DOCTOR OF PHILOSOPHY

Microbial mats : a source of primary production on mudflats of the North-Western Arabian Gulf

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Microbial Mats:
A Source of Primary Production on Mudflats of the North-Western Arabian Gulf, Kuwait

A Thesis in Marine Ecology
By
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بسم اللة الرحمن الرحيم

IN THE NAME OF ALLAH, MOST GRACIOUS
MOST MERCIFUL

The Sea is Life
The Sea is Sustenance
Without it
We Perish Under the Sand...

"Old proverb from Arabian Gulf"

Flamingos feeding during rising tide

Diatom-dominated mats on mudflats of Sulaibikhat Bay

SUMMARY

Mudflat habitats represent approximately fifty percent of the Kuwaiti coast, and although they lack macro-vegetation, they exhibit an exceptional biodiversity. Accordingly, the hypothesis that microbial mats form a major source of nutrition supporting mudflat fauna was investigated for a small tidal embayment, Sulaibikhat Bay, within Kuwait Bay.

The ecology and community structure at two sites within the Bay was investigated in detail for the first time. Although environmental factors (temperature, salinity, pH) fluctuated, they exhibited strong seasonality. Qualitative and quantitative sampling revealed a total of 33 macro-species on the accessible upper intertidal mudflats, with brachyurans representing 40% of the total species assemblage. Both total abundance and biomass were lowest during summer (101 individuals m^{-2} and 6.41g AFDW m^{-2} respectively) and highest during winter (304 individuals m^{-2} and 9.4g AFDW m^{-2} respectively), and were comparable with similar tropical habitats world-wide.

A comparison between a virtually pristine site on the northwestern coast and an environmentally modified/disturbed site on the southern coast, revealed that both biodiversity and species abundance were lower at the latter site. The population dynamics of two dominating brachyuran species, *Tylodiplax indica* and *Ilyoplax stevensi* were investigated as potential bio-indicators. Low population levels and recruitment of *T. indica*, at the disturbed site indicates that at this site the Bay is stressed due to physical modification of the upper littoral, and anoxicity due to sewage discharge. As *I. stevensi* did not demonstrate any difference in population structure between sites, *T. indica* may be a more suitable bio-indicator of environmental stress.

In the absence of macro-vegetation microbial mats appear to be a major source of primary productivity. Speciation of the mats was highly dependent on location along the intertidal gradient and in association with sediment type and temperature. Diatoms dominated the mat assemblage with 61%, while

Cyanophytes formed 30% of the mats. Field experiments showed that under natural grazing conditions the mat standing stock varied both temporally and spatially even on a small scale. The annual gross mat production within Sulaibikhat Bay is estimated to be 190.97 g C m^{-2}, making these mudflats as productive as similar habitats elsewhere. Preliminary calculations also reveal that this habitat may be more productive than other vegetated biotopes within the Gulf region, contributing a gross primary production (GPP) of 12.72×10^{11} g C y^{-1}, which is 30% of the total GPP of Kuwaiti coastal waters.

Gut and faecal analysis revealed that 9 out of 13 faunal species consumed mats. Stable carbon isotopic analysis confirmed that despite the presence of other sources of primary productivity, fauna either directly grazed on mats, or preyed upon primary consumers.

It is concluded that these mudflats are unique due to their high biodiversity, endemic species, and high faunal abundances. It is further demonstrated that microbial mats support much of the benthic faunal production supplying the energy requirements of commercial fish and shellfish. There is an urgent requirement for conservation of the last pristine area within the Bay.

CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENT

"It seems to me that no man need be ashamed of being curious about nature. It could even be argued that this is what he got his brains for and that no greater insult to nature and to oneself is possible than to be indifferent to nature."

Niko Tinbergen

First and foremost, I thank God for granting me the faith, will and strength to accomplish such a mission.

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To those whom keep the smile on my face and the warmth of love in my daily life; You keep the true meaning of life in focus.

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CHAPTER I

GENERAL INTRODUCTION

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Marine Environment: Arabian Gulf and Kuwait

The Arabian Gulf occupies one of the most extreme regions of the tropical Indo-Pacific Ocean, the largest ecological and biological realm on earth (Figure 1.1). The Gulf is a relatively large, semi-enclosed body of water, with a volume of $6x10^3$ km^3, and an average depth of 35m generally deeper in the south (Figure 1.2), and is separated from the Gulf of Oman by the Strait of Hormuz (Figure 1.3). The Shatt al-Arab and its associated rivers (Tigris, Euphrates, Karun) is the major source of freshwater and nutrient input from the north (Figure 1.4), with an annual freshwater inflow estimation ranging between $5x10^6$ (Grasshoff, 1976) and $2x10^{10}$ m^3 (Hadi *et al.*, 1984) of nutrient rich water per year.

The bottom topography of the Gulf is generally flat and featureless. As a whole, it is dominated by soft substrate ecosystems mostly of sand and mud, due to the generally extremely gradual elevation and depth contours which have led to the occurrence of a high sedimentary environment (Figure 1.5). Air temperatures in the north reach around 0°C in winter and 50°C and above in summer, and are reflected in the water temperatures which show fluctuations between 10 and 39°C in near-shore waters, and moderate fluctuations ranging between 18 and 33°C in offshore surface water. Salinity is also influenced by the arid climate in the region, which in turn influences water density, currents, water mixing, and species composition. Precipitation and inflow of fresh water contribute 13-54cm to the sea level annually. However due to the arid nature of the region and extremely hot summers, between 140-500cm of freshwater is evaporated from the system per year. As a consequence salinity in the area normally ranges from between 40 and 50‰. Since evaporation exceeds freshwater input, a density gradient is largely responsible for driving the currents in the Gulf in a counter clockwise direction (Figure 1.6). Semi-diurnal tides predominate in the Gulf, however tides of the north-central, north-eastern and south-eastern parts are mixed.

Because the Gulf is the result of the re-flooding of a shallow sedimentary basin during the Holocene transgression (Sheppard *et al.*, 1992), the present day marine biota are considered to be of recent origin. Despite this and the aridity of the region, and limited riverine input, the biota is considerably richer than expected (Basson *et al.*, 1977). It also supports a range of endemic marine species (Jones and Clayton, 1983; Apel and Türkay, 1999).

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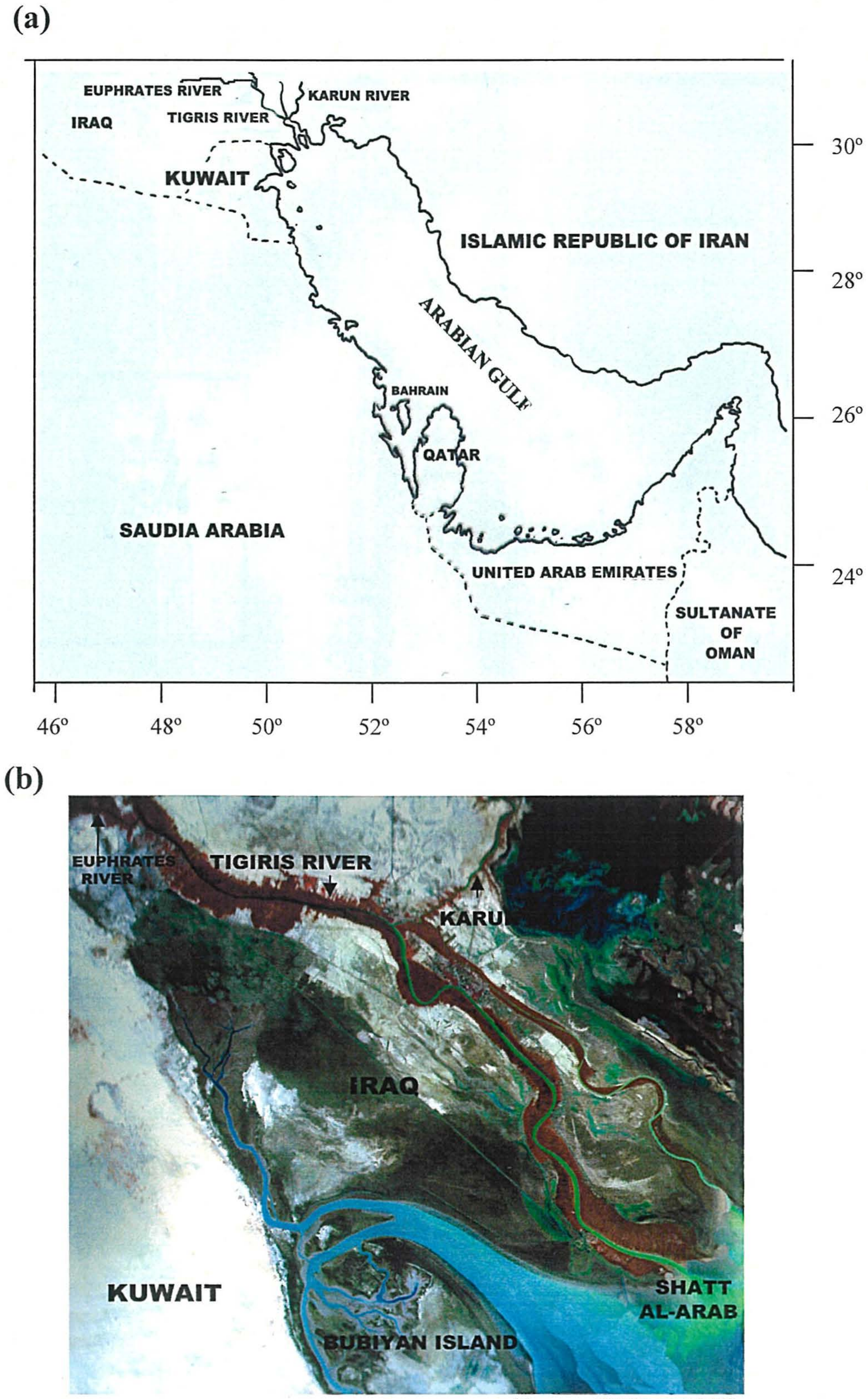
Figure 1.1 Location of Arabian Gulf in respect to the Indo-Pacific Ocean and surrounding water bodies (Source: National Geographic Society, 2000).

Figure 1.2 Bathymetric depths along the Arabian Gulf (Source: ROPME, 2000).

Figure 1.3 Location of the Strait of Hormuz within the Arabian Gulf region (Source: National Geographic Society, 2000).



(Source: ROPME 2000)

Figure 1.4 Major Riverine system in the Arabian Gulf (a) location (b) satellite image of Shatt Al-Arab.

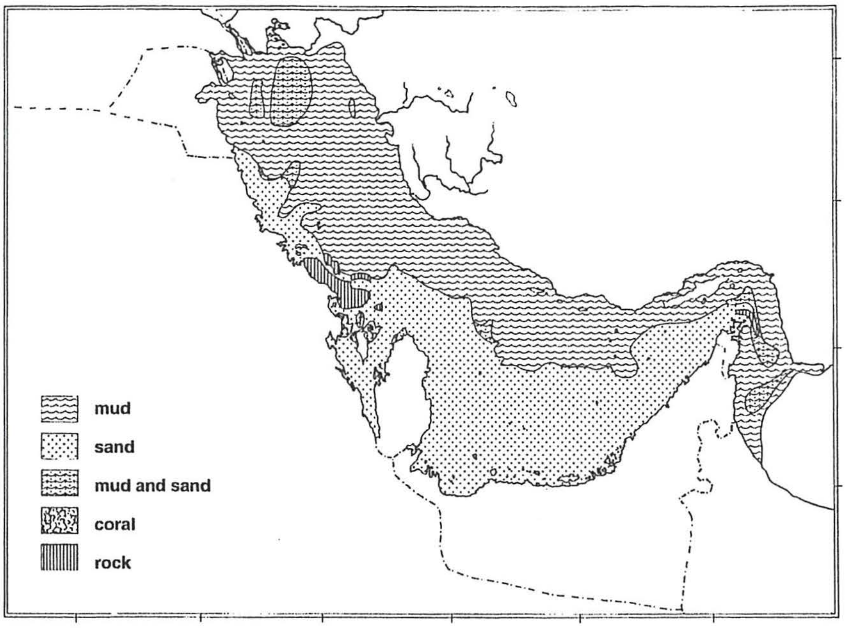


Figure 1.5 Sedimentary characteristics of the Arabian Gulf (Source: Carpenter *et al.*, 1997).

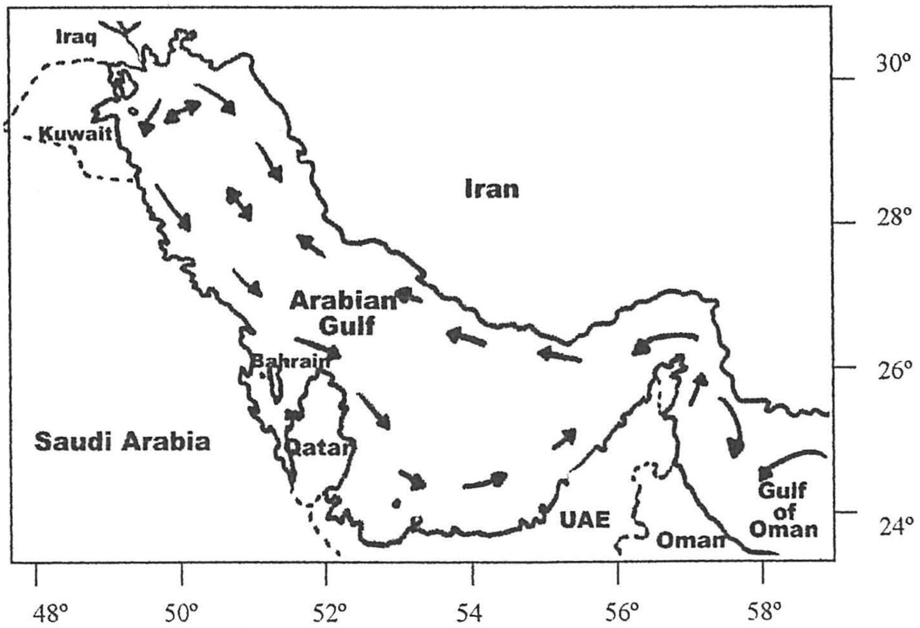


Figure 1.6 Major surface current pattern in the Arabian Gulf (Source: Carpenter *et al.*, 1997).

