with serrate setae in *M. indica* and spinose setae in *M. messor* and *E. orientalis*, and all species have a smaller third maxilliped relative to body size.

The present study has shown that a typical mangal fauna exists in Qatari natural mangroves and salt marshes, with a diversity and population abundance typical of the central Gulf region. Elements of this biota, particularly brachyurans, are absent from planted mangroves which have not yet accumulated the fine sediments with high organic contents typical of natural mangroves. The distribution, biology and population dynamics of 5 mangrove crab species have been studied for these species in Qatar waters for the first time. A further study of the relations between habitat, feeding and morphology of the mouthparts and preventriculus confirms that presence and absence of these species is dependent upon sediment characteristics. As there are in turn dependent upon mangrove development it is expected that full biological diversity will evolve in planted mangroves with time.

REFERENCES

REFERENCES

Ahmed, M., 1980. The breeding and recruitment of marine animals of the coast of Pakistan bordering the Arabian Sea. *Proc. First. Pakistan Congr. Zool.*, 55-96.

Al-Aidaroos, A., 1993. Planktonic Decapoda from the western coast of the Gulf. *Mar. Poll. Bull.*, 27: 245 - 249.

Al-Aidaroos, A. and Apel, M. (1994). Decapod larvae monitoring Programme. In: Establishment of a Marine Habitat and Wildlife Sanctuary for the Gulf Region. *Final Report for Phase* II: 495 - 500. Jubail & Frankfurt, CEC / NCWCD.

Al-Attar, M and Ikenous, H. 1974. spawning season of shrimp *Penaeus semisulcatus* in the sea along the coast of Kuwait, *Kuwait Sci. Res. Pub*. MAP 1, V II, 74.

Alcock, A. 1895. Material for a carcinological fauna of India. No 1: The Brachyura Oxyrhyncha. *J. Asiat. Soc. Bengal,* 64 (2): 157-291.

Alcock, A. 1896. Material for a carcinological fauna of India. No 2: The Brachyura Oxystomata. *J. Asiat. Soc. Bengal,* 65 (2): 134-296.

Alcock, A. 1898. Material for acarcinological fauna of India. No 3: The Brachyura Cyclometopa. Part I. The family Xanthidae. *J. Asiat. Soc. Bengal*, 67 (2): 67-233.

Alcock, A. 1899a. Material for a carcinological fauna of India. No. 4:The Barchyura Cyclometopa. Part II: A revision of Cyclometopa, with an account of the families Portunidae, Cancridae and Corystidae. *J. Asiat. Soc. Bengal*, 68 (2) :1-104.

Alcock, A. 1899b. Material for a carcinological fauna of India. No. 5: The Barchyura Primigenia or Dromiacea. *J. Asiat. Soc. Bengal*, 68 (2): 123-169.

Alcock, A. 1900. Material for a carcinological fauna of India. No. 6: The Barchyura Catometopa or Grapsoidae., *J. Asiat. Soc. Bengal*, 69 (2): 279-456.

Alcock, A. 1901. Catalogue of the Indian Decapod Crustacea in the collection of the Indian Museum. Part 1. Brachyura. *Fasc.I. Introduction and Dromides or Dromiacea* (Brachyura Primigenia). Calcutta, pp. 1-80.

Alcock, A. 1905. Catalogue of the Indian Decapod Crustacea in the collection of the Indian Museum. Part II. *Anomura. Fasc. I. Pagurides*. Catalogue of the Indian Decapod in the collection of the Indian Mus., 2: 1-197.

Alexander, C. G., 1988. The paragnaths of some intertidal crustacean. *J. Mar. Biol. Ass. U.K.*, 68: 581-590.

Alongi, D. M., 1990. Effect of mangrove detrital outwelling on nutrient regeneration and oxygen fluxes in coastal sediments of the Central Great Barrier Reef lagoon. *Estuar. Coast. Shelf. Sci.*, 31: 581-598.

Al-Taher, E. Y., 1990. The impact of the Doha west power station effluent on the upper eulittoral benthos of western Sulaibikhat Bay, Kuwait. M.sc. Thesis, Kuwait University.

Altevogt, R., 1955. Some studies on two species of Indian fiddler crabs, *Uca marionis nitidus* (Dana) and *U. annulipes* (Latr.). *J. Bombay Nat. Hist. Soc.*, 52: 702-716.

Altevogt, R., 1957. Untersuchungen Zur Biologie, Okologie und Physiologie indischer Winkerkrabben. *Z. Morph. Okol. Tiere,* 46:1-110.

Anger, K. 1983. Temperature and the larval development of *Hyas araneus* L. (Decapoda: Majidae); extrapolations of laboratory data to field conditions. *J. Exper. Mar. Biol. Ecol.,* 69: 203-215.

Anderson, S. S., 1972. The ecology of Morecambe Bay, 2. Intertidal invertebrates and factors affecting their Distribution. *J. Applied Ecol.*, 2: 161- 178.

Apel, M. & Turkay, M.1992.The intertidal crabs and hermit crabs (Crustacea: Decapoda: Brachyura and Paguridea) in the study area their condition after oil spill. Establishment of a marine habitat and wildlife sanctuary for the Gulf region. *Final report for phase* 1: Jubail & Frankfurt .

Apel, M., 1994. Biology, ecology and taxonomy of brachyuran and paguridean crustacea. Establishment of a marine habitat and wildlife sanctuary for the Gulf region. *Final report for phase* II: 406-437. Jubail & Frankfurt.

Badar, R. G., 1954. The role of organic matter in determining the distribution of pelecypods in marine sediments. *J. Mar. Res.*, 13: 32-47.

Baker, J. M. & Dicks, B., 1982. The environmental effects of pollution from the Gulf oil industry. IUCN/MEPA report for the Expert Meeting of the Gulf Co-ordinating Council to review environmental issues.

Banner, D. M. and Banner, AH., 1981. Annotated checklist of the Alpheid shrimp of the Red Sea and Gulf of Aden. *Zoologische Verhandelingen*, Leiden 190: 1-5.

Barnard, K.H.1950. Descriptive catalogue of South African Decapod Crustacea. *Ann. S. Afr. Mus.*, 38: 1-836.

Barnard, K.H.1955. Addition to the fauna list of South African Crustacea and Pycnogonida. *Ann. S. Afr. Mus.*, 43:1-107.

Barnes, R.S.K. 1977. Concluding contribution towrds revision of, and a key to the genus *Macrophthalmus* (Crustacea, Brachyura). *J. Zool. Lond.*, 182: 267-280.

Basson, P.W., J.E.Burchard, Jr.J.T.Hardy and A.R.G.Price. 1977. *Biotopes of the Western Arabian Gulf. Marine life and environments of Saudi Arabia.* Dhahran, Saudi Arabia: ARAMCO, Department of Loss Prevention and Environmental Affairs. 284 pp.

Beefink, W.G. 1977. *Salt marshes In The Coastlines*. Barnes, R.S.K. (ed). Wiley Chichester, 93-121.

Beltagy, A. I. 1983. Some oceanographic measurements in the Gulf waters around Qatar peninsula. *Qatar Univ. Sci. Bull.* 3: 329-341.

Bennett, 1964 (Xanthidae, Pilumniae). *New Zealand J. Mar. Freshwat. Res.*, 1 (4): 482-535.

Blaber, S. J. and Blaber, T. G., 1980. Factors affecting the distribution of Juvenile estuarine and inshore fish. *J. Fish Biology*. 17: 143-162.

Blaber, S. J. M. and Milton, D. A., 1990. Dynamic distribution of nutrients and variation of environmental factors in Tamshui estuary ecosystem. *Proc. Natl. Sci. Counc., Rep. China*. Part B, 14 (3): 131-141.

Blegvad, H. & Loppenthin, B ., 1944. Fishes of the Iranian Gulf. *Dan. Sci. Invest. Iran*, Part. 3: 1-247.

Bliss, D. E., 1968. Transition from water to land in decapod crustaceans. *Am. Zool.* 8: 355-392.

Boër, B., 1994. Status, environmental factors and recovery of the intertidal and terrestrial vegetation between Ras as-Zaur and Abu Ali island after the Gulf war oil spill. *Final report for phase* II: 229-253. Jubail & Frankfurt.

Brafield, A. E. 1978. Life in sandy shores. *Inst. Biol. Study Series*, 89, Edward Arnold, London.

Campbell, C. R. and Fielder, D. R. 1986. Size at sexual maturity and occurrence of ovigerous females in three species of commercially exploited portunid crabs in S. E. Queensland. *Proc. R. Soc., Qd.* 97: 79-87.

Cano, G. 1892b. Sviluppo dei Portunidi-Morfologia dei Portunidie Corystoidei. Memo. *Matematica Fisica Società Italiana Sci.*, (Roma), (6), 8, 1-29.

Chapman, V. J., 1944. 1939 Cambridge University Expedition to Jamaica. *J. Linn. Soc. Bot.* (Lond.), 52: 407-533.

Chapman, V. J. 1960. *Salt Marshes and Salt Deserts of the World.* Hill, London.

Chapman, V. J. 1976. *Mangrove Vegetation.* Cramer, Vaduz. 447pp.

Chapman, V. J. 1984. Mangrove biogeography. In: Por, F. D. and Dor, I. (eds.) distribution limits. *Nature* (London), 239: 644-645.

Cherif, Omar H., Al-Rifaiy, Ibrahim A. and Al-Zamel, Abdullah 1994. Sedimentary facies of the tidal creeks of Khor Al-Mufateh and Khor Al-Mamlaha, Khiran area, Kuwait. *J. Univ. Kuwait* (Sci.) 21: 87-105.

Chhapgar, B.F. 1957. On the marine crabs of Bombay state. Part 1 & 2. *J. Bombay Nat. Hist. Soc.*, 54: 399-439 & 503-549.

Clayton, D.A. 1986. Ecology of the mudflats with particular reference to those of the northern Arabian Gulf. In Marine Environment and pollution. *Proc. First Arabian Gulf Conf. on Environment and Pollution*, Eds. Halwagy, R., Clayton, D. A and Behbehani, M. Kuwait University. 348pp. Akllen Press, London.

Clayton, D.A., 1988. Hood construction as a spacing mechanism in *Cleistostoma kuwaitense* (Crustacae: Ocypodidae). *Marine Biology* 99: 57-61.

Clayton, D. A. and Vaughan, T. C., 1988. Ethogram of *Boleophthalmus boddarti* (Pallas) (Teleostei, Gobiidae), a mudskipper found on the mudflats of Kuwait. *The J. Univ. Kuwait*, 15: 115-138.

Collins, M. J., Jones, D. A. and Clayton, D. A., 1984. Redescription of *Uca sindensis* (Alcock, 1900) (Brachyura: Ocypodidae) with notes on the ecology of population from Kuwait. *J. Crust. Biol.* 4: 318-328.

Clough, B. F., 1993. Constraints on the growth, propagation and utilization of mangroves in arid regions. In: H. Lieth and A. Al-masoom (eds): *Towards the rational use of high salinity tolerant plants*. Vol. 1: 341-352. Kluwer Academic Publishers, Netherlands.

Cone, J. E. and H. Diaz 1989. The mangrove tree crab *Aratus pisonii* in a tropical coastal lagoon. *Est. Coast. Shelf Sci.*, 28: 639-650.

Crane, J., 1941. Crabs of the genus *Uca* from the west coast of Central America. *Zoologica*, N. Y. 26: 145:208.

Crane, J., 1943. Crabs of the genus *Uca* from Venezuela. *Zoologica*, 28:33-44.

Crane, J. H., 1975. *Fiddler crabs of the world* (Ocypodidae: genus *Uca*). Princeton Univ. Press, New Jersey: 736pp.

Crane, J. H., 1975. The mangrove fauna of the Morrumbene estuary, Mozambique: In Walsh, G., Snedaker, S. C. and Teas H. (eds.), Proc. *Int. Symp. biology and management of mangroves*: 415-430 (University of Florida, Florida).

Crosnier, A. 1962. Crustaces Decapodes Portunidae. *Faune de Madagascar*, 16: 1-154.

Crosnier, A. 1965. Crustaces Decapodes, Grapsidae et Ocypodidae. *Faune de Madagasscar*, 18: 1-143.

Davies, G. R., 1970. Carbonate sedimentation, eastern Shark Bay, Western Australia. American *Asso. Petr. Geol. Mem.*, 13: 85- 168.

Davis, J. H. J. 1940. The ecology and geologic role of mangroves in Florida. Papers from Tortugas Lab. 32. *Carnegie Inct. Wash. Publ.*, 517: 305-412.

Davis, J.H. J. 1942. The ecology of the Vegetation and topography of the sand keys of Florida. Papers from Tortugas Lab. 33. *Carnegie Inst. Wash. Publ.* 524:113-195.

Dawirs, R. R. 1985. Temperature and larval development of *Carcinus maenas* (Decapoda) in the labortory; predictions of larval dynamics in the sea. *Mar. Ecol. Prog. Ser.*, 24: 297-302.

Day, J. H., 1974. The ecology of Morrunbene estuary, Mozambique. *Trans. Roy. Soc. Africa* Part 1: 43-95.

Dechance, M. 1963. Sur des paguristes littoraux d ouest de I ocean Indian. *Bull. Mus. Natn.Hist. Nat.*, Paris (2), 35(3): 291-301.

Dittel, A. I., C. E. Epifanio, J. B. Chavarria 1985. Population biology of the portunid crab *Callinectes arcuatus* Ordway in the Gulf of Nicoya, Costa Rica, Central America. *Est. Coast. Shelf. Sci.*, 20:593-602.

Dorgham, M. M., and Moftah., A. M. (1989). Environmental conditions and phytoplankton distribution in the Arabian Gulf and Gulf of Oman, September 1986. *J. Mar. Bio. Ass. India*, 31 (1&2): 36-53.

Edmondson, C.H. 1954. Hawaiian Portunidae. *Occ. Pap. Bishop Mus.*, Honolulu, 21(12): 217-274.

Embabi, N. S.,1993. Environmental aspects of geographical distribution of mangrove in the United Arab Emirates. In: H. Lieth and A. Al Masoom (eds): *Towards the rational use of high salinity tolerant plants*. Vol. 1: 45-58.

Emmerson, W. D. 1994. Seasonal breeding cycles and six ratios of eight species of crabs from Mgazana, a mangrove estuary in Transkei, Southern Africa. *J. Crust. Biology* 14 (3): 568-578.

Emery, K. O., 1956. Sediments and water of the Parsian Gulf. *Bull. American Associ. Petr. Geol.,* 40: 2354-2383.

Enomoto, Y. 1971. Oceanographic survey and biological study of shrimps in the waters adjacent to the eastern coast of the State of Kuwait. *Bull. Tokai Reg. Fish. Res. Lab.*, 66: 1-74.

Ewusie, J. Y. 1980. *Elements of Tropical Ecology*. Heinemann E. B. Ltd. London.

Farmer, A. S., 1974. The functional morphology of the mouthparts and pereiopods of *Nephrops norvegicus* (L.) (Decapoda: Nephropidae). *J. Nat. Hist.*, 8: 121-142.

Fish, S., 1972. The setae of *Eurydice pulchra* (Crustacea : Isopoda). *J. Zool., Lond.*, 166: 163-177.

Fishelson, 1971. Ecology and distribution of benthic fauna in the shallow waters of the Red Sea. *Marine Biology*, 10: 113-133.

Flok, R. L. and Ward, W. C. 1957. Brazos river bar in the significance of grain - size para - meters. *J. Geol.,* V.62. pp. 344 - 359.

Folk. R. L., 1965. *Petrology of sedimentary Rocks*. Hemphill's, Austin, Texas, 154 pp.

Flores-Vergudo, F. J., Day, J. W. and Briseno-Duenas, R., 1987. Structure, litterfall, decomposition and detritus dynamics of mangroves in a maxican coastal lagoon with an ephemeral inlet. *Mar. Ecol. Prog. Ser.,* 35: 83-90.

Frith, D. W., Tantansiriwang, R and Bhatia. 1976. Zonation of Macrofauna on a mangrove shore, Phuket Island. *Phuket Mar. Biol. Cent., Res. Bull.* 10: 1-13.

Frith, D. W. and Frith, C. B. 1977b. Observations on fiddler crabs (Ocypodidae: Genus Uca) on Surin Island, western peninsular Thailand, with special reference to *Uca tetragonon* (Herbst). *Phuket Mar. Biol. Cent. Res. Bull.,* 18: 1-14.

Frith, D. W., and S. Brunenmeister. 1980. Ecological and population studies of fiddler crabs (Ocypodidae, genus *Uca*) on a mangrove shore at Phuket Island, western peninsular Thailand. *Crustaceana* 39: 157-184.

Frontier, S., 1963a. Zooplancton recolté en Mer d'Arabie, Golfe Persique et Golf d'Aden. I. Données génerales. Répartition quantitative. *Cahier* ORSTOM.

Galloway, R. W., 1982. Distribution and physiographic communities of Australian mangrove ecosystems in Australia. In: B. F. Clough (ed.), *Mangrove ecosystems in Australia: Structure, function and management. Australian* National University Press, Canberra 31-54.

Giese, A. C., and J. S. Pearse. 1974. Introduction: general principles. In: A. C. Giese and J. S. earse, eds., *Reproduction of marine invertebrates.* Acoelomate Press, New York, New York 546pp.

Guinot, D. 1967. La faune carcinologique (Crustacea, Brachyura) de I Ocean Indian occidental et de la Mer Rouge. Catalogue remarques biogeographiques et bibliographie. *Mem. Inst. Franc. Afr. Noire*, 77: 235-352.

Gunter, G. 1957. Temperature. In: Treatise on marine Ecology and Paleoecology. Vol. I: 159-184. Ecology (J. W. Hedgpeth, ed). *Memoir* 67, *Geol. Soc. America.*

Haig, J. (1966b). The Porcellanidae (Crustacea Anomura) of the Iranian Gulf and Gulf of Oman. *Videns. Med. Dansk naturhis. For. Kjobenhavn.* 129: 49-65.

Hails, A. J. and Yaziz, S., 1982. Abundance, breeding and growth of the ocypodid crab *Dotilla myctiroides* (Milne-Edwards) on a west Malaysian beach. *Estuar. Coast. Shelf Sci.*, 15: 229-239.

Haley, S. R., 1972. Reproductive cycling in the ghost crab *Ocypode quadrate* (Febr.) (Brachyura, Ocypodidae). *Crustaceana* 23: 1-11.

Haley, S. R. 1979. Sex ratio as a function of size in *Hippa pacifica* Dana Crustacea, Anomura, Hippidae): test of the sex reversal and differential growth rate hypothesis. *American Nat.*, 113: 391-397.

Halwagy, R. & Halwagy, M., 1977. Ecological studies on the desert of Kuwait. III. The vegetation of the coastal salt Marshes. *J. Univ. Kuwait* (Sci.) 4: 33-67.

Hart, M. G. R., 1959. Sulphur oxidation in tidal mangrove soils of Sierra Leone. *Pl. Soil*, 11: 215-36.

Hartnoll, R. G. 1973. Factors affecting the distribution and behaviour of the crab *Dotilla fenestrata* on east African Shores. *Estuar. Coast. Mar. Sci.*, 1: 137-152.

Hartnoll, R. G. 1975. The Grapsidae and Ocypodidae of Tanzania. *J. Zool. Lond.*, 177: 305-328.

Hartnoll, R. G. 1982. Brachyura. *In Reproduction of Marine Invertebrates*. (A. C. Giese and J. S pearse, eds.), Vol. 8. Academic Press, New Yourk.

Hogarth, P. J. 1988. Anomuran Crustacea from Oman, principally from Dhofar Province, Southern Oman. *J. Nat. Hist.*, 22(4): 1095-1110.

Hogarth, P.J. 1989. The marine Crustacea of Dofar, Southern Oman. *J. Oman Stud.*, 10 : 99 -124.

Holthuis, L.B. 1958. Crustacea Decapoda from the Northern Red Sea (Gulf of Aquaba and Sinia peninsula. 2. Hippidae and Brachyura (Dromiacea, Oxystomata and Grapsidea). *Contr. Knowledge of the Red Sea. No. 9, Sea Fish. Res. Stn. Haifa, Bull.*, 17: 41-54.

Holthuis, L.B. 1977. The Grapsidae, Gecarcinidae and Palicidae (Crustacea: Decapoda: Brachyura) of the Red Sea. *Israel J. Zool.*; 26 (3-4): 141-192.

Hywel-Davies, A., 1994. A quantitative analysis of the horizontal and vertical zonation of brachyura and mollusca associated with Qurm mangal, Muscat, Sultanate of Oman. M.Sc. thesis, University of Wales, Bangor, N. Wales, U.K.

Ingle R. 1992. *Larval stages of Northestern Atlantic crabs.* Chapman & Hall. London. 363pp.

Icely, J. D., Jones, D. A., 1978. Factors affecting the distribution of the genus *Uca* (Crustacea : Ocypodidae) on an East African shore. *Estuar. Coast. Mar. Sci.* 6: 315-325.