The State of Kuwait lies at the head of the Arabian Gulf within its north-western corner. It is situated in the north-eastern corner of the Arabian Peninsula extending between 28° 30' N & 30° 05' N, and 46° 33' E & 48° 30' E. It is part of a large, low-altitude desert that covers most of eastern Arabia, lying on a gently sloping plain rising westward from the Arabian Gulf and reaching an elevation of 290m at Ras-Shagaya. It has an area of approximately 17,818 square kilometres, and is bound on the west and north by Iraq, on the south by Saudi Arabia and on the east by the Arabian Gulf (Figure 1.7).

Kuwait has a typical desert climate, which is characterised by temperature extremes, little and variable rainfall, a high percentage of sunshine and frequently occurring dust storms. The contrast between summer (April through October) and winter (November through March) is great. Summer temperatures average at 44°C and occasionally reach 54°C during the hottest season (July & August). However, mild and pleasant days characterise the weather during winter, where temperatures average about 16°C in the coolest months but may reach a low of 4°C during the night. The 1 to 10cm of annual precipitation fall almost exclusively in winter (between November and April), although thunderstorms can bring as much as 3cm at a time. Winds are frequent in Kuwait. The prevailing north-westerly winds are cool in winter and spring, but hot in summer. However the south-easterly winds are usually hot and damp occurring during July and October. Humidity can reach the 90% range during July and October making it extremely unpleasant. Strong dust storms called 'Tauz' occur mostly during late spring and summer lasting up to several days.

The coastal environment of Kuwait is highly influenced by the climatological conditions associated with the aridity of the mainland. Seawater temperature and salinity show significant seasonal differences, with summer temperature exceeding 32°C and salinities 42 ‰ (Samhan, 1989). The marine water column is generally well mixed throughout the year except the deeper southern waters in summer where surface waters may be 4-7 °C warmer and 1-2 ‰ more saline than bottom waters (Al-Muzaini *et al.* 1991). Net surface currents are highly affected by the prevailing north-westerly winds that tend to drive the pattern in a general counter-clockwise circulation (Figure 1.8).

The marine coastal environment is generally characterised by shallow depths that increase to the south-east (<10m depths, Figure 1.9). In Kuwaiti territorial waters the tides are mostly semidiurnal, and are found to be in phase from south to north, with a tidal range increasing from south to the north at a rate of approximately 0.125×10^{-1}m km^{-1}. Table 1.1 lists the mean tidal heights for Kuwait. Tidal currents are strongly bimodal in direction, causing one third of Kuwait Bay's water to be exchanged with open Gulf water every tidal cycle (Al-Muzaini *et al.* 1991).

Because of the bathymetric configuration of the sea bottom and the presence of Failaka Island in Kuwait's northern territorial waters, the wave heights in the northern part of Kuwait waters are lower than in the southern part (Khalaf, 1988). Waves approaching Kuwait Bay in the north are mainly from the east or southeast.

The sediments along the Kuwaiti coast vary in size from silt and clay to large boulders (Figure 1.10). Clean medium grade sand beaches prevail along the open coast south of Kuwait City, extending down to the Saudi Arabian border but never reach the level of exposure seen on oceanic shores. In the sheltered northern coast (Kuwait Bay) soft sediment shores grade from mud to muddy sand predominated by silt and clay that originates from the Shatt-Al-Arab Estuary. Generally, carbonate sediments predominate in the south, while land-derived clastics dominate in the north.

Figure 1.7 Map of the north-western part of the Arabian Gulf emphasizing the location of Kuwait (Source: National Geographic Society, 2000).

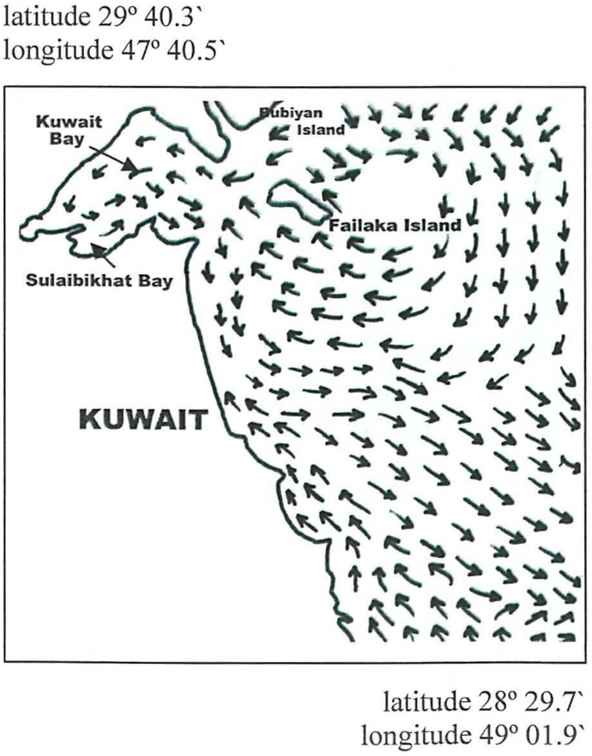


Figure 1.8 Surface current patterns of coastal waters of Kuwait (Source: Al-Sarawi *et al.*, 1985).

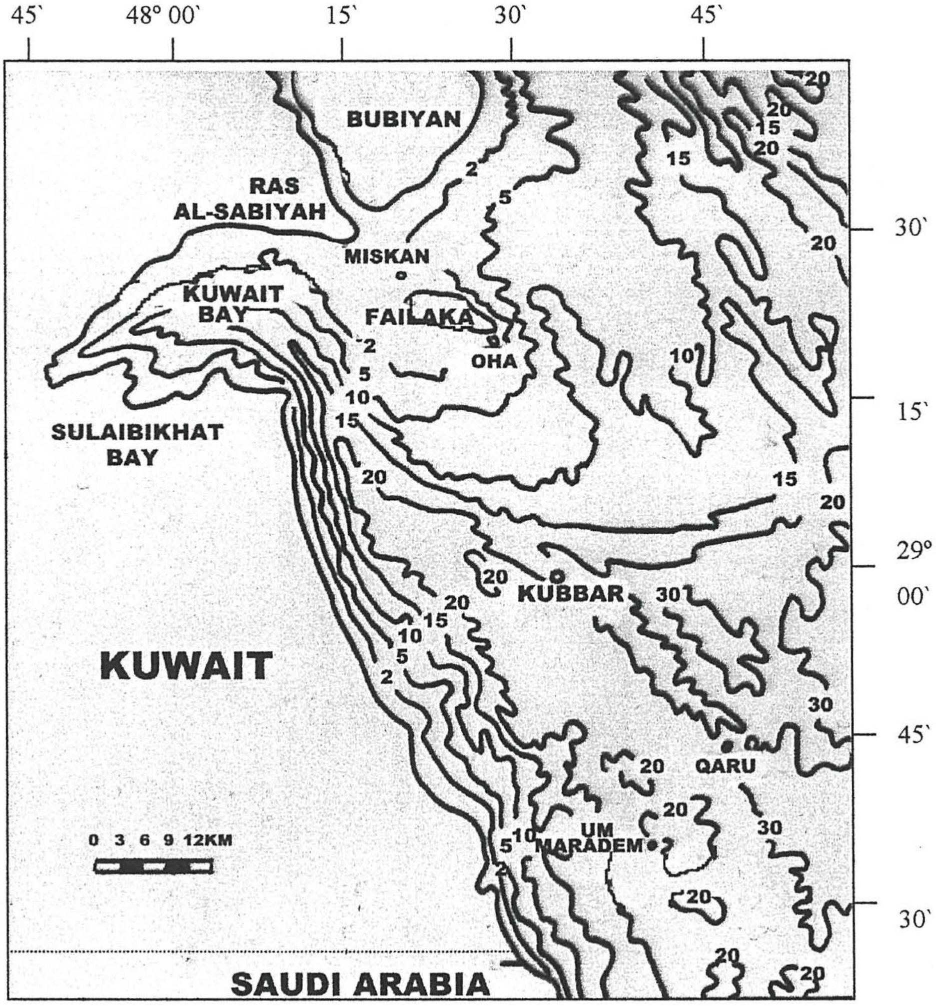


Figure 1.9 Bathymetric depths of Kuwait's territorial waters.

Table 1.1 Mean tide levels for Kuwait. Datum is Kuwait Land Datum (KLD), which is 0.47m above British Admiralty Chart Datum (Al-Sarawi *et al.*, 1985).

Tidal Levels	Height (KLD) in metres
Higher high water, Springs	+3.58
Higher high water (MHHW)	+2.94
Lower high water (MLHW)	+2.36
Higher low water (MHLW)	+0.90
Lower low water (MLLW)	+0.05
Lower low water, Springs	-0.72

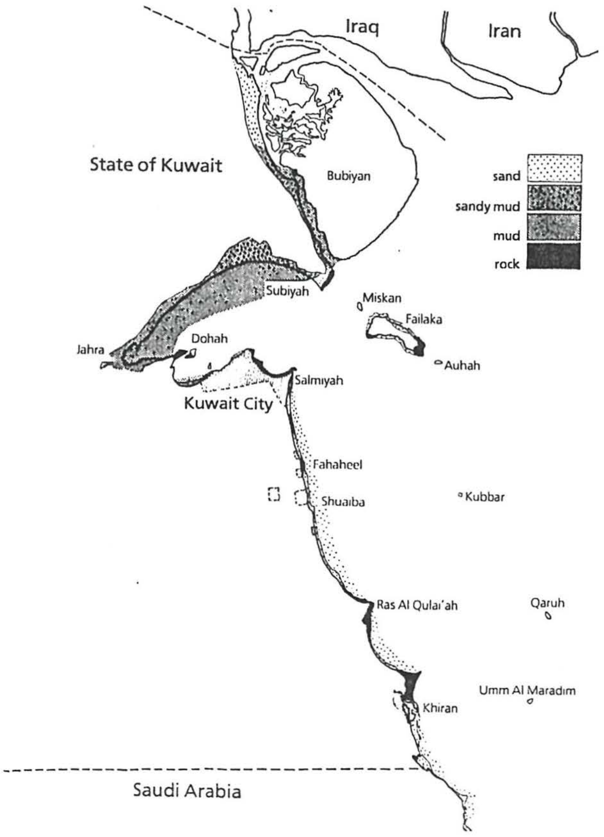


Figure 1.10 Sedimentary characteristics of the coastline of Kuwait (Source: Jones, 1986a).

Primary Production: Arabian Gulf and Kuwait

The Gulf is thought to be more productive than previously, due to its high pelagic and benthic productivity. A full review of past biological and ecological studies conducted in the region is presented in appendix 1.1 (Jones *et al.*, 2002a). Primary production is relatively high because most of the Gulf lies within the photic zone. In the Saudi Arabian Gulf waters, which represent a large portion of the Arabian Gulf as a whole, phytoplankton contribute to 57% of gross primary production, while sand and mud contribute to 16%, macroalgae 13%, seagrass 7%, and corals 7% (IUCN, 1987).

From these estimates that were achieved by IUCN, by calculating the area of biotopes using ground truthing of LAD SAT TM imagery and other sources of literature (Table 1.2), Jones *et al.* (1998, 2002a) calculated primary productivity estimates for subtidal as well as intertidal biotopes in the Gulf. From such applications they were able to evaluate the importance of each biotope in terms if its contribution to the Gulf ecosystem and local fisheries (Table 1.2). Estimates made on biotopes of Kuwaiti waters show that microbial mats may make a far more important contribution to primary production than coral reefs, macroalgae or seagrass (Table 1.3 and table 1.4). These algal or microbial mats, associated with the tidal mudflats, have also been suggested to be a far greater contributor to primary production in the Gulf as a whole than mangroves and salt marsh halophytes (Price *et al.*, 1993), due to their high productivity, rapid turnover, their direct utilisation by grazers, and their productivity in winter months when the autotrophic production is low.

During the environmental research and conservation following the 1991 Gulf War oil spill in Jubail Wildlife Sanctuary in Saudi Arabia, Jones *et al.* (1996) described a sequence on Saudi Arabian mudflats where, after widespread destruction of intertidal macrofauna, microbial mats flourished and extended to cover much of the intertidal zone. With long-term monitoring they were able to follow the contraction of these mats back to their original zone around high water as the grazing macrofauna re-established on the shore. The recovery of the macrofauna was correlated with the regression of microbial mats to their former upper intertidal zone (Jones *et al.*, 1996). This provides indirect evidence to suggest that grazing may control microbial mat production. In view of their high gross primary production (Table 1.4), it appears that mats may play a vital role in supporting intertidal food webs.

Table 1.2 Estimated values for gross, and net primary production, where available, for intertidal and subtidal Gulf biotopes [GPP = Gross Primary Production, NPP = Net Primary Production] (Jones *et al.*, 1998).

Biotopes	**GPP** **g Cm^{-2} y^{-1}**	**NPP** **G Cm^{-2} y^{-1}**	**References**
Subtidal			
Phytoplankton **Overall Gulf**	47.6 – 200 (124)	-	IUCN, (1987)
Phytoplankton (< 5m)	394*	-	
Macroalgae (kelp)	400 - 1900	120 - 1330	Mann, (1982)
Seagrass	651*	100	Jones *et al.* ,(1987) Basson *et al.*, (1977)
Reef algae	500	300*	Sheppard *et al.*, (1992)
Corals (Florida)	3880	140	Odum, (1957)
Corals, algae & Seagrass	1820	-	IUCN, (1987)
Intertidal			
Mangroves	500	200*	Sheppard *et al.*, (1992) Mann, (1982)
Saltmarsh (Texas)	1 - 2000	2 – 5000	Mann, (1982)
Microbial mat **(Australia, Mexico)**	854*	-	Bauld, (1984) Javor and Castenholz, (1984)
Intertidal algae **(Red Sea)**	0 – 65*	-	Dor and Levy, (1984)

(* values recalculated from figures in the literature)

Table 1.3 Approximate estimates of the areas of the biotopes within Kuwaiti waters (Jones *et al.*, 1998).