Ismail, N. S. 1985. The effects of hydraulic dredgung to control oyster drills on benthic macrofauna of oyster grounds in Delaware Bay, New Jersey. Int. Revue Ges. *Hydrobiol.* 70: 379-395.

Ismail, N. S, and Ahmed, M. A. E., 1993. Macrobenthic invertebrates of mangrove Avicennia Marina (Forscål) and intertidal flats of Khor Kalba, U. A. E., Gulf of Oman. In: H. lieth and A. Al-masoom (eds): *Towards the rational use of high salinity tolerant plants.* Vol. 1: 341-352. Kluwer Academic Publishers, Netherlands.

Jacob, R., Prasad, P. N. and Kusuma, M. S. 1990. Maturity and dimensional studies in female crabs of *Portunus sanguinolentus* and *P. pelagicus* (Decapoda: Portunidae). *Indian J. Mar. Sci.*, 19: 221-223.

Jones, D. A. 1968. The functional morphology of the digestive system in the carnivorous intertidal isopod *Eurydice. J. Zoology*, London. 156: 363-376.

Jones, D. A. 1974. The systematics and ecology of some sand beach isopods from the coasts of Saudi Arabia. *Crustaceana.* 26: 201-211.

Jones, D. A., Price, A. R. G. and Hughes, R. N., 1978. Ecology of high saline lagoons, Dawhat as Sayh, Arabian Gulf, Saudi Arabia. *Estuar. Coast. Mar. Sci.* 6: 253-262.

Jones, D.A. 1983. Ecology of the rocky and sandy shores of Kuwait. In: Marine Environment and Pollution. In: Halwagy, R., Clayton, D. A. and Behbehani, M. (eds): *Proc. First Gulf Confer. Environment and Pollution.* 348pp. Akllen Press, London.

Jones, D. A. and D. Clayton. 1983. The Systematics and ecology of the crabs belonging to the genera *Cleistostoma* De Haan and *Paracleistostoma* De Man on Kuwait mudflats. *Crustaceana*, 45(2): 183-199.

Jones, D. A., 1984. Crabs of the Mangal ecosystem. In: Por, F. D. and Dor, I. Dr. W. Junk (eds.) Hydrobiology of the Mangal. *The Ecosystems of the Mangrove Forests*, 89-109. The Hague. 260 pp.

Jones, D. A., 1985. An onshore and offshore environmental survey related to the proposed development of the Qatar north gas field. Ecological survey and report. Unpublished. University of Wales, Bangor, N. Wales, U.K. pp 1-16.

Jones, D. A. 1986. *A field guide to the sea shores of Kuwait and the Arabian Gulf.* Univ. of Kuwait. Blandford Press, Poole, Kuwait (1986): 1-192.

Jones, D. A., Ghamrawy, M. and Wahbeh, M. I., 1987. Littoral and shallow subtidal environments. In: Edwards, A. and Head, S. M. (eds.) *Red Sea.* Pergamon Press, Oxford. pp. 169-193.

Jones, D. A. and Richmond, D. M., 1992. Intertidal and subtidal Marine habitat surveys. In: Establishment of a marine Habitat and wildlife sanctuary for the Gulf region. *Final report for phase I*: 134-161. Jubail and Frankfurt. CEC/NCWCD.

Jones, D. A., 1994. Mangroves in the Gulf and the importance of pollution impact on their biota. Unpublished. University of Wales, Bangor, N. Wales, U.K.

Kemp, S., 1914. Notes on the Crustacea Decapoda in the Indian Museum. V. Hippolytidae. *Rec. Ind. Mus.* 10: 81-129.

Kemp, S. 1915. Crustacea Decapoda, fauna of the Chilka Lake. *Mem. Indian Mus.*, 5(3): 199-326.

Kemp, S., 1916. Notes on the Crustacea Decapoda in the Indian Museum. VII. Further notes on Hippolytidae. *Rec. Indian Mus.* 12: 385-405.

Kemp, S,. 1919a. Notes on Crustacea Decapoda in the Indian Museum. XII. Scopimerinae. *Rec. Indian Mus.*, 16 (5): 305-348.

Kemp. S. 1919b. Notes on Crustacea Decapoda in the Indian Museum. XIII. The Indian species of *Macrophthalmus*. *Rec. Indian Mus.*, 16 (5): 383-348.

Kemp, S., 1922. Notes on the Crustacea Decapoda in the Indian Museum. XV. Pontoniinae. *Rec. Indian Mus.*, 12: 385-405.

Kinne, O. 1970. Temperature; Animals; Invertebrates. In: *Marine Ecology* Vol. 1, Part 1: 407-511 (O. Kinne, ed.). New York.

Kimor, B. 1973. Planckton relations of the Red Sea, Persian Gulf and Arabian Sea. In: *The Biology of the Indian Ocean*. Zeitzschel, B. (ed.): 221-232. New York, Springer Verlag.

Kogo, M., 1986. Introduction: Our activities on mangroves in Arabia. In: *A report of mangrove research in Sultanate of Oman. The Fourth Research on Mangroves in the Middle East.* Japan Co-operation Center for the Middle East, No. 191, pp. 9-16.

Lear, R. and Turner, T., 1977. *Mangroves of Australia*. Queensland, University of Queensland Press, St. Lucia. 84pp.

Lebour, M. V. 1927. Studies of the Plymoth Brachyura. II. The rearing of crabs in captivity, with a description of the larval stages of *Inachus dorsettensis, Macropodia longirostris* and *Maja squinado. J. Mar. Biol Assoc. U.K.* (Plymouth), 14, 795-820.

Lebour, M. V. 1927a. Researches on rearing a crab. *Discovery* (London and Norwich), 8, 311-313.

Lebour, M. V. 1928). Studies of the Plymouth Brachura. II. The larval Stages of *Ebalia* and *Pinnotheres. J. Mar. Biol. Assoc. U. K.* (Plymouth), 15, 109-122.

Leh, C. M. U. and Sasekumar, A., 1984. Feeding ecology of prawns in shallow waters adjoining mangrove shores. In: *Proc. Asian symp. on mangrove environment, research and management* 331-353. (Eds Soepadmo, E., Rao, A. N. and Macintosh, D. J.) University of Malaya and UNESCO.

Lenanton, R. C. J., 1982. Alternative non-estuarine nursery habitats for some commercially and recreationally important fish species of south-western Australia. *Aust. J. Mar. Freshwat. Res.*, 33: 881-900.

Lewinsohn, CH. 1969. Die Anomuren des Roten Meeres (Decapoda: Paguridea, Galatheidea, Hippidea). *Zool. Verhandelingen*, 104: 1-213.

Lewinsohn, CH. 1977b. Die Ocypodidae des Roten Meeres (Crustacea, Decapoda, Brachyura). *Zool. Verhandelingen*, 151: 3-41.

Lewis, J. R., 1964. *The ecology of rocky shores*. The English University Press, London, 323pp.

Lim, S. L., K. L. NG, and W. H. Tan. 1984. The larval development of *Heteropanope glabra* Stimpson, 1858 (Decapoda, Xanthidae) in the laboratory. *Crustaceana* 47: 1-16.

Lim, S. L., K. L. NG, and W. H. Tan. 1984. The complete larval development of *Pilumnopeus eucratoides* Stimpson, 1858 (Decapoda: Brachyura: Pilumnidae) in the laboratory. *Crustaceana* 50: 265-277.

Linnaeus, C. 1767. Systema Naturae per Regna Tria Naturae, Secudum Classes, Ordines, genera, Species, cum Characteribus, Differentiis, Synonymus, Locis, Edition 12, I (Pt2), Stockholm, pp. 533-1327.

Long, S.P. & Mason, C.F. 1982. *Salt Marshes Ecology*. Blackie, Glasgow, and London.

Lugo, A.E. & Snedaker, S.C. 1974. The Ecology Of Mangroves. *Ann. Rev. Ecol. Syst*. 5: 39-64.

Lugo, A. E. and Patterson-Zucca, C., 1977. The impact of low temperature stress on mangrove structure and growth. *Tropical Ecology*, 18: 149-161.

Macintosh, D. A.,1984. Ecology and Productivity of Malaysian mangrove crab populations (Decapoda:Brachyura). In: *Proc. Asian symp. on mangrove environment, research and management*, 354-377. (eds) Soepadmo, E., Rao, A. N. and MacIntosh, D. J. University of Malaysia and UNESCO.

Macintosh, D. J., 1977. Some reasponces of tropical mangrove fiddler crabs (Uca spp.) to high environmental temperatures. In: *proc. 12th Europ. Mar. biol. Symp*. McLusky. D. S. and Berry, A. J. (eds.) Pergamon Press: Oxford. pp 49-56.

Macintosh, D. J., 1983. Fisheries and aquaculture significance of mangrove swamps, with special reference to the Indo-West Pacific Region. In: *Recent advances in aquaculture*: 4-85. (eds Muir, J. F. and Roberts, R. J.). Croom Helm, England

Macintosh, D. J., 1988. The ecology and physiology of decapods of mangrove swamps. In: Fincham A. A. and Rainbow, P. S. (eds) Aspects of decapod crustacean biology. *Symp. Zool. Soc.* London, 59: 315-341.

MacNae, W., and Kalk, M.,1962. The ecology of the mangrove swamps at Inhaca Island, Mozambique. *J. Ecology* 50: 19-34.

MacNae, W., 1966. Mangroves in eastern and southern Australia. *Australian J. Bot.*, 14: 67-104.

MacNae, W., 1968. Ageneral account of the fauna and flora of mangrove swamps and forests in the Indo-West-Pacific region. *Advan. Mar. Biol.* 6: 73-270.

MacNae, 1974. Mangroves forest and fisheries. FAO/UNDP Indian Ocean Fishery Programme. Indian Ocean Fishery Commission. Pub. IOFC/Dev/74/34. 35pp.

Maitland, D. P., 1990. Feeding and mouthpart morphology in the semaphore crab *Heloecius cordiformis* (Decapoda: Brachyura: Ocypodidae). *Marine Biology* 105: 287-296.

Malley, D. F., 1978. Degradation of mangrove litter by the tropical sesarmid crab *Chiromanthes onychophorum*. *Marine Biology*, 49: 377-386.

Manning, R. B. and L. B. Holthuis 1981. West African brachyuran crabs. *Smithson. Contrib. Zool.* 306: xii+379pp.

Manning, R. B. 1991. The status of *Cleistostoma dotilliforme* Alkock, 1900 (Crustacea: Decapoda: Ocypodidae), With the description of a New Genus. *Raffles Bull. Zool.*, 39 (2): 299-306.

Michel, H., Behbenhani, M. and Herring, D. 1986a. Zooplankton of the western Arabian Gulf south of Kuwait waters. *Kuwait Bull. Mar. Sci.*, 8: 1-36.

Michel, H., Behbenhani, M., Arar, D. Al-Shoushani, M and Brakoniecki, T. 1986b. Zooplankton diversity, distribution and abundance in Kuwait waters. *Kuwait Bull. Mar. Sci.*, 8: 37-105.

Miller, D. C., 1961. The feeding mechanism of fiddler crabs, with ecological considerations of feeding adaptions. *Zoologica* N.Y. 46: 89-100.

Mohammed, S. Z. and Al-Khayat, Jassim A., 1994. A preliminary check-list of benthic mollusca on the Qatari coasts, Arabian Gulf. *Qatar Univ. Sci. J.*, 14 (1): 201-206.

Newell, R., 1965. The role of detritus in the nutrition of two marine deposit feeders, the prsobranch *Hydrobis ulvae* and the bivalve *Macoma baltica. Proc. Zool. Soc. Lond.* 144: 25-45.

Newell, R. C.,1970. *Biology of intertidal animals.* Logos Press, London, 555pp.

Nobili, G. 1905a. Decapodes nouveaux des cotes d' Arabie et du Golfe Persique (diagnoses perliminaires). *Bull. Mus. Nat. d'Hist. Natur.*, Paris 11:158-164.

Nobili, G. 1906a. Fauna carcinologique de la Mer Rouge. Decapodes et Stomatopodes. *Ann. Sci. Nat.* (9), 4: 1-347.

Nobili, G. 1906b. Crustaces decapodes et stomatopodes Mission J. Bonnier et CH. Perez (Golfe Persique, 1901). *Bull. Sci. France et Belgique*, 40: 13-159.

Odum, H. T., 1971. *Environment, power, and Society.* Nwe York: Wiley-Interscience. 331 pp.

Odum, W. E. and Heald, E. J., 1972. Trophic analyses of an estuarine mangrove community. *Bull. Mar. Sci.,* 22 (2): 671-738.

Odum, W. E. and Heald, E. J., 1975. The detritus-based food web of an estuarine mangrove community. In: *Estuarine research*, Vol. 1, Ed. L. E. Cronin, Academic Press, New York, pp. 256-286.

Ono, Y., 1965. On the ecological distribution of ocypodid crabs in the estuary. *Mem. Fac. Sci. Kyushu Univ.* (Ser. E) 4: 1-60.

Orton, J. H. 1920. Sea temperature, breeding and distribution in marine animals. *J. Mar. Biol. Assoc. U. K.,* 12: 339-366.

Paine, R. T., 1964. Ash and calorific determination of sponge and opisthobranch tissue. *Ecology*, 45: 384-387.

Pasupathi, K. and T. Kannupandi. 1988. The Zoeae, megalopa and first crab of the mangrove crab Metaplax elegans De Man, cultured in the laboratory. Mahasagar, *Bull. Nat. Inst. Ocean.*, 21: 145-160.

Pasupathi, K. and T. Kannupandi. 1988. The Complete larval development of the Mangrove Ocypodid crab Macrophthalmus depressus Ruppell, 1830 (Brachyura: Macrophthalminae) reared in the laboratory. *J. Nat. His.* 22: 1533-1544.

Peters, H. M., 1955. Die Winkgebäande von *Uca* und *Minuca* (Brachyura) in vergleichend-ethologischer,ökologischer und morphologischer- anatomischer -Betrachtung. *Z. Morph. ökol. Tiere* 43, 425-500.

Philips, F. X., 1972. The ecology of the macroinvertebrates of Barnegat Bay. New Jersey. Ph.D. Thesis, Rutgers University, NewvBrunswick, N.J.

Pillay, K. K., and N. B. Nair. 1971. The annual reproductive cycles of *Uca annulipes, Portunus pelagicus* and *Metapenaeus affinis* (Decapoda: Crustacea) from the south-west coast of India. *Marine Biology*. 11: 152-166.

Pillay, K. K., and N. B. Nair. 1973. Observations of the breeding biology of some crabs from the south-west coast of India. *J. Mar. Biol. Assoc. India* 15: 754-770.

Por, F. D., Dor, I. and Amir, A., 1977. The mangal of sanai. Limits of an ecosystem. *Helgolander Wissenschaftliche Meeresuntersuchungu* 30: 295-314.

Porter, H. J. 1960. Zoeal stages of the stone crab, *Menippe mercenaria* Say. *Chesapeake Sci.* 1: 168-177.

Prasad, R. P. and Tampi, P. R. S., 1954. Some aspects of relative growth in the blue swimming crab *Neptunus pelagicus* (Linnaeus). *Proc. Natn. Inst. Sci., (India)*. 20 (2): 218-234.

Pretzmann, G. 1971. Ergebnisse einiger Sammelreisen nach Vorderasien. 2. Teil: Marine Brachyura. *Ann. Naturhistor. Mus. Wien*, 75: 477-487.

Price, A. R. G. 1979. Temporal variation in abundance of Penaeid shrimp larvae and oceanographic condition off Rass Tanura, Western Arabian Gulf. *Estuar. Coast. Mar. Sci.*, 9: 451-465.

Price, A. R. G. 1982. Distribution of penaeid shrimp larvae along the Arabian Gulf coast of Saudi Arabia. *J. Nat. Hist.*, 16: 745-757.

Price, A. R. G., Medley, P. A. H., McDowall, R. J., Dawson-Shepherd, A. R., Hogarth, P. J. and Ormond, R. F. G., 1987. Aspects of mangal ecology along the Red Sea coast of Saudia Arabia. *J. Nat. Hist.*, 21: 449-464.

Privett, D. W. 1959. Monthly charts of evaporation from the North Indian Ocean, including the Red Sea and the Persian Gulf. *Quart. J. Roy. Meteorol. Soc.*, London, 85: 424 - 428.

Purser, B. H. & Seibold, E. 1973. The principal environmental factors influencing Holocene sedimentation and diagenesis in the Persian Gulf. In: Purser, B. H. *The Persian Gulf*. Springer Verlag, New York. pp. 1-9.

Ranwell, D.S. 1972. *Ecology of Salt Marshes and Sand Dunes*. Chapman Hall, London.

Raymont, J. E. G., 1983. *Plankton and productivity in the oceans* (2nd edn.). Pergamon Press, Oxford.

Reeby, J., Prasad, P. N. and Kusuma, M. S., 1990. Size at maturity in the male crabs of *Portunus sanguinolentus* and *P. pelagicus*. *Fish Technol.*, 27 (2): 115-119.

Rice, A. L. 1975. The first zoeal stages of *Cancer pagurus* L., *Pinnotheres pisum (Pennant)* and *Macrophthalmus depressus* Ruppell (Crustacea, Deca*poda,* Brachyura). *Bull. British Mus. Nat. His.* (Zoology) 28: 237-247.

Rice, A. L. 1980. Crab zoeal morphology and its bearing on the classification of Brachyura. *Trans. Zool. Soc. London*. 35 (3): 271-424.

Rice, A. L. 1980a. Crab zoeal morphology and its bearing on the classification of the Brachyura. *Trans. Zool. Soc. Lond.* 35: 271-424.

Rice, A. L. 1981. Crab zoeae and brachyuran classification: a re-appraisal. *Bull. Br. Mus. Nat. Hist.* (Zool.) 40 (5): 287-269.

Robertson, A. I., 1986. Leaf burying cras: their influence on energy flow and export from mixed mangrove forests (Rhizophora spp) in north-eastern Australia. *J. Exp. Mar. Biol. Ecol.,* 102: 237-248.

Robertson, A. I. and Duke, N. C., 1987. Mangroves as nursery sites: comparisons of the abundance and species composition of fish and crustaceans in mangroves and other nearshore habitats in trobical Australia. *Marine Biology*, 96: 193-205.

Robertson, A. I. and Duke, N. C., 1990. Mangrove fish-communities in tropical Queensland, Australia: spatial and temporal patterns in densities, biomass and community structure, *Marine Biology*, 104: 369-379.

Rodelli, M. R., Gearing, J. N., Gearing, P. J., Marshall, N. and Sasekumar, A., 1984. Stable isotope ratio as a tracer of mangrove carbon in Malaysian ecosystems. *Oecologia*, 61 (3): 326-333.

Rodriguez, A. and D. A. Jones. 1993. Larval development of *Uca tangeri* (Eydoux, 1835) (Decapoda: Ocypodidae) reared in the laboratory. *J. Crust. Biol.*, 13(2): 309-321.

Sasekumar, A., 1974. Distribution of macrofauna on Malaysian mangrove shore. *J. Ani. Ecol.*, 43: 51-69.

Sastry, A. N. 1983. Ecological aspects of reproduction. In: D. E. Bliss, ed.-in chief, *The biology of Crustacea*. Vol. 8. F. J. Vernberg and W. B. Vernberg, eds., Environmental adaptations. pp. 179-270. Academic Press, New York, New York.

Schembri, P. J. 1982a. The functional morphology of the feeding and grooming appendages of *Ebalia tuberosa* (Pennant) (Crustacea: Leucosidae). *J. Nat. Hist.* 16: 467-80.

Schmper, A. F. W. 1903. *Plant Geography on a Physiological Basis*. Oxford: Oxford University Press. 839 pp.

Seba, M., M. Takeda and Y. Nakasone. 1978a. Larval development of *Epixanthus dentatus* (White) (Brachyura, Xanthidae). *Bull. Natn. Sci. Mus.*, (A) (Zool), 4 (2): 151-161.

Selvakumar, S., S. Ajmalkhan and R. Natarajan. 1988. Laboratory reared larval stages of Ocypodid crab *Macropthalmus (venitus) latreilli* (Desmarest) Mahasagar, *Bull. Nat. Inst. Ocean.*, 21: 145-160.

Serene, R. 1971. Observations preliminaires sur des Brachyures nouveaux ou mal connus du sudest Asiatique. *Bull.Mus. Natl. Hist. Nat.* (2) 42 (5): 903-918.

Serene, R. 1984. Crustaces Decapodes Brachyures de l ocean Indien occidental et de la Mer Rouge (Xanthoidea: Xanthidae et Trapeziidae). Avec un addendum par A. Crosnier: carpiliidae et Menippidae. *Faune Tropicale*, 24:1-400.

Serene, R. & Lundoer, S. 1974. Observations on the male pleopod of the genus *Ilyoplax* Stimpson with a key to the identification of the species. *Res. Bull., Phuket Mar. Biol. Cent.*, 3: 3-10.