Biotope	Total Km^2	Area %
Sea surface	15477	100
[1]Shallow (less than 5m) sand / mud	2541	15.3
[1]Deep (over 5m) sand / /mud	12936	83.0
[2]Coral Reef	3.5	0.02
[3]Rock / algae	65	0.4
[4]Productive intertidal mud / sand flats	155	1.0
[5]Seagrass	50?	0.3

[1] calculated from Khalaf *et al.*, (1984); [2] from Carpenter *et al.*, (1997); [3] from Bishop *et al.*, (1994); [4] from Al-Sarawi *et al.*, (1985), and Kwarteng and Al-Ajmi, (1997); [5] estimate only.

Table 1.4 Estimates of gross primary production (GPP) for different subtidal and intertidal biotopes in Kuwait (Jones *et al.*, 2002a).

Biotopes	Total km^2	Area %	GPP x 10^{11} (g $Cm^{-2}y^{-1}$)	GPP%
Phytoplankton	15477	100	26.2	70.0
Shallow sand/mud	2541	16	4.57	12.3
Deep sand/mud	12936	83	4.65	12.5
Reef corals	3.5	0.02	0.06	0.1
Rock/algae	65	0.4	0.3	0.8
Seagrasss	50	0.3	0.3	0.8
Productive intertidal mud/sand flats	155	1.0	1.3	3.5

In Kuwait Bay, soft mud intertidal flats, which form the commonest shoreline type in the north, extend for several kilometres, and support a rich and diverse biota. Primary production in this un-vegetated habitat, which is occasionally bordered by salt marshes but lacks mangroves, is thought to be restricted to microbial production. Some of the macrofaunal organisms inhabiting these mudflats have received a great deal of taxonomic and biological attention (Jones & Clayton 1983; Clayton 1986; Clayton & Vaughan 1988; Snowden *et al.* 1991, 1994), and recently the marine ecology of the whole region has been reviewed (Jones *et al.*, 2002a; appendix 1.1). However, there has not been any attempt to investigate the food web links operating within this ecosystem. Hence, present work aims to provide experimental evidence to determine the importance of microbial mats as a source of nutrition for major intertidal herbivores on mudflat habitats in Kuwait Bay on the north-western part of the Gulf.

Chapter 1 (current chapter) introduces the reader to the environmental characteristics of the region undergoing the investigation, and gives an overall view, a preface, of the topics discussed in the subsequent chapters.

Chapter 2 includes a qualitative and quantitative investigation of the mudflat macrobiota conducted over a 13-month period. This includes assessment of both physical (transect profile; physical and chemical parameters) and biological (zonation scheme of biota; abundance, distribution and seasonal biomass of major faunal species) aspects of the habitat.

In chapter 3 the population dynamics of the most conspicuous and numerically dominating macroscopic brachyuran crabs (*Tylodiplax indica*, *Ilyoplax stevensi*) inhabiting the intertidal mudflats are discussed and assessed in association with habitat modification (impacts). Their potential as bio-indicators on mudflats of Sulaibikhat Bay is also discussed.

Chapter 4 contains a series of field and laboratory investigations and experimentation to assess the role of microbial mats as a source of nutrition for major faunal species on Sulaibikhat mudflats by: (a) identifying species composition of the mats, (b) determining their standing stock and daily growth, (c) attempt to determine the consumption rate of mats by certain macrofaunal species, and (d) providing a preliminary estimate of the mat primary production based on calculated standing stock.

Chapter 5 deals with isotopic analyses conducted on major intertidal species occurring along the mudflats of Sulaibikhat Bay, to examine food web dynamics in association with microbial mat, and to help identify possible grazers and first level predators.

Chapter 6, a general discussion, links all the topics discussed individually in the previous chapters to consider the general hypothesis that microbial mats are the major source of nutrition for intertidal benthic food webs of Sulaibikhat Bay.

CHAPTER II

QUANTITATIVE AND QUALITATIVE ECOLOGY OF SELECTED MUDFLAT HABITATS IN SULAIBIKHAT BAY

Part of this work has been accepted for publication:
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INTRODUCTION

Mudflats: Soft-shore habitats

The term 'mud' is loosely applied to deposits containing a high proportion of silt or clay particles. Such particles tend to deposit only on shores where conditions are normally sheltered, without strong currents and have a gentle slope hence the term 'mudflat'. Although mudflats are among the least attractive of marine environments, they are thought to be the most productive natural ecosystems in the world harbouring rich and diverse communities, due to the stability of the sediment surface and high organic content which provides a rich source of nutrition (Schelske & Odum, 1962; Eltringham, 1971; Basson *et al.*, 1977; Clayton, 1986; Sheppard *et al.*, 1992; Little, 2000).

The macrobiotic zonation and distribution is one of the most interesting biological features of these mudflats. Many benthic organisms in the intertidal mudflats show characteristic patterns of habitat selection that favours their survival. Such selection depends on the influence of both physical (changes in temperature, salinity, oxygen concentration, nutrient availability) and biological factors (competition, predation & parasitism) that effect their distribution in and on the mud, as well as along the intertidal gradient (Raffaelli *et al.*, 1997).

In the Arabian Gulf, extensive mudflat habitats are confined to the north-western corner, where fine silt accompanying the fresh water output from the Shatt-al-Arab estuary is deposited, and elsewhere to sheltered areas of the Saudi Arabian coast. In 1975 the first ever year-long study on tidal mudflats along the Coast of Tarut Island, Tarut Bay, Saudi Arabia (Basson *et al.*, 1977) revealed that these tidal mudflats were characterised by a series of well defined zones, each occupied by a different community of organisms (Figure 2.1).

The marsh grass zone, lying above the average spring high tide level, is covered by a luxuriant meadow of salt-tolerant plants often dominated by the reed *Phragmites communis, Aeluropus lagopoides* and *Bienertia cycloptera.* The uppermost portion of the true intertidal region is the halophyte zone. It forms a wide flat platform of stable firm mud which is covered by only a few centimetres of water on spring high tides, and is densely covered with halophytes (*Arthocnemon macrostachyum, Halocnemon strobilaceum*). The dominant macrobiota in this zone are the ocypodid crab *Nasima dotilliformis*, and the grapsid crab *Metapograpsus messor*.

The seaward edge of the halophyte zone is marked by a transition from firm mud to the wet mud which is occupied by a belt of *Avicennia marina* and forms the mangrove zone. These mangroves trap wet fine-grained, organically rich and anoxic sediments with their extensive root system, but are absent from Kuwait, probably due to the low winter temperatures. Seaward of the mangrove belt is the zone of microbial or algal mats where sediment is covered by a mat composed of Cyanophyta, bacteria and benthic diatoms. Many microscopic organisms inhabit the mat including gastropods, ostracods, polychaetes, and copepods. Large organisms such as crabs and gastropods fail to establish in this top-shore region as there is little protection from desiccation.

Below the microbial mat zone, the *Macrophthalmus* zone is a broad expansion of very wet liquid mud which, even at low tide, is always covered by a thin film of adherent water. This region is dominated by the deposit-feeding crab *Macrophthalmus depressus*, together with *Cerithidea cingulata* and the predatory crab *Metaplax indica*. The xanthid crab *Eurycarcinus sp.* often extends down to this zone predating on other crabs.

The zone following the *Macrophthalmus* zone extends down to the level of the lowest spring tide and is dominated by *Cerithidea cingulata* reaching densities up to 2,100 individuals/m^2. Also in this zone occurs the predatory snail *Murex kusterianus*, and the echurian worm *Ikeda taenioides*.

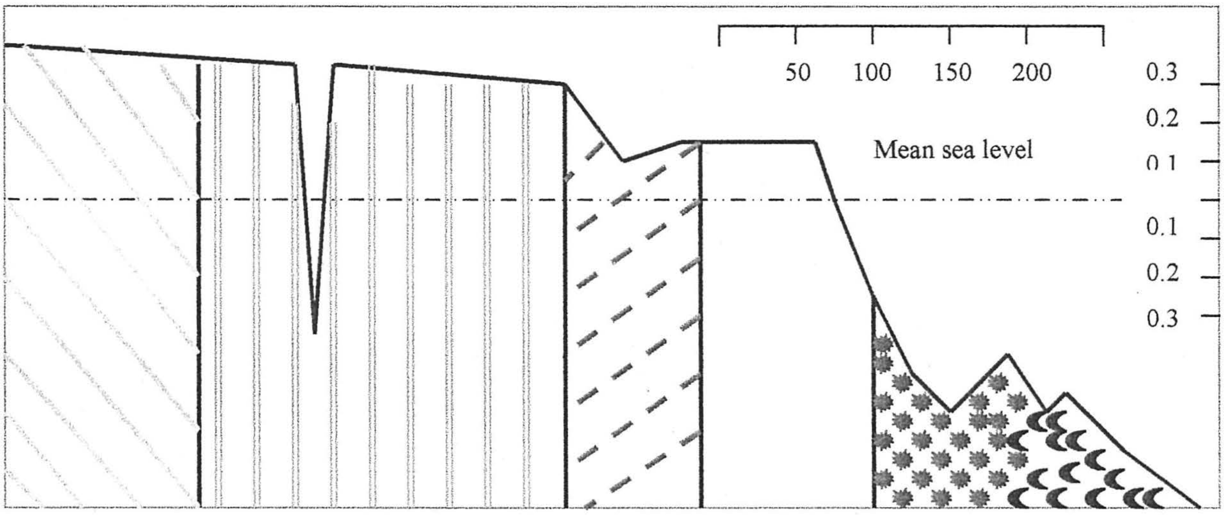


Figure 2.1 Diagram of the tidal mudflats transect line on Tarut Island, showing the major life zones (Basson *et al.*, 1977).

[KEY: ⟍ Marsh Grass zone; ‖ Halophyte zone; ⁄ Mangrove zone; Algal mat zone; ✸ *Macrophthalmus* zone; ☾ *Cerithidea* zone]

This zonation pattern described for Tarut Bay as well as in other areas along the Saudi Arabian coast has been modified for other areas along the western Arabian Gulf coast. In 1985, Jones reported the biological characteristics of the marine habitats found within the ROPME sea area, and included the major floral and faunal components of Kuwait muddy shores (Table 2.1). Clayton (1986) later reviewed the structure, composition and zonation scheme for the mudflat community in Kuwait Bay, based mainly on studies in Kathma and Sulaibikhat (Figure 2.2). Accordingly, the mudflats were divided into 5 distinctive zones.

The Halophyte zone, located at the supralittoral fringe, is comprised of *Salicornia*, *Juncus*, *Halocnemon*, *Seidlitzia*, *Nitraria* and *Zygophyllum*, with the nocturnal crab, *Sersarma plicata* found burrowing among the *Halocnemon* bushes.

An algal (microbial) mat zone (littoral fringe) may occur below the halophyte zone depending on the dominating sediment. If the sediment is of a silt/clay nature, microbial mats characterised by filamentous and unicellular blue-green algae and diatoms will dominate. However, if the sediment is well drained, composed mainly of sand, then deposit-feeding crabs such as *Scopimera scabricauda* and *Dotilla blanfordi* may replace this zone.

The next zone, just above the MHHW, is known as the fiddler crab zone due to the occurrence of the fiddler crabs *Austruca lactea annulipes* (*Uca annulipes albimana*) [sandy mud areas], *Uca sindensis* and *Cleistostoma kuwaitense* (*Leptochryseus kuwaitense*) [muddy sand areas].

Slightly overlapping with the fiddler crab zone but extending down to the wet mud, is the mudskipper zone named after the three species of gobies which are found in Kuwait. The most common and amphibious is the carnivorous goby *Periophthalmus waltoni*. In contrast, *Boleophthalmus boddarti* the largest mudskipper on Kuwait mudflats, is a surface grazing herbivore which prefers wet mud surfaces and overlaps with the *Periophthalmus*. The least amphibious of the three is *Scartelaos viridis*. It is an omnivore found only in areas with surface water. Small crabs also occur in this zone and are preyed upon by *Periophthalmus*. *Nasima dotilliformis* and *Ilyoplax stevensi* prefer a mudskipper zone that is moist with a superficial layer of soft mud, whilst *Ilyoplax frater* and *Macrophthalmus grandidieri* occur in areas dominated by sandy sediments.

With the appearance of the water-table at the surface, the *Macrophthalmus* zone begins. This zone is characterised by the dominance of the largest mudflat crab *Macrophthalmus pectinipes*. The deposit feeder *Macrophthalmus depressus*, and predators *Metaplax indica* and *Eurycarcinus orientalis* are common inhabitants of this zone, in addition to the small mud-feeding *Tylodiplax indica*. *Ilyoplax stevensi* and *Ilyoplax frater* can also been seen in this zone but in lower numbers than found in the mudskipper zone.

Extending from about the middle of the mudskipper zone at the level of *Bolephthalmus* right through the *Macrophthalmus* zone is the echiuran worm *Ikeda* sp. molluscan fauna are restricted to the lower shore, however, the gastropod *Cerithidea cingulata* can be found at all levels on the shore.

Table 2.1 Distribution of the major floral and faunal components of muddy shores of Kuwait (Jones, 1985; 1986a).

Zone	Species
Landward fringe	Saltmarsh with *Zygophyllum* - *Aeluropus* – *Juncus* – *Halocnemon* zonation
High Water Springs	*Sesarma plicatum*
High Water Springs and High Water Neaps	*Leptochryseus kuwaitense* *Uca sindensis*
High Water Neaps To Mean Sea Level	*Ilyograpsus paludicola* *Nasima dotilliformis* *Ilyoplax stevensi* *Ilyoplax frater* *Eurycarcinus orientalis* *Periophthalmus waltoni* *Boleophthalmus boddarti* *Tylodiplax indica* *Metaplax indica*
Mean Sea Level To Low Water Level	*Macrophthalmus grandidieri* *Macrophthalmus depressus* *Scartelaos viridis* *Cerithidea cingulata* *Macrophthlamus dentipes*
Sub-Littoral Fringe	*Portunus pelagicus*

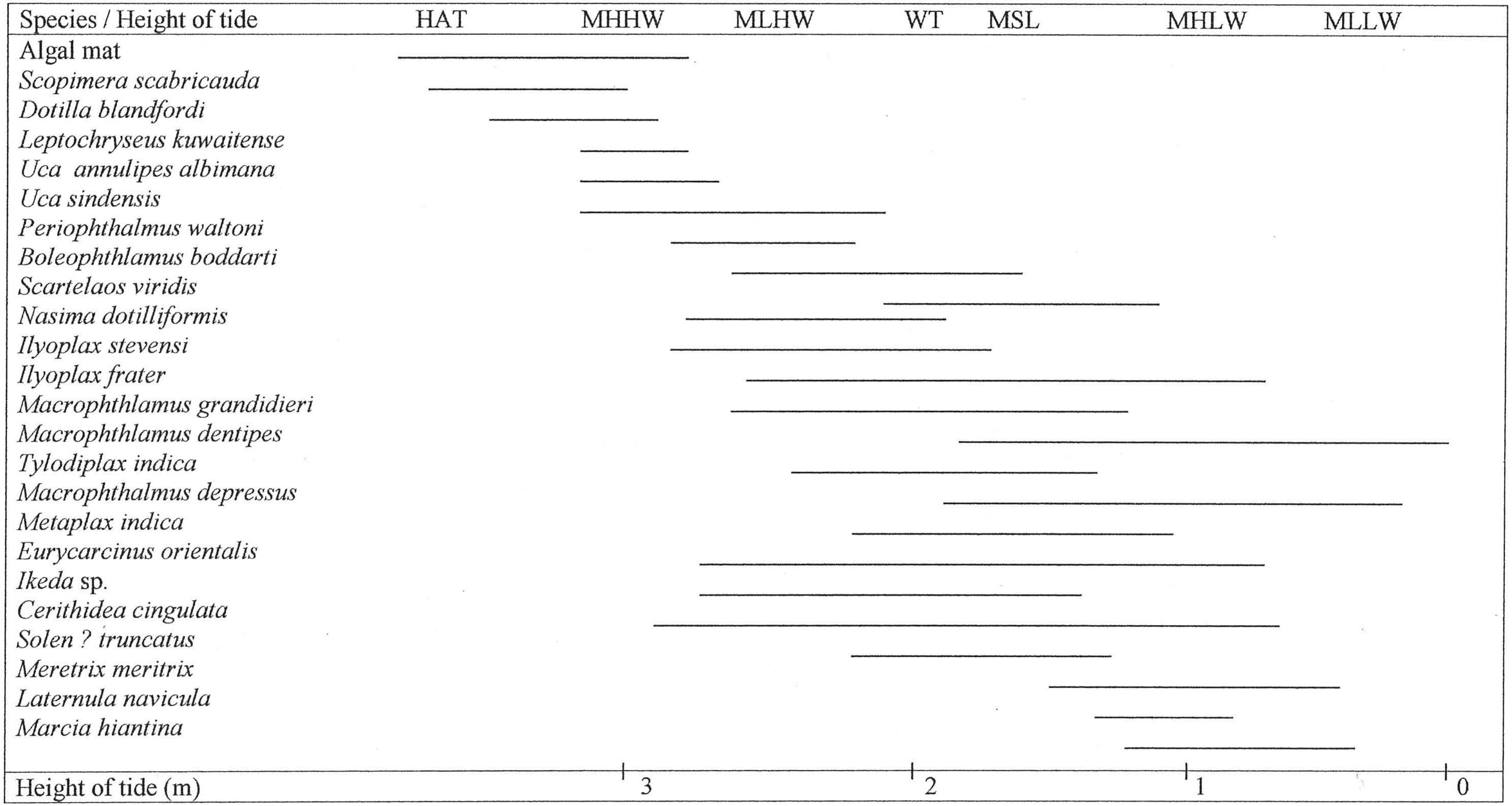


Figure 2.2 Zonation of the fauna of the intertidal mudflats of Kuwait. (HAT: highest annual tide, MHHW: mean highest high water, MLHW: mean lowest high water, WT: water table, MSL: mean sea level, MHLW: mean highest low water, MLLW: mean lowest low water) (Source: Clayton, 1986)

Vousden (1987) conducted a study on the marine habitats in the waters of Bahrain including muddy shores. This study revealed that although naturally occurring muddy shores are rare in Bahrain, due to its coastal topography, true muddy shores occur at a small area of the open region in the Askar Region and Tubli Bay. These areas both possess characteristic fauna (Table 2.2) with densities higher than anywhere else in Bahrain. Recently Al-Zaidan (1999) conducted a preliminary short-term survey on mudflats in Sulaibikhat Bay – Kuwait, to determine the status of the mudflats during Kuwait's extreme summer months (June 98 - August 98), and the effect of anthropogenic influences on their biodiversity. This study showed that the pristine site (Ashish Al-Doha) was more diverse and species rich than the site (Sulaibikhat) which had been subjected to various forms of anthropogenic factors (infilling, sewage discharge, public access)(Table 2.3).

Table 2.2 Distribution of the major floral and faunal components of muddy shores of Bahrain (Vousden, 1987).

Zone	**Species**
Landward fringe	Saltmarsh and *Avicennia marina*
High Water Springs	*Planaxis sulcata*
High Water Springs And High Water Neaps	
High Water Neaps To Mean Sea Level	*Ilyograpsus paludicola* *Nasima dotilliformis* *Ilyoplax frater* *Eurycarcinus orientalis* *Metapograpsus messor* *Metaplax indica*
Mean Sea Level To Low Water Level	*Macrophthalmus depressus* *Cerithidea cingulata* *Pirinella conica*
Sub-Littoral Fringe	*Portunus pelagicus*

Table 2.3 Species list of macrobiota collected at Site I (Ashish Al-Doha: pristine site) and Site II (Sulaibikhat: influenced site) – Sulaibikhat Bay (Source: Al-Zaidan, 1999).

Species	**Site I (Ashish Al-Doha)**	**Site II (Sulaibikhat)**
Angiospermae		
Zygophyllum coccineum	X	-
Halocnemon strobilaceum	X	-
Salicornia herbacea	X	X
Crustacea		
Decopoda		
Ocypodidae		
Leptochryseus kuwaitense	X	-
Uca annulipes albimana	X	-
Uca sindensis	X	X
Nasima dotilliformis	X*	X
Manninngis arabicum	X	-
Macrophthalmus dentipes	X	-
Ilyoplax stevensi	X	X
Tylodiplax indica	X	X*
Xanthidae		
Eurycarcinus orientalis	X	X
Grapsidae		
Metapograpsus messor	-	X
Osteichthyes		
Gobiidae		
Periophthalmus waltoni	X	X
Boleophthalmus boddarti	X	-
Gastropoda		
Prosobranchia		
Cerithidea cingulata	X	X
Sipuncula		
Sipunculoidea		
Ikeda taenoides	X	-
Total number of species/site	16	9

X*. species found only once in quadrat extract sample during sampling period.

Study area

Kuwait Bay is a semi-estuarine bay located along the northern province of the Kuwaiti coast. It extends 48 km inland from the Arabian Gulf, and is 40 km long and 25km wide at the mouth. Occupying the southern shore of the bay is a natural harbour, Shuwaikh harbour, and the Capital City, Kuwait (Figure 2.3). Waves approaching the bay are mainly from the east and are of relatively low energy when compared to the open coast, although even here waves generally do not exceed 1.5m in height (Khalaf, 1988). It is a tide-dominated area, exhibiting a general counter clockwise circulation forced by the prevailing north-westerly winds (Al-Sarawi *et al.*, 1985; Figure 2.4). Kuwait Bay is characterised by shallow depths not exceeding 8m at its entrance (Kuronuma & Abe, 1972; Khalaf, 1988). Surrounding the bay are wide intertidal mudflats (4 km wide during low tide), with associated salt marsh, deposited by the soft mud and clay brought in by the rivers via the Shatt-Al-Arab and desert sand storms. Due to the semi-estuarine nature of this bay, it is a considered to be a major nursery ground for many commercial fishery species (Wright 1988), and also harbours endemic species for the Gulf region (Al-Khayat & Jones, 1996; Apel and Türkay, 1999). Many coastal parts of this bay have been subjected to various forms of modification since the mid 1980's, such as infilling, reclamation, construction of sewage outlets thus affecting the system as a whole.

The samples obtained for the present study were collected from 2 transects located within a small tidal embayment, which lies within the south-western corner of Kuwait Bay, known as Sulaibikhat Bay (approx. 70 km^2)(Figure 2.5). It is bound from the north-west by Ras-Ushairij, and by Ras-Ajuza from the south-east. Most of this shoreline has been subjected to reclamation and infilling.

This chapter describes quantitatively the spatial and temporal changes in macrofauna over a full annual cycle at the sites referred to above, and results are related to prevailing environmental conditions.

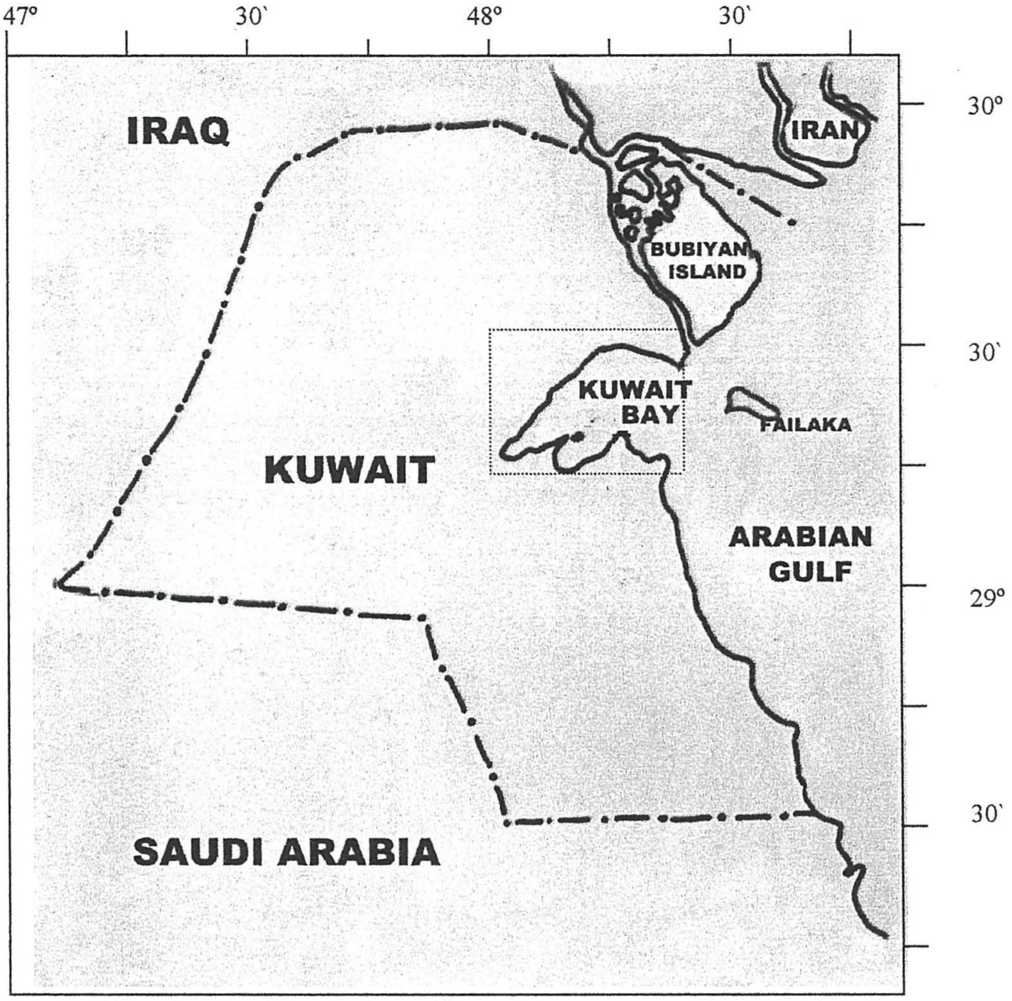


Figure 2.3 Location of Kuwait Bay along the Kuwaiti coastline.