Sheppard, C., Price, A., & Roberts, C., 1992. *Marine Ecology of the Arabian Region. Patterns and Processes in Extrem Tropical Environments*. Academic Press Limited, London. 359 pp.

Simons, M. J., and M. B. Jones. 1981. Population and reproductive biology of the mud crab, Macrophthalmus hirtipes (Jacquinot, 1853) (Ocypodidae), from marine and estuarine habitats. *J. Nat. Hist.*, 15: 981-994.

Skilleter, G. A., Anderson, D. T., 1986. Functional morphology of the chelipeds, mouthparts and gastic mill of *Ozius truncatte* (Milne Edwards) (Xanthidae) and *Leptograpsus variegate* (Fabricius) (Grapsidae) (Brachyura). *Aust. J. Mar. Freshwat. Res.* 37: 67-79.

Slabber, M. 1778. Natuurkundige Verlustigingen, behelzende microscopise waarneemingen van in-en uitlandse water-en Land - Dieren, Haarlem, i-xiv+166 pp.

Smith, W. K. and Miller, P. C., 1973. The thermal ecology of two south Florida fiddler Crabs: *Uca rapax* Smith and *U. pugilator* Bosc. *Physiol. Zool.* 46: 186-207.

Snowden, R. J., Clayton, D. A., and Al-taher., 1991. Populaion biology of *Ilyoplax stevensi* (Brachyura: Ocypodidae) on a Kuwait mudflat. *Mar. Ecol. Prog. Ser.*, 71: 219-225.

Snowden, R. J., Clayton, D. A., and Al-taher., 1994. Aspects of the ecology of Tylodiplax indica Alcock (Brachyura: Ocypodidae) on a Kuwait mudflat. *J. Univ. Kuwait* (Sci) 21: 219-229.

Snowden, R. J. and Clayton, D. A., 1995. Aspects of the life history and seasonal ecology of *Nasima dotilliformis* (Alcock) (Brachyura: Ocypodidae) on a Kuwait mudflat. *J. Univ. Kuwait* (Sci) 22 (1): 84-94.

Soh, 1968. Studies on some biological aspects of Sesama (Decapoda, Brachyura) of singapore. M.Sc. thesis, Univ. of Singapore.

Spenceley, A. P., 1976. Unvegetated saline tidal flats in North Queensland. *J. Trop. Geogr., 42: 78-85.*

Stephensen, K. 1945. The Brachyura of the Iranian Gulf. *Danish Scientific Investigations in Iran*, Part IV.E. Munksgaard, Copenh.: 57-137.

Stephenson, W. 1972a. Portunid crabs from the Indo-West Pacific and Western America in the Zoological Museum, Copenhagen (Decapoda, Brachyura, Portunidae). *Steenstrupia*, 2 (9): 127-156.

Stephenson, W. 1972. An annotated checklist and key to the Indo- West Pacific Swimming-crabs (Portunidae). *Proc. Roy. Soc. N. Zealand*, 10: 1-64.

Stephenson, W. 1976. Notes on Indo-West Pacific Portunids (Decapoda, Portunidae) in the Smithsonian Institution. *Crustaceana*, 31 (1): 11-26.

Suda, S. Al-Kuwari, S. 1983. A report on mangrove (*Avicennia Marina*) of Qatar. Dept. Gardens and Parks Min. Municip. Affairs and Agric., Qatar. pp. 1-68.

Suda, S. Al-Kuwari, S. 1989. A report on mangrove (*Avicennia Marina*) of Qatar. Dept. Gardens and Parks Min. Municip. Affairs and Agric., Qatar. pp. 1-15.

Suda, S. Al-Kuwari, S. 1990. A report on mangrove (*Avicennia Marina*) of Qatar. Dept. Gardens and Parks Min. Municip. Affairs and Agric., Qatar. pp. 1-76.

Suda, S. Al-Kuwari, S. 1993. A research report on the mangrove (*Avicennia Marina*) of Qatar. Dept. Gardens and Parks Min. Municip. Affairs and Agric., Qatar. pp. 1-11.

Sulkin, S. D. 1975. The significance of diet in the growth and development of larvae of the blue crab, *Callinectes sapidus* Rathbun, under laboratory conditions. *J. Exp. Mar. Biol. Ecol.*, 20: 119-135.

Tagatz, M. E. 1965. The fishery of blue crabs in the St. Johns River, Florida, with special reference to flutuation in yield between 1961 and 1962. *U.S. Fish Wildl. Spec. Sci. Rep. Fish.*, 501: iii+11pp.

Tesch, J.J. 1915. The Catometopous Genus *Macrophthalmus* as represented in the collection of the Leiden Museum. *Zool. Mededel. Leiden*, 1 (3-4): 149-204.

Tirmizi, N. M. and Kazim, Q. B., 1979. New decapod crustacean records for the northern Arabian Sea. *Crustaceana*, 36 (2): 181-185.

Tirmizi, N.M. 1980a. Marine Crustacea (Decapoda and Stomatopoda) of Pakistan. *Proc. 1st Pakistan Cong. on Zoology*. 1 (A): 97-114.

Tirmizi, N. M. 1980b. Two caridean shrimps new to the northern Arabian Sea (Decapoda, Caridea). *Crustaceana*. 39 (1): 107-110.

Tirmizi, N. M., and Ghani, N. 1982. Three Brachyrhynchan crabs new to the coast al waters of Pakistan (Decapoda, Brachyura). *Crustaceana*, 43 (1): 105-110.

Tirmizi, N.M. and Siddiqui, F.A. 1982. *The Marine Fauna of Pakistan*: 1. Hermit crabs (Crustacea, Anomura). Saad publications, Karachi: 103p.

Tirmizi, N.M., Kazimi, Q. B., and Ghani, N. 1982. *Planes cyaneus* Dana, a grapsoid crab new to the Arabian Sea with note on *Metaplax indica* Milne-Edwards (Decapoda, Brachyura, Grapsidae). *Pakistan J. Zool.*, 14 (2): 169-173.

Tirmizi, N. M., and Kazmi, Q. B. 1984. A northern record for *Hippolyte ventricosa* H. Milne- Edwards, 1837 with a note on *Palaemon pacificus* (Stimpson, 1860) (Decapoda: Caridea). *Crustaceana*, 46(3): 313-317.

Tirmizi, N. M., Kazmi, Q. B. and Ghani N. 1985. Five brachyuran crabs new to the northern Arabian Sea (Karachi), *Pakistan J. Zool.* 17 (1): 21-27.

Tirmizi, N. M., and Ghani, N. 1988. Occurence of two interesting brachyhynchan crabs in Karachi waters. *Proc. Int. Conf. on Mar. Sc. Arabian Sea, held in 1986, Karachi.*: 137-142.

Titgen, R.H. 1982. The systematics and ecology of the Decapods of Dubai, and their zoogeographic relationships to the Arabian Gulf and the Western Indian Ocean. D. Phil. thesis, Texas A&M University.

Tweedie, M. W. F. 1950. Notes on grapsoid crabs from the Raffles Museum. *Bull. Raffles Mus.*, 23: 310-324.

Tzeng, Wann-Nian and Wang Yu-Tzu, 1992. Structure, composition and seasonal dynamics of the larval and juvenile fish community in the mangrove estuary of Tanshui River, Taiwan. *Marine Biology*, 113: 481-490.

UNEP. 1985. Ecological interactions between tropical coastal ecosystems. UNEP Regional Seas Reports & Studies No. 37. 71 pp.

Vannin, M. & Valmori, P. 1981a. Researches on the coast of Somalia. The shore and the dune of Sar Uanle. 30. Grapsidae (Decapoda, Brachyura). *Monitore Zool. Ital.* (N.S.) Suppl. 14: 57-101.

Vannini, M. & Valmori, P. 1981b. Researches on the coast of Somalia. The shore and dune of Sar Uanle. 31. Ocypodidae and Gecarcinidae and Gecarcinidae. *Monitore Zool. Ital.* (N.S.) Suppl. 14: 199-226.

Von Hagen, H. O. 1970. Adaptations to the special intertidal level of habitat in ocypodid crabs (Decapoda: Brachyura). *Forma et Functio* 2: 361-413.

Vousden. D.H. 1987. The Bahrain Marine Habitat Survey. A study of the marine habitats in the waters of Bahrain and their relationship to physical, chemical, biological and anthropogenic influences. Publ. by: ROPME (Kuwait),95 pp. + Appendices.

Vousden. D.H. 1989. The Bahrain Marine Habitat Survey. A study of the marine habitats in the waters of Bahrain and their relationship to physical, chemical, biological and anthropogenic influences. *The Technical Report,* 1. UNEP. 103PP.

Wada, 1981. Growth, breeding and recruitment in *Scopimera globosa* and *Ilyoplax pusillus* (Crustacea: Ocypodidae) in the estuary of Waka River, middle Japan. *Pub. Seto Mar. Biol. Lab.,* 26: 243-259.

Wada, H. and Takagi, T., 1988. Soil-water-plant relationships of Mangroves in Thailand. *Galaxea*, 7: 257-270.

Wada, H. and Seisuwan, B., 1988. The process of Pyrite formation in mangrove soils. P. 24-37. In: Dost, H. (ed.) *Selected papers of Dakar Symposium on Acid Sulfate soils*, Dakar, Senegal, January, 1986. ILRI.

Waisely, Y. 1972. *Biology of Halophytes.* New York: Acadimic Press.

Walsh, G. E. 1974. Mangrove: a review. In : *Ecology of halophytes*. Acadimic Press. Inc., New York.

Warner, G. F. 1968. The larval development of the mangrove tree crab *Aratus pisonii* (H. Milne Edwards), in the laboratory Brachyura, Grabsidae). *Crustaceana Suppl.* 2: 249-258.

Warner, G. F. 1969. The occurrence and distribution of crabs in a Jamaican mangrove swamp, *J. Ani. Ecol.*, 38: 379-389.

Warren, G. F., 1969. The occurrence and distribution of crabs in Jamaican mangrove swamp. *J. Ani. Ecol.* 38: 379-389.

Wear, R. G. 1967. Life history studies on New Zealand Brachyura 1. Embryonic and post embryonic development of *Pilumnus novaezealandiae* Filhol, 1886, and of *P. lumpinus* Bennet, 1964 (Xanthidae, Pilumninae). *New Zealand J. Mar. Frishwat. Res.*, 1: 482-535.