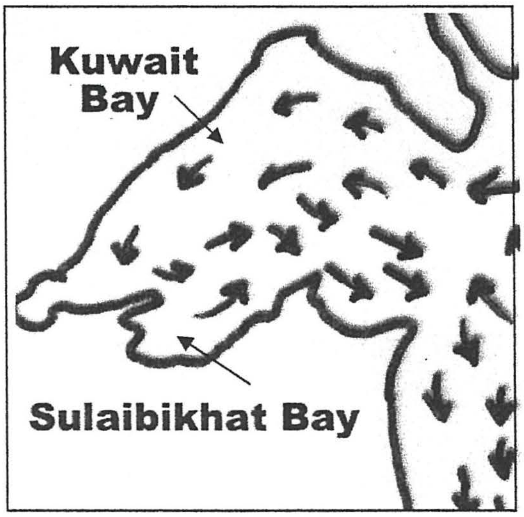


Figure 2.4 Surface current patterns within Kuwait Bay

(Source: Al-Sarawi *et al.*, 1985)

(a)

(b)

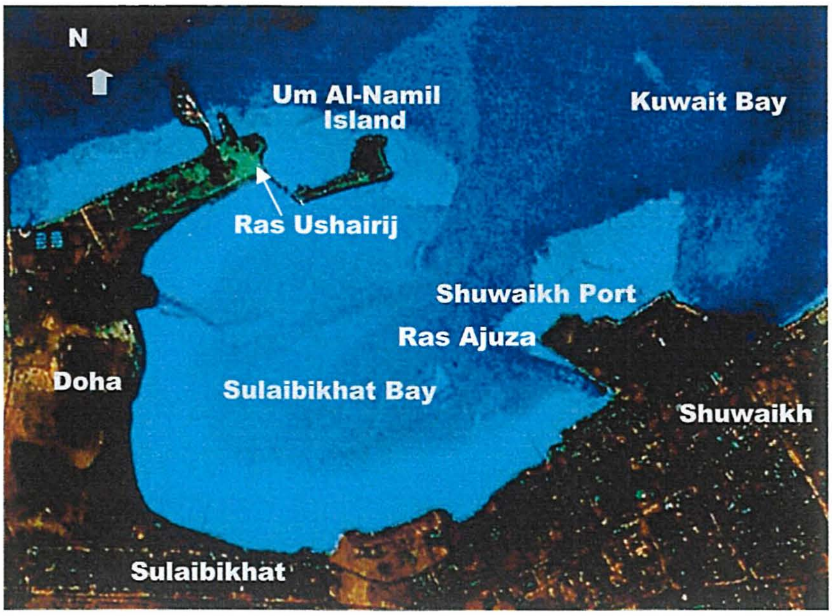


Figure 2.5 Satellite image of Sulaibikhat Bay

(Modified from KFAS, 1997)

(a) location in relation to Kuwait Bay

(b) surrounding areas

METHODOLOGY

Abiotic Survey

Transect profile

The mudflat habitat was examined using the transect method, where two lines at pre-determined distance from one another are extended at right angles to the shoreline from the low tide line to the upper portion of the flat within the bay. The low waterline is normally determined by marking the water level at the exact time of low tide. However, in the present case the low waterline was inaccessible due to the extreme width of the flat which extends several kilometres into the bay and the depth of the soft mud. Also as microbial mats are centred on the upper shore, the horizontal region from mean highest high water (MHHW) down to the highest accessible water-table (WT) was marked as the survey boundary (tidal height at TI: from 3.85m to 2.35m; TII: from 3.77m to 2.85m). Along each transect, poles were placed dividing the transect into 3 horizontal zones according to the visible characters of the habitat (distinctive zonation pattern). Vertical heights of the various zones within this transect, were measured using a surveying level and a pole marked at regular intervals, and calibrated by marking water levels at the exact time of the highest predicted tidal level on calm days with average atmospheric pressure. The profile was determined by subtracting the depth of the water on the poles from the highest predicted tidal level on that day, and plotting these values against the measured horizontal distance along the shore to estimate the gradual slope of the transect. As the transect sites selected are those used by Al-Zaidan, (1999) during the 3 month preliminary survey, the profiles were recalculated at other times of the year (January 2000) for further verification using the permanent transect markers installed during the 1999 study.

Physical parameters

Relevant physical and chemical measurements were taken upon arrival at the site bimonthly before commencing biotic sampling. Replicate determinations per zone (3x) for each of the factors were conducted to obtain reproducible results. The measurements recorded during the preliminary study (June-August 1998) have been incorporated into the data set collected during present fieldwork (September 98- June 99) to give a full annual data set so that environmental seasonal changes can be assessed. Arrival at each site always took place 30min. prior to the lowest predicted tidal level. Since the sites were sampled in consecutive days, there was approximately a 45-60min. difference in the sampling time at both sites, which will inevitably cause significant changes in the temperature recordings taken at both sites.

Temperature is considered to be one of the major physical factors that may affect biota causing alterations to the structure, composition and distribution of the aquatic community. Therefore a mercury thermometer with an accuracy of ± 0.5 °C was used to measure the air and water temperature upon arrival to the site. In addition, a digital thermocouple thermometer (model No. 8528-10 JTEK, Cole-Parmer Instrument Co., Chicago) was used to record the surface sediment temperature, as well as the temperature 15cm below mud surface and 25cm below the mud surface.

Although biota may show a certain degree of adaptation to changes in the salinity, some faunal species may respond to wide fluctuations by burrowing into the substratum or even migrating to escape severe changes in salinity. The water required to measure the intertidal salinity was obtained by digging a 15cm deep hole in the sediment allowing the water to seep up, then determining the salinity by measuring the refractive index of the sea water, which changes with increase in salinity, using a handheld refractometer read to the nearest part per thousand (‰)(KHALSICO., California).

Since most biota inhabiting the mudflats are burrowers, it is important to determine the acidity of the water and the sediment particularly in muddy environments which are subject to fluctuation. A handheld digital pH/millivoltmeter with an electrode was used to measure the mixture of water and sediment in water-filled pools. The electrode was calibrated with an appropriate standard (Buffer at the neutral pH value of 7) prior to obtaining the measurements. The probe was left in the mud/water mixture until the reading stabilised since it needed time to equilibrate.

Sediment particle-size analysis

Since the results of the 1999 preliminary study are incorporated with data of the current study, the results of the particle-size analysis mentioned in Al-Zaidan (1999) have been used. The robust and widely used particle-size fractionation method described by Buchanan & Kain (1971), which basically follows the Wentworth Scale, was used by Al-Zaidan (1999) in the preliminary study. However, these results have been recalculated using the new and most recent classification presented by Flemming (2000). This modified textural classification of sediments is made up of merging, modifying and expanding the classification schemes of Reineck and Siefert (1980) and Pejrup (1988) [in Flemming, 2000]. Accordingly, Flemming proposed 2 interrelated classification schemes: (a) a simple scheme based on mud/sand ratio (MS) (Figure 2.6, Table 2.4) where mud is classified as anything $< 62.5\mu m$ (mud = silt + clay), and (b) a more complex scheme based on the sand/silt/clay ratio (SSC) (Figure 2.7, Table 2.5). Determination of these sedimentary characteristics was undertaken during the study in order to relate the distribution of the major macrofauna to the sediment particle size.

Biotic survey

Quantitative biological sampling

Species distribution and abundance: The transect intersects all the vertical zones of the upper-shore biotic community, allowing full sampling of the macro-species composition. Since zonation can only be examined superficially by recording the position of surface organisms along a transect line which is marked at regular intervals, sediment extracts were obtained at pre-determined sampling stations along the transect. A $9.5 \times 10^{-3}\ m^3$ sample (area $\cong 0.05 m^2$; depth 0.15m) was removed at each station using a spade, and placed in a pre-labelled bucket. As the intertidal area stretches for several km into the bay it was difficult to reach the waters edge in order to wash samples, so each of the samples was transferred to the laboratory for further processing. In the laboratory the best method for separating the macrobiota from the mud was by sieving. Each sample was gently washed with water through a wire sieve with a mesh width of $500\mu m$. All organisms in the sample were then placed in pre-labelled polyethylene bags, and stored in a freezer for later analysis. After a sample was defrosted, it was placed in a petri-dish, and placed under a dissecting microscope for species identification and enumeration of the number of individuals of each species.

Some macrofaunal species were too large to be taken quantitatively in the sediment samples, and some were difficult to catch. Since these species have very distinctive and identifiable burrows, their frequency was calculated by counting the number of burrows present in a random sample. Three replicate counts of $9m^2$ quadrat were taken for each zone.

Co-efficient of Variation (CV) and Index of Dispersion (ID): To measure the relative variability in distribution when comparing between organisms collected using different units of quadrat, the co-efficient of variation was calculated: CV = standard deviation/mean, where higher values denote more variability. To measure dispersion of the organisms, Index of Dispersion was calculated, where ID = variance/mean [ID $\cong$ 1: random dispersion, ID $>$ 1: clumped, ID $<$ 1: regular]

Biomass: Ash-free dry weight determination was made for individual species and combined organisms at each station on each transect per month. After grouping individuals of the same species together, their wet weight was measured. Each group was then dried to constant weight in an oven at 60°C, and re-weighed to determine the dry weight. They were then placed in crucibles and incinerated in a muffle furnace at 450-500°C for 6h, and re-weighed. Biomass was determined as the difference between dry and ash weight: Biomass = dry wt (X) – ash wt (Y) (Coles and McCain, 1990).

Qualitative biological sampling

Visual observations are one of the most important tools used in the analysis of biological communities, providing they are carefully recorded. Across intertidal mudflats, many species are difficult to catch and collect. However they or their burrows may be readily identified by sight without the necessity of actual collection. Hence, the presence of some macrofauna (such as birds, crabs, mudskippers) on the transects and their numbers have been recorded on the basis of such "sight records" and by video recording. These direct observations are also a valuable source of information on the interrelations of different species and on the composition and boundaries of the biological communities within the mudflat habitat. These observations were either recorded in a logbook, or stored for analysis by video and audio recordings as well as by photography. Other specimens were collected by hand-net or by using baited fish traps (using shrimp or mullets as bait), and returned to the laboratory for study and identification. Due to the high air temperature and insulation levels, it was of critical importance to select the appropriate time of day and have a good supply of water and a source of shade, since during fieldwork air temperatures at 7am regularly reach 40°C.

As the soft mud rapidly became deep enough to trap a researcher, it was of crucial importance that at least two individuals, accompanied by a 4-wheel drive vehicle, were present during all aspects of the fieldwork. In addition, the location and timing of all field trips were recorded before hand at the university and communication by mobile phone was maintained.

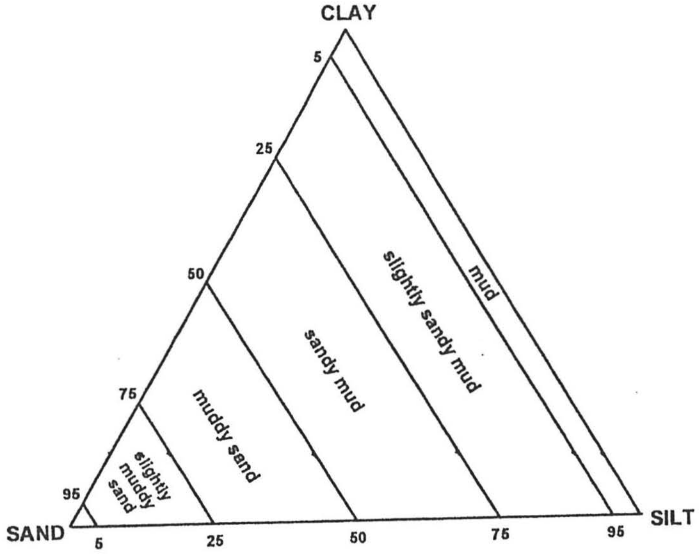


Figure 2.6 Ternary diagram for revised textural classification of sediments on the basis of sand/mud ratios (Source: Flemming, 2000).

Table 2.4 Descriptive terminology for the 6 textural classes based on mud content as defined in figure 2.6 (Source: Flemming, 2000).

Mud content (%)	Textural class
<5	Sand
5-25	Slightly muddy sand
25-50	Muddy sand
50-75	Sandy mud
75-95	Slightly sandy mud
>95	Mud

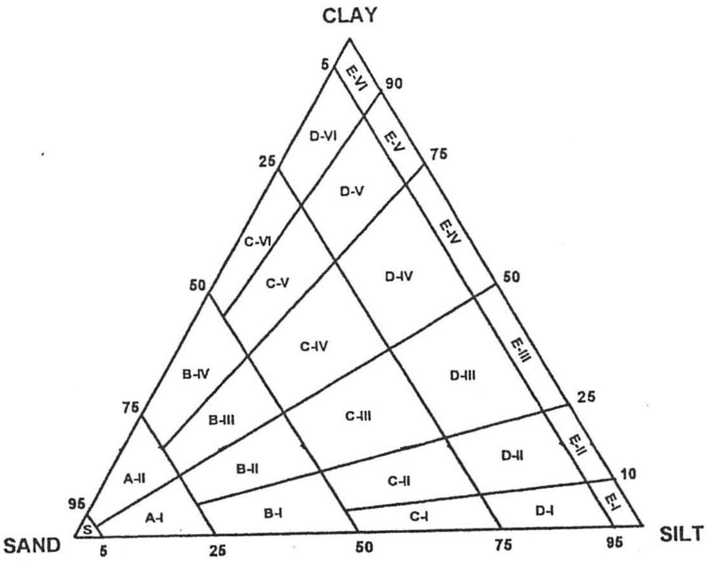


Figure 2.7 Ternary diagram for a revised textural classification of hydrodynamic subdivisions on the basis of sand/silt/clay ratios (Source: Flemming, 2000).

Table 2.5 Letter-number codes and descriptive terminology for the 25 textural classes based on sand/silt/clay ratios defined in figure 2.7 (Flemming, 2000)

Code	Textural class	Code	Textural class
S	Sand	**D-I**	Extremely silty slightly sandy mud
A-I	Slightly silty sand	**D-II**	Very silty slightly sandy mud
A-II	Slightly clayey sand	**D-III**	Silty slightly sandy mud
B-I	Very silty sand	**D-IV**	Clayey slightly sandy mud
B-II	Silty sand	**D-V**	Very clayey slightly sandy mud
B-III	Clayey sand	**D-VI**	Extremely clayey slightly sandy mud
B-IV	Very clayey sand	**E-I**	Silt
C-I	Extremely silty sandy mud	**E-II**	Slightly clayey silt
C-II	Very silty sandy mud	**E-III**	Clayey silt
C-III	Silty sandy mud	**E-IV**	Silty clay
C-IV	Clayey sandy mud	**E-V**	Slightly silty clay
C-V	Very clayey sandy mud	**E-VI**	Clay
C-VI	Extremely clayey sandy mud		

RESULTS

The physical values recorded during the bimonthly visits (spring and neap), as well as the results of the quantitative biological sampling were combined and the mean was calculated to give values on a monthly basis as no significant trend was noticed in relation to spring and neap tide.

Abiotic Survey

Transect profile

Location of the 2 transects undergoing the study is shown in figure 2.8. Profiles of transect I at Ashish Al-Doha (SI), and transect II at Sulaibikhat (SII), sampled during the study are shown in figures 2.9 and 2.10 respectively. Figure 2.11 represents the profiles of the two transects, Ashish Al-Doha (TI), and Sulaibikhat (TII) plotted against tidal levels and each other.

Transect I occurs at a site (SI: Ashish Al-Doha) that has not undergone any form of anthropogenic modification. Although the LT extends some 1.5-2km into the bay, the lowest accessible point was approximately 249m from marked high tidal level, a point above MHLW (at tidal level of 2.35m) (Figure 2.11).

In contrast transect II at Sulaibikhat (SII), is in an area where dumping and infilling appear to have occurred. Several items, mostly building material and remains of old buildings, makeup the infill material dumped onto the top of the shore. To access the shore, it was necessary to traverse the infill, dropping approximately 2.60m (Height of infill) to reach MHHW (3.77m). At this site the transect extended only 29.9m down the shore, a point approximately equivalent to WTL (water table level, 2.80m) (Figure 2.11).

Comparing both sites together, it was obvious that TI extends approximately 8 times further down into the bay than TII, nevertheless both transects cover the same tidal range (Figure 2.11). Zone I of TII overlaps with the highest point within the similar zone at TI, while zone II at the same transect overlaps with the mid and lower section of zone I at TI. At transect II, zone III overlaps with the upper and mid section of ZII at transect I. The lower section of ZII and the whole of ZIII at transect I are non-accessible at TII due to the nature of the sediment.

Predicted tidal levels: Appendix 2.1 shows the predicted tidal levels at the actual sampling day and the date of arrival at both sites. Figure 2.12 and 2.13 show the mean predicted tidal level (according to Al-Ojairey, 1998; 1999) during the sampling periods at both transects.

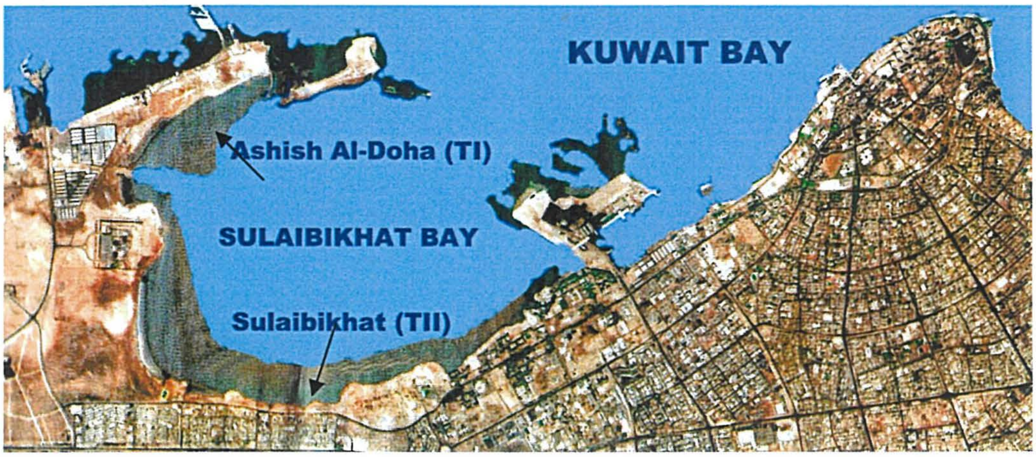


Figure 2.8 Sulaibikhat Bay, showing location of both transects: TI = Ashish Al-Doha, TII = Sulaibikhat.

Figure 2.9

Transect profile at Ashish Al-Doha site (a) view of the transect (b) diagram showing the profile & length of transect, location of rods and level of water during MHHW, and transect divisions into zones (ZI= zone 1, ZII = zone 2, ZIII = zone 3)(distance from track road = 50m; MHHW occurs at 0m distance from track road).

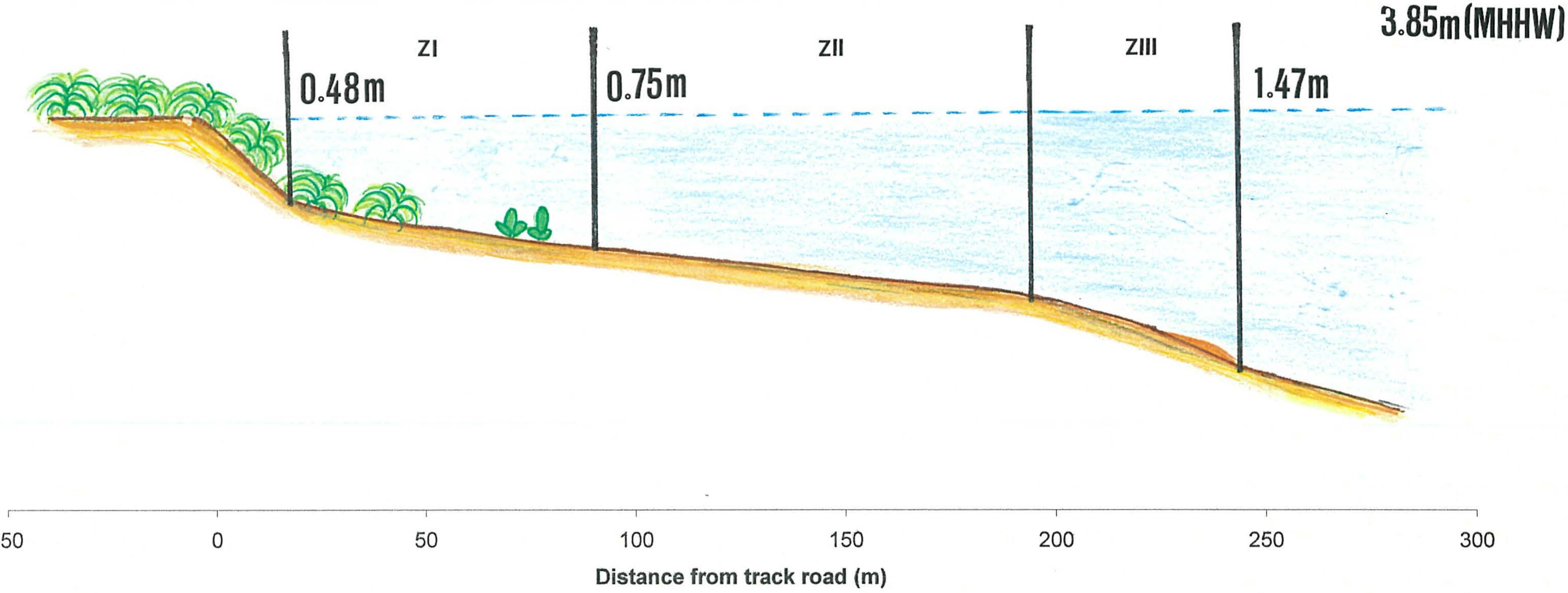
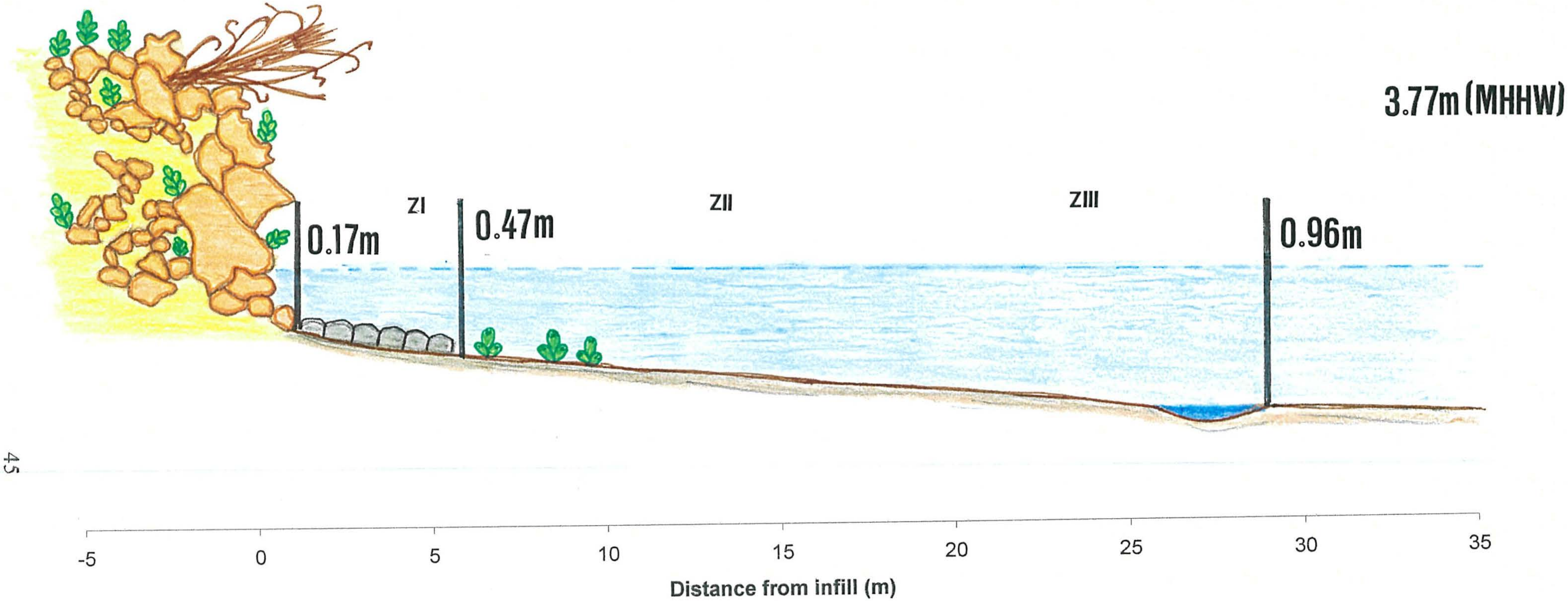

3.85m(MHHW)
ZI
ZII
ZIII
0.48m
0.75m
1.47m
-50
0
50
100
150
200
250
300
Distance from track road (m)

Figure 2.10

Transect profile at Sulaibikhat site (a) view of the transect (b) diagram showing the profile & length of transect, location of rods and level of water at MHHW, and transect divisions into zones (distance from infill = 0m; ZI= zone 1, ZII = zone 2, ZIII = zone 3).


3.77m (MHHW)
ZI
ZII
ZIII
0.17m
0.47m
0.96m
-5
0
5
10
15
20
25
30
35
Distance from infill (m)

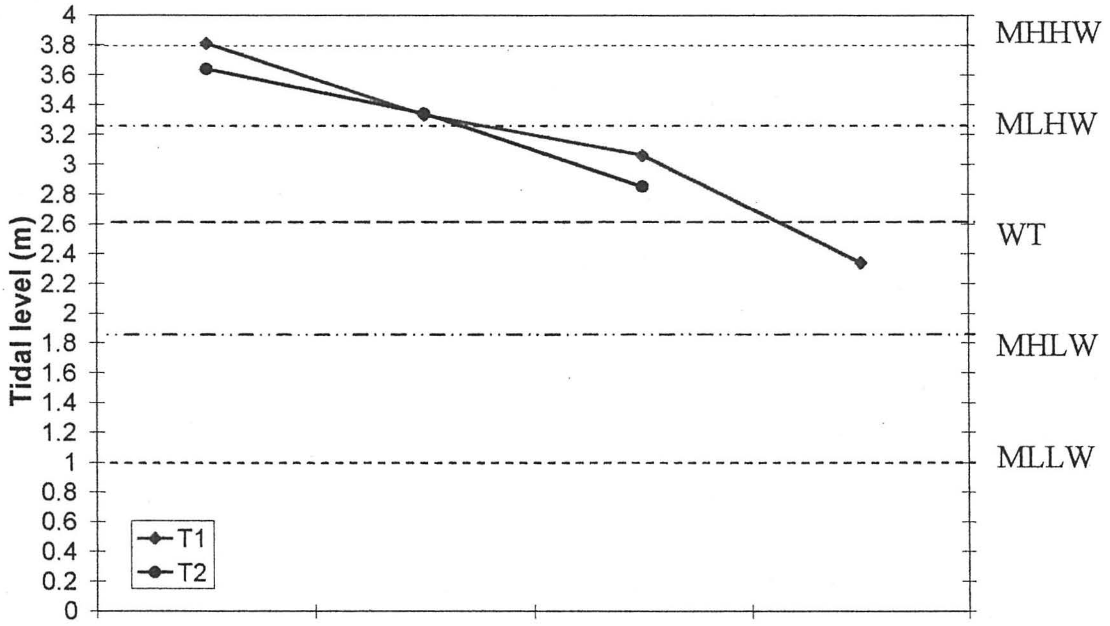


Figure 2.11 Comparison of both transects to tidal height and each other [T1: Ashish Al-Doha, T2: Sulaibikhat, MHHW: mean highest high water, MLHW: mean lowest high water, WT: water table, MHLW: mean highest low water, MLLW: mean lowest low water].