Wear, R. G. 1968. Life history studies on New Zealand Brachyura 2. Family Xanthidae. Larvae of *Heterozius rotundifrons* A. Milne Edwards, 1867, *Ozius truncatus* H. Milne Edwards, 1834 and *Heteropanope (Pilumnopeus) serratifrons* (Kinahan, 1865). *New Zealand J. mar. Freshwat. Res.*, 2 (2):293-332.

Wear, R. G. 1970. Notes and bibliography on the larvae of Xanthid crabs. *Pacif. Sci.* 24: 84-89.

Wenner, A. M. 1972. Sex ratio as a function of size in marine crustacea. *Amer. Nat.*, 106 (949): 321- 350.

Western, A. R., 1989. *The Flora of the United Arab Emirates*: An Introduction. U.A.E. University, Al-Ain, 188pp.

Williamson, H. C. 1911. Report on the Larval and later stages of *Portunus holsatus*, Fabr.; *Portunus puber*, L.; *Portunus depurator*, Leach; *Hyas areneus* (L.); *Eupagurus bernhardus*, L; *Galathea dispersa*, Spence Bate; *Crangon Trispinosus* (Hailstone); *Cancer pagurus L. Sci. Inv. Fish. Boa. Scotland.*, (1909:Dec. 1910), 1: 1-20.

Williamson, H. C. 1915. VI. Crustacea Decapoda. Larven. *Nordisches Plankton* (Keil). *L. Sci. Inv. Fish. Boa. Scotland* (6), 18: 315-588.

Williamson, D. I. 1992. *Larvae and evolution toward a new zoology*. Chapman & Hall, London. 223pp.

Yamaguchi T. and Tanaka, M., 1974. Studies on the ecology of a sand bubbler crab, *Scopimera globosa* De Haan- I seasonal variation of population structure. *Japanese J. Ecol.*, 24: 165-174.

Yamazi, I. 1974. Analyses of the data on temperature, salinity and chemical properties of the surface water, and zooplankton communities in the Arabian Gulf in December 1968. *Trans. Tokyo Univ. Fish.*, (1): 26-51.

Zar, J. H., 1984. *Biostatistical Analysis*. Printice-Hall inc., Englewood Cliffs, New Jersey. 718pp.

APPENDIX 1

Table 1: Air temperature records at Doha Airport for 31 years (1962 - 1993).

	Monthly	Mean (%) Daily Maximum	Daily Minimum	Absolute Maximum (C°)	Absolute Minimum (C°)
January	17.0	21.7	12.8	31.2 (1985)	3.8 (1964)
February	17.9	22.9	13.7	36.0 (1973)	5.0 (1967)
March	21.2	26.8	16.7	39.0 (1966)	8.2 (1984)
April	25.7	31.9	20.6	46.0 (1973)	10.5 (1967)
May	31.0	38.2	25.0	47.7 (1986)	15.2 (1971)
June	33.8	41.2	27.7	49.0 (1962)	21.0 (1975)
July	34.7	41.5	29.1	48.2 (1987)	23.5 (1969)
August	34.3	40.7	28.9	48.0 (1977)	22.4 (1971)
September	32.2	38.6	26.5	45.5 (1989)	20.3 (1964)
October	28.9	35.2	23.4	43.4 (1967)	16.6 (1975)
November	24.2	29.5	19.5	38.0 (1969)	11.8 (1963)
December	19.2	24.2	15.0	32.2 (1968)	6.4 (1963)
Year	26.7	32.7	21.6	49.0	3.8 (1964)

Table 2: Global radiation (mWh/cm²) records at Doha Airport for 17 years (1976 - 93) and mean daily insolation (hr) records for 18 years (1975 - 93) .

Month	Mean Monthly	Absolute Highest Maximum	Absolute Lowest Minimum	Mean Daily sunshine hr.
January	374.9	502.4 (1982)	81.2 (1992)	7.9
February	436.6	663.1 (1984)	66.3 (1993)	8.0
March	489.3	757.8 (1984)	58.3 (1987)	7.8
April	569.9	781.9 (1976)	156.9 (1993)	9.0
May	620.4	777.1 (1976)	214.4 (1992)	10.5
June	646.3	799.5 (1976)	335.9 (1993)	11.4
July	605.1	802.7 (1976)	299.4 (1991)	10.6
August	584.7	718.2 (1979)	266.0 (1991)	10.7
September	545.8	697.6 (1976)	319.8 (1977)	10.2
October	481.7	673.2 (1978)	303.8 (1977)	9.9
November	414.9	560.6 (1981)	201.1 (1982)	9.3
December	349.8	455.2 (1979)	47.4 (1986)	7.8
Year	509.9	802.7	47.4 (1986)	9.4

*Global radiation (mWh/cm²) = Milliwatt hour/square cm

Table 3: Rainfall (mm) records at Doha International Airport for 31 years (1962 - 1993).

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
	Month												
1962			0.2	0.2									0.4
1963				1.5	106.4						5.6	1.5	115.0
1964	93.1	38.8	13.0	2.5								1.55	302.8
1965	5.0	1.2		68.1							13.0		87.3
1966		40.5		3.4									43.9
1967		2.0	3.3	13.9									19.2
1968		40.4		27.8									68.2
1969	101.8	0.2		15.1									117.1
1970	10.7		1.5										12.2
1971	0.6	5.8		8.4								0.2	15.0
1972	1.8	6.7	57.7	9.6							1.0	7.9	84.7
1973	22.0			0.2									22.2
1974	5.8	23.4	16.7	1.7	0.2							4.1	51.9
1975	31.3	46.3	1.1	1.8	Trace							4.4	84.9
1976	25.2	53.9	23.1	40.3	Trace		Trace			5.4	45.5	Trace	193.4
1977	41.4	17.9	0.5	2.3						17.3	8.1	3.1	90.6
1978		12.8	1.0	5.9			Trace				Trace	Trace	19.7
1979	5.7	0.1	68.9	Trace	Trace					Trace		27.2	101.9
1980	12.7	30.8	6.6	Trace	0.7						Trace	Trace	50.8
1981	6.4	2.4	23.4	Trace	1.6							Trace	33.8
1982	2.7	18.7	102.3	2.1					Trace	Trace	20.3	21.2	167.3
1983	8.0	5.4	46.2	6.9	0.9			0.7				Trace	68.1
1984	Trace	Trace	23.5	Trace	0.2							17.2	40.9
1985	1.7		0.5	Trace	Trace			Trace			Trace	7.5	9.7
1986	4.7	4.7	5.7	32.6	Trace						Trace	27.6	78.0
1987	0.9	0.1	60.1	Trace	Trace					Trace		0.2	61.3
1988	6.8	130.5	2.7	12.8			Trace					Trace	152.8
1989	Trace	2.0	12.6	2.7							9.2	43.2	69.7
1990	10.7	13.7	0.6	4.6	Trace								29.6
1991	0.3	1.3	26.2	1.0								3.1	31.9
1992	8.7	26.8	1.9	2.9	0.1					12.2		50.6	103.2
1993	12.1	74.4	2.3	6.4	2.6		Trace					Trace	97.8
Mean	13.1	18.9	15.7	8.6	3.5					1.1	3.2	11.7	75.8
Total	420.1	603.5	501.6	274.7	112.7		Trace	0.7	Trace	34.9	102.7	374.4	2425.3

* Trace means that the amount of rain which has fallen is not large enough to be measured (less than 0.1 mm).

Table 4: Rainfall particulars at Doha airport for 31 years (1962 - 1993).

Month	Mean rainfall (mm)	Mean no. of rain days (1mm and more)	Maximum rainfall in a month (mm)	Maximum rainfall in 24 h (mm)
January	13.1	1.7	101.8 (1969)	58.0 (1969)
February	18.9	2.1	130.5 (1988)	44.6 (1993)
March	15.7	1.8	102.3 (1982)	48.8 (1979)
April	8.6	1.4	68.1 (1965)	34.4 (1976)
May	3.5	0.2	106.4 (1963)	64.0 (1963)
Jun	0.0	0.0	-	-
July	Trace	0.0	-	-
August	0.7	0.0	0.7 (1983)	0.7 (1983)
September	Trace	0.0	-	-
October	1.1	0.1	17.3 (1977)	17.3 (1977)
November	3.2	0.2	45.5 (1976)	45.0 (1976)
December	11.7	1.2	155.4 (1964)	80.1 (1964)
Year	75.8	8.8	155.4 (1964)	80.1 (1964)

Table 5: Relative humidity records at Doha Airport for 19 years (1974 - 1993).

Month	Monthly	Mean (%) Daily Maximum	Daily Minimum	Absolute Maximum (%)	Absolute Minimum (%)
January	71	88	48	100	15
February	70	88	47	100	8
March	63	84	38	100	9
April	53	75	28	100	6
May	44	67	21	100	4
June	42	66	20	100	4
July	49	74	24	100	4
August	55	78	30	100	6
September	62	84	34	100	7
October	63	83	36	100	8
November	66	85	42	100	8
December	71	87	49	100	15
Year	59	80	35	100	4

Table 6: Pan evaporation (mm) records at Doha International Airport 17 years (1976 - 1993).

Month	Mean	Absolute Max.	Absolute Min.
January	3.81	11.56 (1992)	0.20 (1990)
February	4.76	11.17 (1983)	0.06 (1988)
March	6.47	13.52 (1986)	0.22 (1982)
April	9.48	20.25 (1987)	2.16 (1989)
May	13.02	28.50 (1989)	3.42 (1976)
Jun	15.53	30.60 (1983)	5.82 (1976)
July	13.08	27.79 (1990)	2.20 (1978)
August	11.78	27.02 (1984)	2.30 (1991)
September	8.97	21.20 (1990)	0.04 (1982)
October	7.47	18.78 (1985)	2.08 (1992)
November	5.34	12.10 (1991)	0.90 (1982)
December	3.79	10.58 (1987)	0.02 (1992)
Year	8.62	30.60 (1983)	0.02 (1992)

(Source: Department of Meteorology).

Table 7: Piche evaporation (mm) records at Doha International Airport 16 years (1977 - 1993).

Month	Mean	Absolute Max.	Absolute Min.
January	6.6	20.4 (1990)	1.5 (1993)
February	8.0	22.9 (1988)	1.4 (1988)
March	10.9	28.0 (1989)	1.7 (1983)
April	15.4	40.2 (1987)	4.2 (1992)
May	21.3	59.4 (1989)	4.2 (1987)
June	25.5	65.6 (1990)	4.6 (1978)
July	20.3	60.8 (1985)	4.2 (1977)
August	17.6	47.8 (1984)	4.1 (1980)
September	12.6	46.9 (1990)	4.5 (1980)
October	11.7	29.1 (1990)	4.5 (1981)
November	9.1	26.7 (1991)	2.8 (1977)
December	7.0	19.2 (1987)	1.1 (1982)
Year	13.8	65.6 (1990)	1.1 (1982)

(Source: Department of Meteorology).