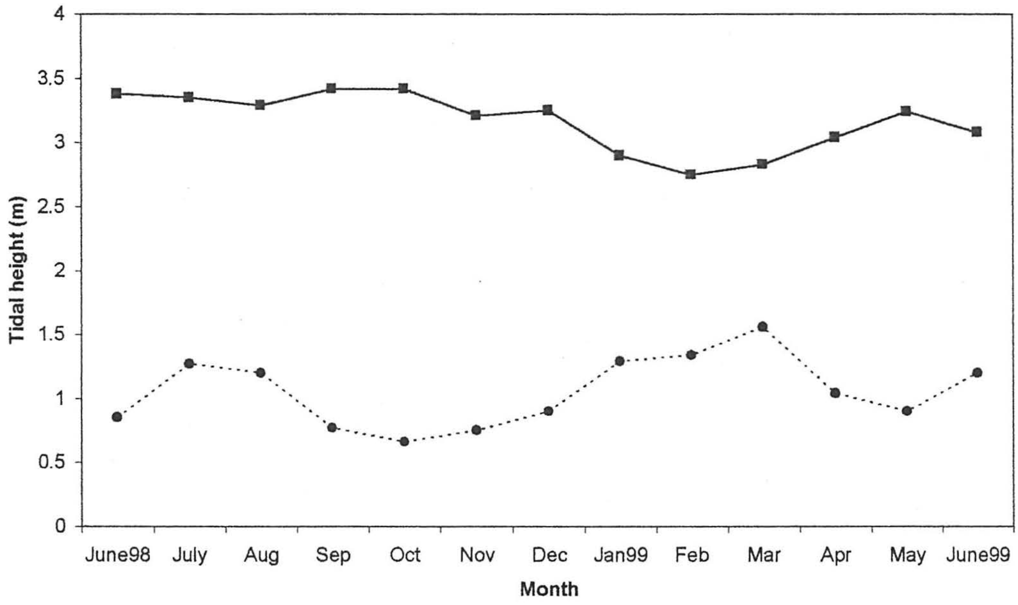


Figure 2.12 Mean predicted tidal level during sampling periods at Ashish Al-Doha site (TI)

(LT: ---●--- HT: —■—)

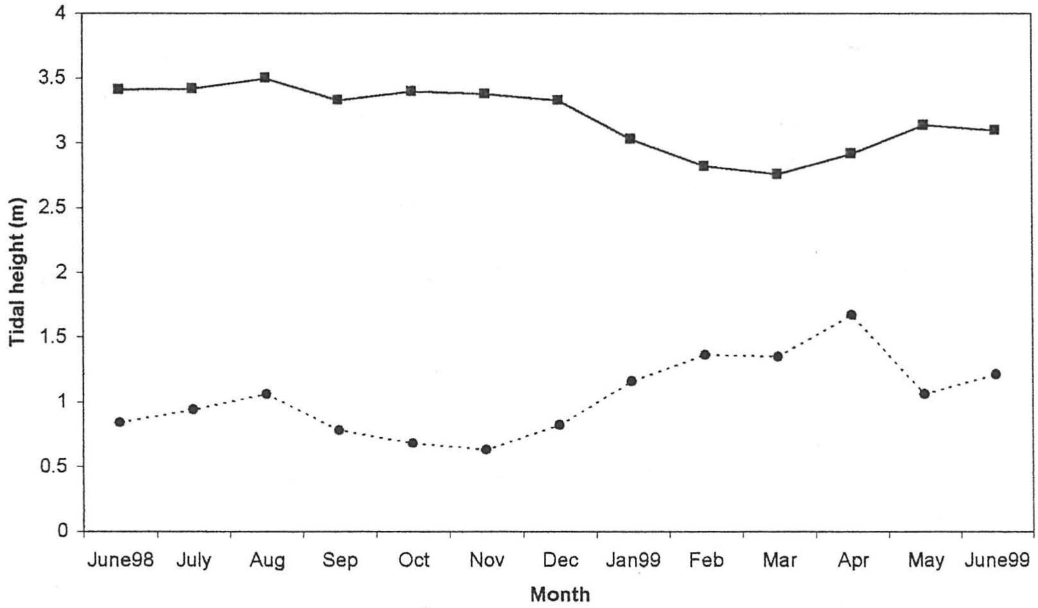


Figure 2.13 Mean predicted tidal level during sampling periods at Sulaibikhat site (TII)

(LT: ---●--- HT: —■—)

Physical parameters

Appendix 2.2 contain the actual temperature, salinity and pH recordings at both transects.

Figures 2.14 - 2.18 compare recorded air, sediment and pool water temperatures, salinity and hydrogen ion concentrations at both transects.

Air temperatures at both transects are somewhat similar (Figure 2.14), with the lowest recorded at both transects in December (TI: 17.5±0.22°C, TII: 16.0±0.00 ±°C). Highest air temperatures recorded at both transects were during June 99, which were higher than those recorded in June 98 (TI: 38.0±1.79°C and 31.0±0.45°C respectively; TII: 38.0±1.34°C and 31.50±0.22°C respectively). Sediment temperature for TI and TII is the mean of the measurements recorded from the surface (0cm), at 15cm depth and at 25cm depth at the different zones of each transect (Figure 2.15). The temperature of the sediment was always lower at TII than at TI. Both transects showed highest measured values during August 1998 (TI: 30.17±0.96°C, TII: 29.50±0.67°C), and lowest during the following December 98 (TI: 17.28± 0.29°C, TII: 15.67±0.48°C). At both transects, temperature at 25cm depth was higher than that measured at 15cm, and at the surface during summer season (25cm > 15cm > 0cm). Although during autumn the temperature at 25cm was higher than at 15cm, that recorded at 0cm was higher than the temperature at 15cm depth (25cm > 15cm < 0cm). During winter and spring, transect II sediment temperatures showed similar trends as summer, but at TI temperature measurements at 25cm were equal to or less than at 15cm and 0cm (25cm ≤ 15cm < 0cm). Pool water temperatures at both sites was at its lowest during December 1998 (TI: 15.17±0.44°C, TII: 14.33±0.44°C), and highest during June 1999 (TI: 28.17±0.17°C, TII: 26.67±0.17°C) (Figure 2.16). At TII the pool water temperature was usually lower than that at TI except during January 1999 when it was slightly higher (TI: 20.50±0.29°C, TII: 21.33±0.33°C). Both transects showed a lower recorded value than the surface seawater temperature recorded by EPA (Environment Public Authority) except in winter when present recordings were higher.

In general, almost all temperature recordings at both transects were highest during August 1998 and lowest during December of the same year, except for air and pool water temperature recordings which showed highest values during June of 1999. The temperature recordings during June 99 were always higher than those recorded during June of the previous year. All temperature recordings showed a dramatic decrease (approx. 3-6°C) in value after August 98, reaching lowest recorded values in December, after which the temperature values start to increase gradually till February 1999 when the temperature increases dramatically (approx. 2-4°C per month)

Intertidal salinity recordings at TII were always lower than those recorded at TI, and relatively higher at both sites than those recorded by EPA (Figure 2.17). Highest recorded salinity for TI & TII occurred during June 1999 (70.83±5.18‰ and 63.67±0.60‰ respectively), while the lowest was recorded during September for TI (51.33±2.62‰), and August for TII (44.67±1.92‰).

Figure 2.18 shows a comparison between the hydrogen ion concentrations (pH) of pool water measured at both transects. At both transects the pH value decreased from July 98 till September 98, after which it increased rapidly, and remained stable. The hydrogen ion value at TI remained below that for TII from August 98 to January 99.

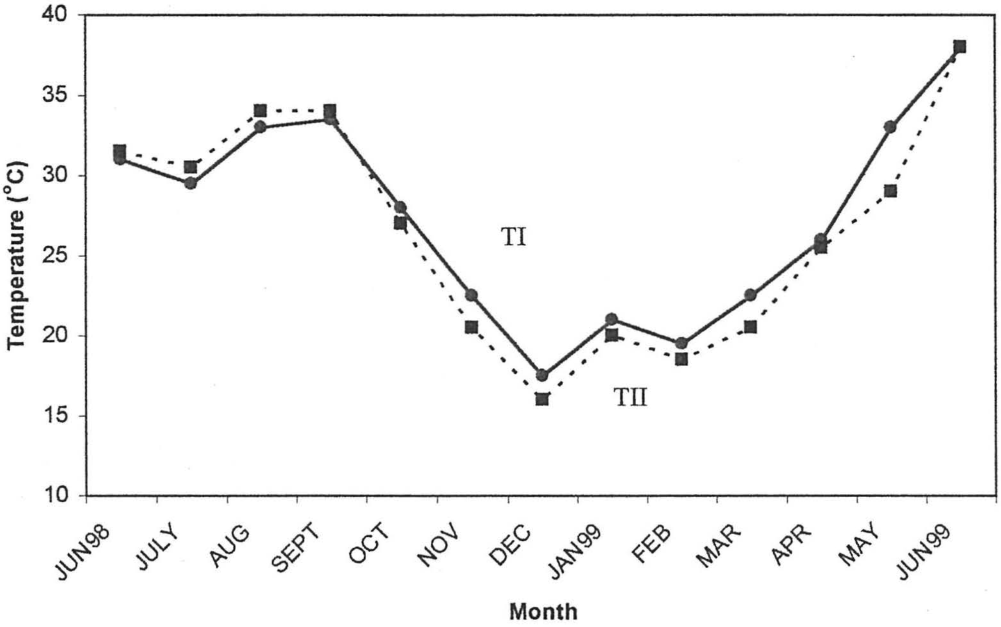


Figure 2.14 Air temperature recordings at both transects, TI: Ashish Al-Doha, TII: Sulaibikhat, from June 98 to June 99.

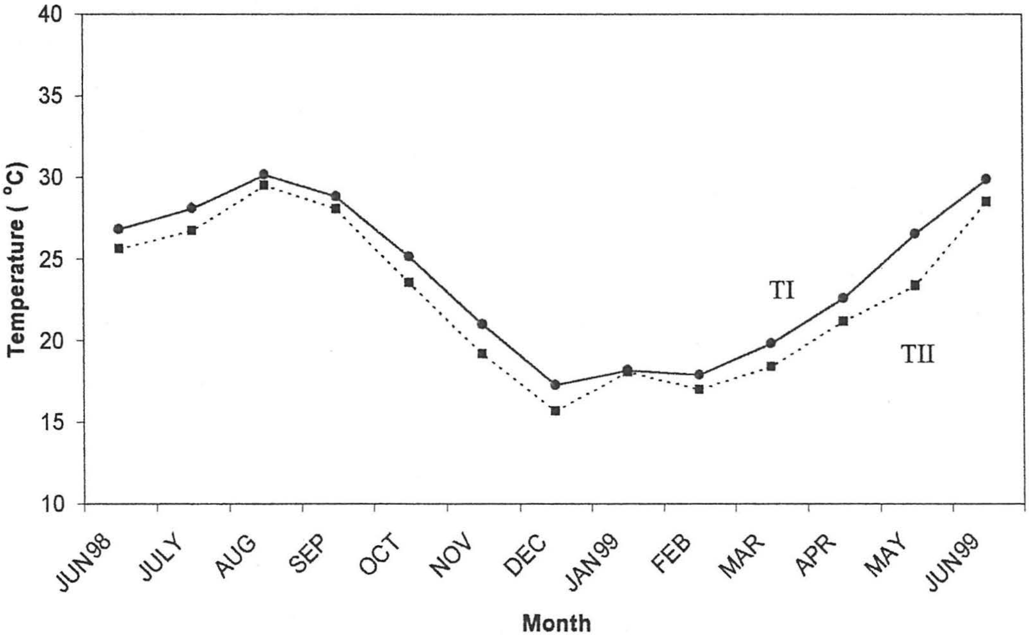


Figure 2.15 Mean sediment temperature recordings at both transects, TI: Ashish Al-Doha, TII: Sulaibikhat, from June 98 to June 99.

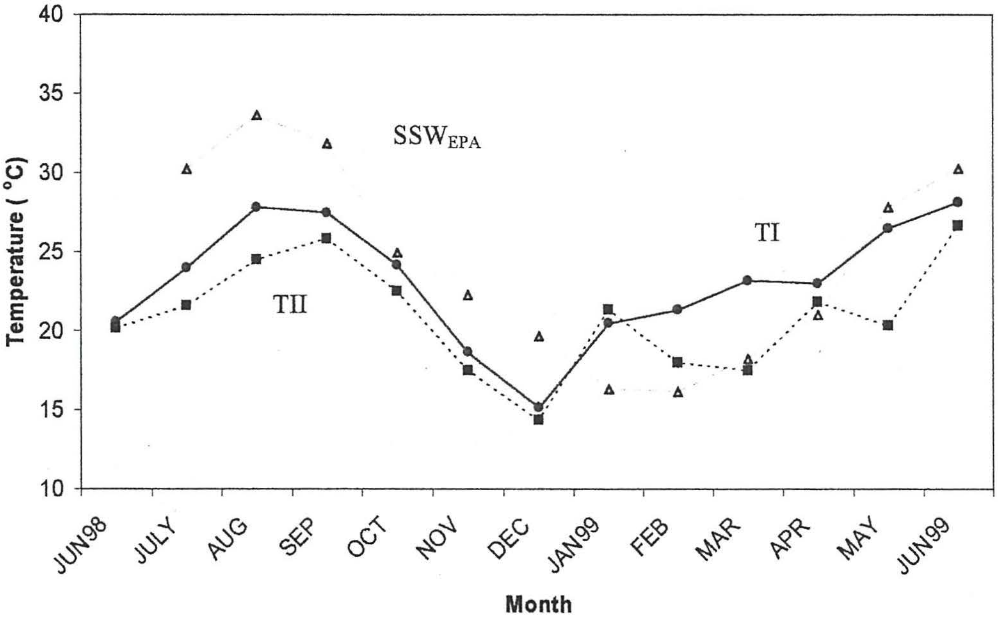


Figure 2.16 Pool water temperature recordings at both transects, TI: Ashish Al-Doha, TII: Sulaibikhat, from June 98 to June 99. SSW_{EPA}: recording of surface seawater temperature by Environmental Protection Authority.