Table 8: Sand and ground temperature (C°) records at Doha (1977 - 1993).

	Sand Temperature (C°)					Ground Minimum temperature (C°)		
	Mean of 0, 6, 12 &18 hrs UTC			Mean of 6 hr UTC		Mean	Absolute	
	Surface	10 cm depth	30 cm depth	50 cm depth	1 m depth	Daily	Minimum	
Period (Years)	17 1977-1993	10 1984-1993	10 1984-1993	14 1977-1990	15 1979-1993	12 1982-1993	12 1982-1993	Year
Jan.	18.2	18.1	20.1	22.4	24.8	10.8	3.2	1992
Feb.	19.8	19.3	20.6	22.4	23.8	12	4.5	1983
Mar.	23.5	22.8	23.3	24.3	24.5	14.9	6.4	1990
Apr.	29.2	27.7	27.5	27.6	26.6	19.1	11.6	1982
May	35	33.4	32.4	31.9	29.7	24.1	16.9	1993
Jun.	37.4	35.7	34.8	34.2	32.2	26.3	21.2	1990
Jul.	38.8	37.6	36.1	35.6	33.7	27.4	21	1984
Aug.	38.5	37.8	36.7	36.2	34.7	27.8	20.6	1983
Sep.	36.1	35.7	35.3	35.3	34.6	25.3	18.4	1983
Oct.	31.9	31.5	32.3	33.1	33.2	21.9	14.9	1992
Nov.	25.9	26.1	28	29.4	30.7	17.6	10.4	1987
Dec.	20.7	20.8	23.1	25	27.3	13.7	6.5	1986
Year	29.6	29.1	29.4	29.8	29.7	20.1	3.2	1992

(Source : Department of Meteorology).

Table 9 : sea water temperature (°C) recorded at Doha (1994 - 1995).

Month	sea water temperature °C (1994)			sea water temperature °C (1995)		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Jan.	20.1	19	21.5	20.1	18.0	21.0
Feb.	18.2	17.9	19.5	19.4	18.5	20.1
Mar.	20.7	18.0	23.0	21.7	20.0	23.0
Apr.	24.8	22.5	28.0	24.3	21.3	27.0
May	28.3	27.0	30.6	29.1	27.5	31.0
Jun.	30.7	29.0	32.2	31.4	30.0	32.3
Jul.	30.4	28.1	31.2	31.5	30.0	33.3
Aug.	32.3	29.4	34.4	34.3	32.5	35.0
Sep.	32.6	31.9	33.2	32.9	31.0	34.0
Oct.	30.3	29.1	31.6	30.2	29.0	31.5
Nov.	26.7	24.0	29.0	26.3	22.5	29.0
Dec.	20.1	18.0	22.5	20.8	18.5	22.5

(Source : Qatar National museum).

Table 10: Sea temperature records at Doha port (1979 - 1989).

Month	Mean Monthly	Absolute Highest Maximum	Absolute Lowest Minimum
January	18	121.7 (1985)	14.2 (1989)
February	18.5	22.2 (1987)	14.4 (1989)
March	21.2	27.4 (1980)	16.6 (1985)
April	25.2	29.6 (1980)	20.3 (1982)
May	29.1	33.3 (1987)	25.3 (1984)
Jun	30.3	34.2 (1988)	26.9 (1986)
July	32.4	36.2 (1989)	27.0 (1986)
August	33.0	36.5 (1987)	28.4 (1984)
September	32.6	35.9 (1988)	28.7 (1984)
October	29.8	33.8 (1986)	25.2 (1984)
November	25.5	31.1 (1988)	20.3 (1982)
December	20.4	26.0 (1983)	15.9 (1982)
Year	26.3	36.5 (1987)	14.2 (1989)

(Source: Department of Meteorology).

APPENDIX 2

Table 1 : Fish caught using a hand net (0.7 cm mesh size) in natural mangrove,planted mangrove and salt-marsh (replicates fishing each 20 min.), during Jun. '94.

Site	N1			N3			P1			P5			S		
Replicates Samples / Species	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Allanetta forskali							1	2							
Aphanius dispar	10	12	9	12	8	13	6	7	5	1	1	2	3	6	5
Liza macrolepis	2	1		2	3	5							1		1
Gnathanodon speciosus				2											
Gerres filamentosus		1		1			1		1						
Gerres oyena	2	1		1	2		1	1		3	2	2	1	1	1
Lethrinus nebulosus	1	1	2												
Platycephalus maculipinna				2	1		1								
Rhabdosargus sarba	3	1	1												
Scolopsis vosmeri	2	1													
Sillago sihama							1		1	2				2	1
Portunus pelagicus	1	2	2	2	1	1	1	2		2	2		1	2	
Total	21	20	14	22	15	19	12	12	7	8	5	4	6	11	10
Mean	18			18			10			5			9		
No. of species	8			7			7			4			5		

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Sites	4	373.7333	93.4333	11.5826	0.0009
Within Sites	10	80.6667	8.0667		
Total	14	454.4000			

Site	Count	Mean	SD	SE	95% Conf. Int. for Mean
N1	3	17.3333	2.8868	1.6667	10.16 To 24.50
N3	3	18.6667	3.5119	2.0276	9.94 To 27.39
P1	3	10.3333	2.8868	1.6667	3.16 To 17.50
P5	3	5.6667	2.0817	1.2019	0.49 To 10.83
S	3	9.0000	2.3458	1.5275	2.42 To 15.57
Total	15	12.2000	5.6971	1.4710	9.04 To 15.35

Site	N1	N3	P1	P5	S	Total
Min	14.0	15.0	7.0	4.0	6.0	4.0
Max.	19.0	22.0	12.0	8.0	11.0	22.0

Multiple Range Tests: Tukey - HSD test with significance level 0.050

The difference between two means is significant if

Mean (J) - Mean (I) > =2.0083 * Range * SQRT (1/N (I) + (1/N (J))

With the following Value(s) for Range: 4.34

(*)Indicates significant differences which are shown in the lower triangle

Mean	Sites					
		P5	S	P1	N1	N2
5.6667	P5					
9.0000	S					
10.3333	P1					
17.3333	N1	*	*			
18.6667	N2	*	*	*		

Table 2: Fish caught using a hand net (0.7 cm mesh size) in natural mangrove (N1), planted mangrove (P1) and sandy rocky beach (SS : Al-Marruna) (replicates fishing each 20 min.). in August 1995.

Site	N1			P1			SS		
Replicates Samples	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Species									
Ablennes hians				1	2	2			
Aphanius dispar	3	6	1	5	6	5			
Mylio bifasciatus							1		
Diplodus kotschyi							1		
Apogon teaniatus								2	1
Lutjanus fulviflamma	1	2	2				1	2	2
Gerres oyena	1	3	2	1	2	3	2	1	2
Platycephalus maculipinna	1		1			1	1	2	
Tylosurus leiurus	1					1	1	1	2
Liza macrolepis	9	9	12	4	3	2			
Therapon jarbua			1	1					
Sillago sihama	1		2	1	1	1			
Rhinobatos granulatus	1								
Pardachirus marmoratus	1								
Total	19	20	21	13	14	15	7	8	7
Mean	20			14			7		
No. of species	10			8			7		

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Sites	4	373.7333	93.4333	11.5826	0.0009
Within Sites	10	80.6667	8.0667		
Total	14	454.4000			

Site	Count	Mean	SD	SE	95% Conf. Int. for Mean
N1	3	17.3333	2.8868	1.6667	10.16 To 24.50
N3	3	18.6667	3.5119	2.0276	9.94 To 27.39
P1	3	10.3333	2.8868	1.6667	3.16 To 17.50
P5	3	5.6667	2.0817	1.2019	0.49 To 10.83
S	3	9.0000	2.3458	1.5275	2.42 To 15.57
Total	15	12.2000	5.6971	1.4710	9.04 To 15.35

Site	N1	N3	P1	P5	S	Total
Min	14.0	15.0	7.0	4.0	6.0	4.0
Max.	19.0	22.0	12.0	8.0	11.0	22.0

Multiple Range Tests: Tukey - HSD test with significance level 0.050

The difference between two means is significant if

Mean (J) - Mean (I) > =2.0083 * Range * SQRT (1/N (I) + (1/N (J))

With the following Value(s) for Range: 4.34

(*)Indicates significant differences which are shown in the lower triangle

Mean	Site	SS	N1	P1
7.33	SS			
14.00	N1	*		
20.00	P1	*	*	

APPENDIX 3

Table 1: Sediment analyses of the samples taken from centers of populations of crab species.

Site	Location	Species	Median diameter (mm)	Mean diameter (mm)	Sorting	Skewnes	% Mean organic content
Al-Khor (N1)	High shore	*N. dotilliformis*	0.19	0.25	0.16	0.35	2.84
	High shore	*E. orientalis*	0.19	0.20	0.11	0.07	2.80
	Mid shore	*M. depressus*	0.22	0.28	0.16	0.35	3.39
Al-khor (N2)	High shore	*S. crabricauda*	0.25	0.30	0.22	0.23	2.97
	High shore	*N. dotilliformis*	0.20	0.26	0.24	0.35	3.25
	Mid shore	*N. dotilliformis*	0.13	0.30	0.21	0.80	3.55
Al-Dhakhira (N3)							
	Mid shore	*M. arabicum*	0.25	0.41	0.37	0.43	4.39
	Mid shore	*I. frater*	0.25	0.41	0.37	0.43	4.39
	Mid shore	*M. arabicum*	0.19	0.35	0.32	0.51	4.90
	Mid shore	*I. frater*	0.19	0.35	0.32	0.51	4.90
	Lower shore	*M. depressus*	0.07	0.31	0.29	0.81	4.37
Al-Dhakhira (N4)							
	High shore	*S. crabricauda*	0.21	0.32	1.61	0.96	2.84
	Mid shore	*M. arabicum*	0.20	0.28	0.25	0.47	3.11
	Lower shore	*M. depressus*	0.20	0.24	0.14	0.26	3.71
Al-Dhakhira (N5)							
	High shore	*S. crabricauda*	0.24	0.32	0.24	0.35	2.00
	High shore	*E. orientalis*	0.16	0.35	0.26	0.75	2.00
	Mid shore	*M. arabicum*	0.13	0.29	0.21	0.80	2.84
	Mid shore	*N. dotilliformis*	0.13	0.29	0.21	0.80	2.84
	Mid shore	*I. frater*	0.19	0.26	0.23	0.36	2.80
	Lower shore	*M. depressus*	0.19	0.22	0.16	0.16	3.50
	Lower shore	*M. indica*	0.19	0.22	0.16	0.16	3.50
Umm Al-Hul (P1)							
	up the bank	*S. leachii*	0.33	0.67	0.58	0.59	3.45
	down the bank	*S. leachii*	0.25	0.47	0.39	0.56	4.06
	Mid shore	*S. crabricauda*	0.55	0.78	0.63	0.36	2.86
	Mid shore	*M. depressus*	0.25	0.36	0.63	0.36	3.56
Al-Wakr ah (P2)							
	* High shore	*S. crabricauda*	0.44	0.47	0.15	0.20	2.40
	* High shore	*M. depressus*	0.43	0.46	0.18	0.17	3.49
	* High shore	*S. crabricauda*	0.36	0.63	0.52	0.52	2.22
	* Lower shore	*M. depressus*	0.38	1.06	0.94	0.72	2.49
	* Lower shore	*M. arabicum*	0.40	0.71	0.59	0.52	4.39
	* Lower shore	*E. orientalis*	0.26	0.45	0.35	0.54	4.27
	* Lower shore	*M. depressus*	0.26	0.45	0.35	0.54	3.27
Fuwairit (P3)							
	* High shore	*S. crabricauda*	0.45	1.09	0.91	0.70	2.18
	* High shore	*E. orientalis*	0.35	0.88	0.72	0.74	2.63
Al-Mafjar (P4)							
	High shore	*S. crabricauda*	0.44	0.84	0.67	0.59	3.47
	Mid shore	*M. depressus*	0.20	0.32	0.20	0.60	4.50
Zekrit (P5)							
	High shore	*S. crabricauda*	0.33	0.94	0.86	0.71	2.29
Doha (S)							
	High shore	*S. crabricauda*	0.42	0.85	0.75	0.57	2.39
	High shore	*S. crabricauda*	0.32	0.94	0.86	0.72	2.40
	High shore	*E. orientalis*	0.18	0.36	0.30	0.59	2.16
	High shore	*M.arabicum*	0.18	0.31	0.26	0.49	2.20
	High shore	*N. dotilliformis*	0.18	0.31	0.26	0.49	2.20
	Mid shore	*M. depressus*	0.16	0.38	0.30	0.73	3.39
	Mid shore	*M. depressus*	0.16	0.42	0.34	0.76	3.40
	Mid shore	*M. depressus*	0.16	0.41	0.33	0.76	4.02

* denote samples collected from out side transect were their no mangrove or salt marsh at Al-wakrah.

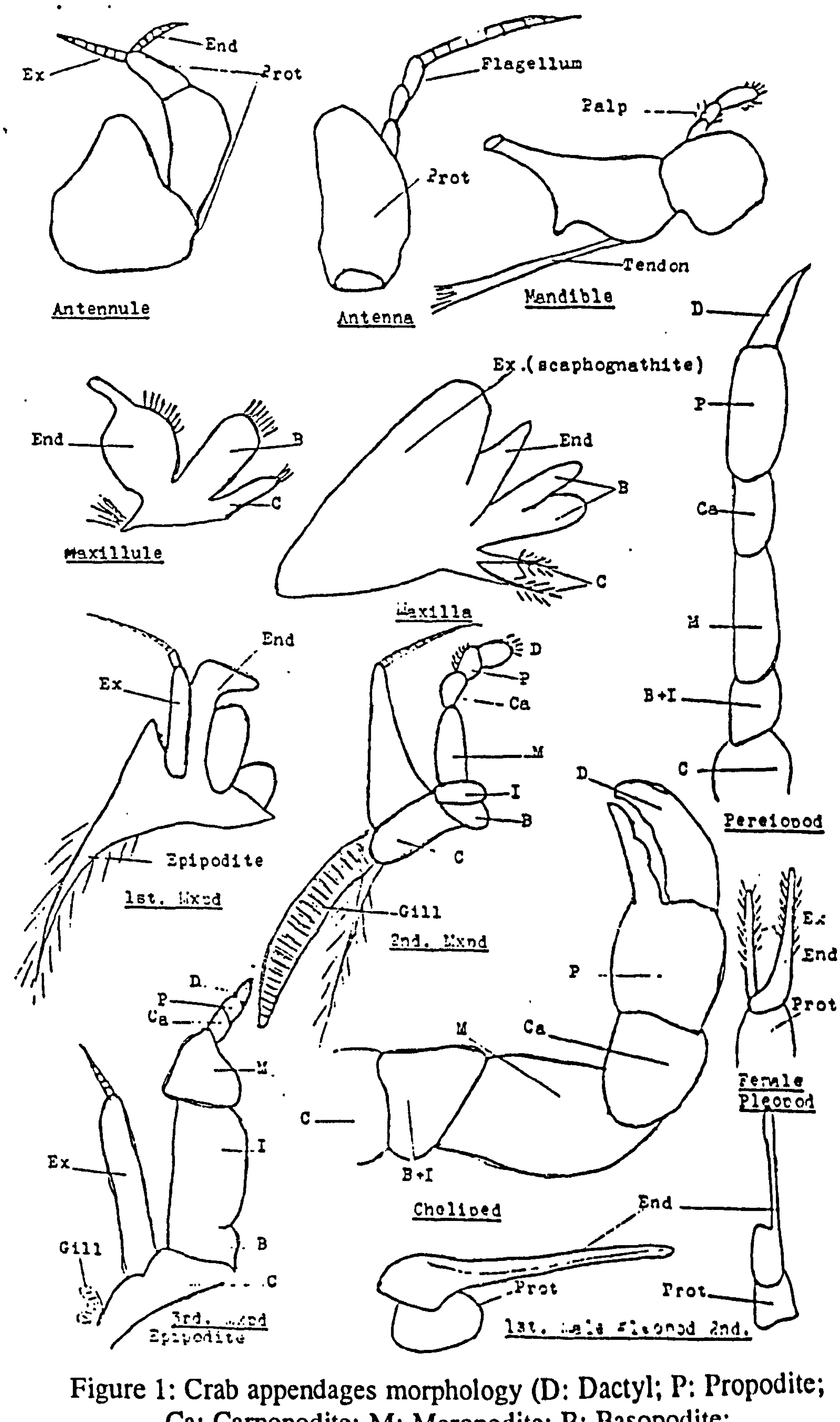


Figure 1: Crab appendages morphology (D: Dactyl; P: Propodite; Ca: Carpopodite; M: Meropodite; B: Basopodite; I: Ischiopodite; C: Coxopodite).

APPENDIX 4

Plate 1: Natural mangrove.

Plate 2: Natural mangrove.

Plate 3: Planted mangrove at the east coast of Qatar.

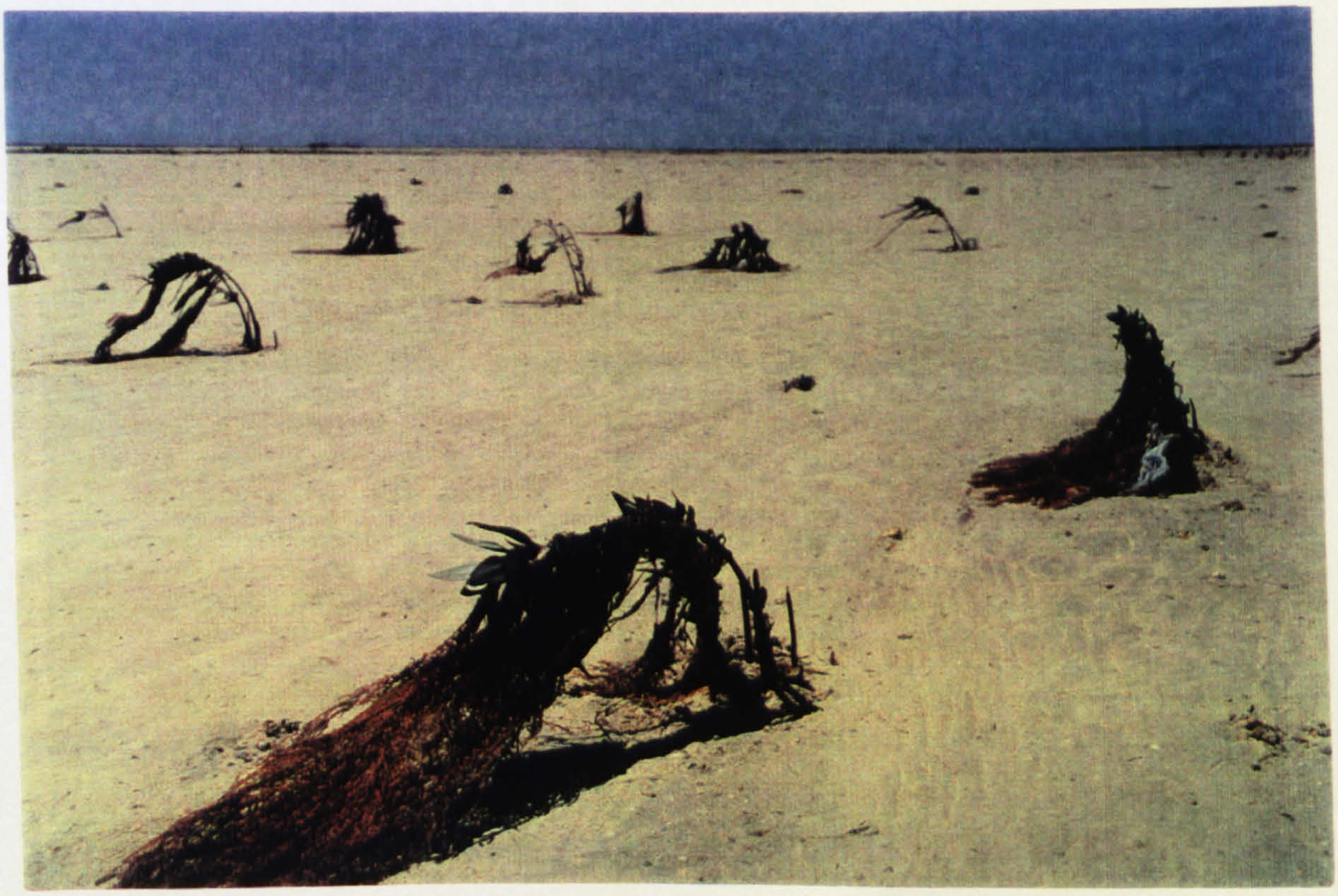


Plate 4: Planted mangrove at the west coast of Qatar.

Plate 5: Seedling growing in a nursery at Fuwairit.

Plate 6: Doha salt marsh.