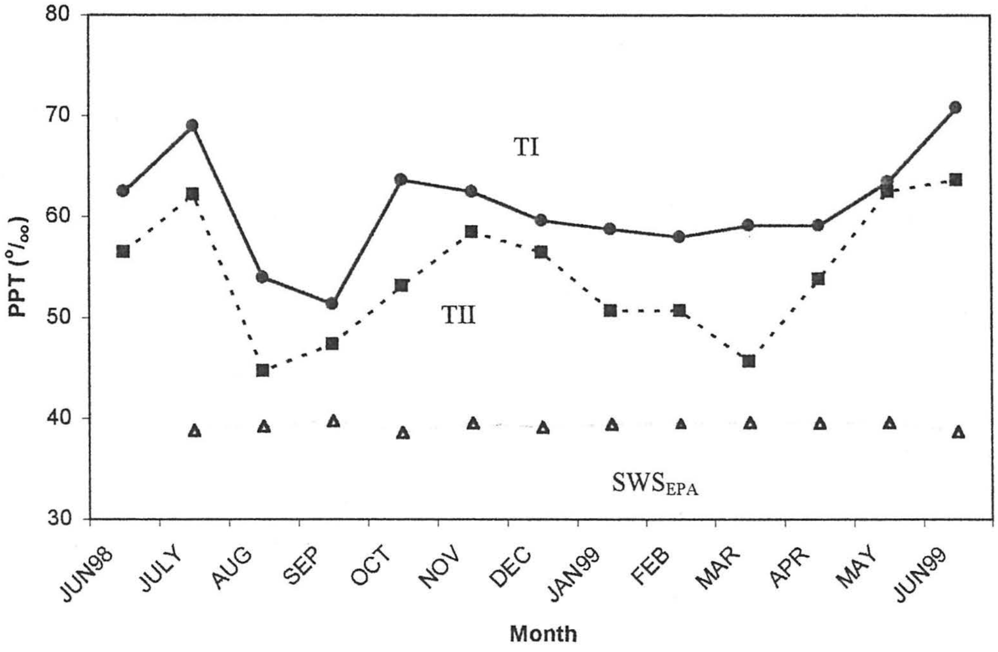


Figure 2.17 Intertidal salinity recordings at both transects, TI: Ashish Al-Doha, TII: Sulaibikhat, from June 98 to June 99. SWS_{EPA}: recording of seawater salinity by Environmental Protection Authority.

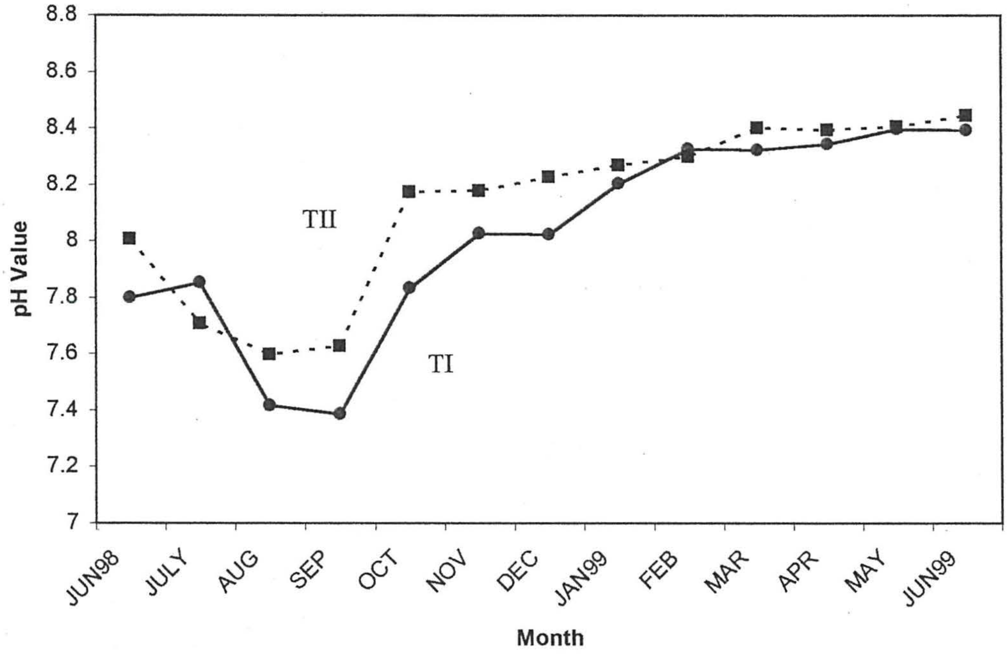


Figure 2.18 Hydrogen ion concentration (pH) of pool water at both transects, TI: Ashish Al-Doha, TII: Sulaibikhat, from June 98 to June 99.

Comparison between zones within each transect:

Figure 2.19A and A` illustrates the sediment surface temperature recordings at transect I and transect II respectively.

TI (Figure 2.19A): The highest recorded temperature at the 3 zones was during June 99 (ZI: 33.50±2.50°C, ZII: 32.0±2.0°C, ZIII: 33.0±3.0°C, Mean: 32.83±0.44°C), while the lowest recorded was during December (ZI: 18.0±0.0°C, ZII: 17.5±0.5°C, ZIII: 16.00±0.0°C, Mean: 17.17±0.60°C). In general, temperature recordings at ZI are always 0.5-2.5°C higher than recordings at ZII, however the same can not be said for Zone III, since in some cases it revealed similar (October: ZI & ZII 26.50±4.50°C) or slightly higher values to those at ZI (July 98: ZI= 27.0±3.00°C and ZIII= 27.50±1.50°C; January 99: ZI= 21.50±0.5°C and ZIII= 22.50±0.5°C; February: ZI= 21.50±0.5°C and ZIII= 23.00±0.0°C; March: ZI= 23.50±1.50°C and ZIII= 24.50±1.50°C). Temperature of the sediment surface at zone II is usually lower than or similar to measurements made at ZIII, except during June 98, August, September and December when values were higher than those at ZIII (25.5±0.50°C & 22.0±0.0°C; 28.0±0.0°C & 27.0±1.0°C; 29.50±1.50°C & 29.0±2.0°C; and 17.50±0.50°C & 16.0±0.0°C).

TII (Figure 2.19A`): the highest recorded values for the 3 zones were during June 1999 (ZI: 30.00±2.00°C; ZII: 30.50±1.50°C; ZIII: 31.50±1.50°C, Mean: 30.67±0.44°C), while the lowest were during December 1998 (ZI: 15.00±1.00°C; ZII: 15.00±0.0°C; ZIII: 14.50±0.50°C, Mean: 14.83±0.17°C). Temperature values at Zone I were often higher than those recorded at ZII and ZIII, except during certain months where the values were either equal (June 98: ZI & ZII= 25.0±0.0°C; September: ZI, ZII & ZIII= 27.50 ±0.5, 1.50 & 2.50°C respectively; October: ZI & ZIII= 24.50±3.50 & 4.50°C respectively; December: ZI & ZII= 15.00±0.0 & 0.50°C respectively; April 99: ZI & ZIII= 23.00±3.0 & 2.0°C respectively) or slightly lower than those recorded at ZII or/and ZIII (January 99: 0.5°C less than ZII; March: 1°C less than ZII and ZIII; May: 0.5°C less than ZII and ZIII; June 99: 0.5°C less than ZII and 1.5°C less than ZIII). Zone II showed higher recorded sediment surface temperature values than ZIII during June 98 (0.5°C↑), July (1.0°C↑), December (0.5°C↑), January 99 (0.5°C↑) and March (1.0°C↑). However, During October, November, February 99, April and June 99, zone II had lower values than zone III (23.00±4.0°C, 1.5°C↓; 19.5±0.5°C, 0.5°C↓; 18.50±4.50°C, 1.0°C↓; 22.50±2.5°C, 0.5°C↓; and 30.50±1.50°C, 1.0°C↓), and similar values during August September and May 99 (28.50±0.5°C; 27.50±1.50°C; and 23.50±0.5°C respectively).

Figure 2.19B and B` show the sediment temperature at 15cm depth for both TI and TII respectively.

TI (Figure 2.19B): the highest temperature recorded at the 3 zones at transect I was during August 98 (ZI: 31.00±0.0°C; ZII: 30.00±1.0°C; ZIII: 29.50±0.5°C, Mean: 30.17±0.44°C), the lowest was during February 99 (ZI: 16.50±0.5°C; ZII: 16.0±0.0°C; ZIII: 15.0±0.0°C, Mean: 15.83±0.44°C). Recorded temperature at ZII was always 0.5-2°C lower than at ZI, except during December 98 and January 99 when it was similar to records at ZI (18.50±0.5°C and 17.0±1.0°C respectively). During most of the months sampled, zone III revealed lower temperatures than zone I (difference ranging between 0.5-3°C) except in June 99 where it was 0.5°C higher than ZI (29.50±2.50°C). Temperatures at zone II were frequently higher than those at zone III, except during certain months when they were lower (July: 27.50±1.50°C, 0.5°C↓; October: 23.50±4.5°C, 0.5°C↓; November: 18.50±1.5°C, 1.0°C↓; June 99: 28.50±1.5°C, 1.0°C↓), or similar to (September: 27.50±1.0°C; May99: 23.0±2.0°C) recordings at ZIII.

TII (figure 2.19B`): During August 98 the highest temperature values were recorded for the 3 zones (ZI: 29.5±0.5°C; ZII: 28.5±0.5°C; ZIII: 28.5±0.5°C, Mean: 28.83±0.33°C), however February 99 had the lowest recorded values (ZI: 16.5±1.5°C; ZII: 15.5±1.5°C; ZIII: 15.5±1.5°C, Mean: 15.83±0.33°C). Generally, temperatures at zone II were lower than at zone I with a difference range of 0.5-1.0°C, except during June 98 and December and January 99 when similar values to those recorded at zone I was recorded (25.0±0.0°C; 15.50±1.0°C and

16.50±0.5°C respectively). During most months ZIII showed lower values than ZI except in October (23.0±5.0°C), December (16.0±1.0°C) and March 99 (18.0±0.0°C) when values were 0.5°C higher than ZI, and in November and April when values were similar to those recorded at the same zone (18.50±0.5°C and 20.50±2.0°C). Recordings at zone II were often equal to those made for zone III. Nevertheless, during June 98, July, September and January 99 temperature values were higher (25.0±0.0°C, 1.5°C↑; 26.50±1.5°C, 1.0°C↑; 28.0±0.0°C, 0.5°C↑ and 16.50±0.5°C, 1.0°C↑ respectively), lower during October, November, December and April 99 (22.0±4.5°C, 1.0°C↓; 18.0±0.0°C, 0.5°C↓; 15.50±0.5°C, 0.5°C↓ and 19.50±2.50°C, 1.0°C↓ respectively).

Recordings of sediment temperature at 25cm depth for transect I and transect II are shown in Figures 2.19C and 2.19C` respectively.

TI (Figure 2.19C): the highest recorded temperature was during August 98 (ZI: 32.50±0.5°C, ZII: 31.50±1.50°C, ZIII: 31.50±0.5°C, Mean: 31.83±0.33°C). During February 99 the lowest value was recorded (ZI: 16.0±0.0°C, ZII: 15.50±0.5°C, ZIII: 15.50±0.5°C, Mean: 15.67±0.17°C). Values recorded at zone I were always higher than those recorded at zone II. However the same can not be said for ZIII, since during October (25.50±4.50°C), March (18.00±1.0°C), April (21.0±1.0°C) and June 99 (28.00±1.0°C) recorded values were similar to recordings at ZI. Throughout the annual sampling, the temperature recordings at zone II were either 0.5°C higher or equal to those recorded at zone III.

TII (Figure 2.19C`): highest recorded temperature at this transect was in August 98 (ZI: 31.50±0.50°C, ZII: 31.00±1.00°C, ZIII: 30.00±1.00°C, Mean: 30.83±0.44°C) while the lowest recorded was in January 99 (all zones: 16.00±0.00°C). Temperature values recorded at zone II and zone III were always lower than those recorded at zone I, except during November and February when ZIII was equal to ZI (19.50±0.50°C and 16.50±0.50°C respectively), and during October and March when both ZII and ZIII had higher values than those for ZI (ZII: 24.00±4.00°C, 0.5°C↑; ZIII: 24.50±4.50°C, 1°C↑ and ZII & ZIII:

18.00±0.00°C, 0.5°C↑ respectively). Zone III frequently had lower temperature values than ZII except in October and February when values were 0.5°C higher than recordings at ZII.

Pool water temperature records for TI and TII are illustrated in figure 2.19D & D` respectively.

TI (Figure 2.19D): During December 98 the lowest temperature values were recorded (ZI: 16.00±0.0°C, ZII: 15.00±0.0°C, ZIII: 14.50±0.50°C, Mean: 15.17±0.44°C), while the highest were recorded during June 99 (ZI: 28.50±0.50°C, ZII: 28.00±0.0°C, ZIII: 28.00±0.0°C, Mean: 28.17±0.17°C). Zone II was either lower than or equal to recorded values at zone I, except during July and October when it was higher than ZI (24.00±3.00°C, 0.5°C↑ and 24.50±4.50°C, 1.0°C↑respectively). Temperature values at ZIII were frequently lower than or equal to those recorded at ZI, however during July (24.50±4.50°C, 1.0°C↑), October (24.50±4.50°C, 1.0°C↑), November (19.00±1.00°C, 0.50°C↑) and February 99 (22.00±0.00°C, 1.0°C↑) the values were 0.5-1.0°C higher than those recorded at ZI. When comparing ZII to ZIII, it is evident that values were always similar to if not lower than recordings at ZIII.

TII (Figure 2.19D`): Lowest recorded values were during December (ZI: 15.00±2.00°C, ZII: 14.50±1.50°C, ZIII: 13.50±150°C, Mean: 14.33±0.44°C) while the highest were during June 99 (ZI: 26.50±0.50°C, ZII: 26.50±0.50°C, ZIII: 27.00±0.00°C, Mean: 26.67±0.17°C). Most temperature recordings at ZII were lower than recordings at ZI, except during September, October, January and February when an increase, ranging between 0.5-1.5°C, was detected (26.00±1.00°C, 1.5°C↑; 22.50±4.50°C, 0.5°C↑; 22.00±1.00°C, 1.0°C↑and 18.00±4.00°C. 0.5°C↑ respectively). During the whole of the study, ZIII had only 3 recordings where temperature was lower than values at ZI (July: 21.25±3.75°C, 0.75°C↓; December: 13.50±1.50°C, 1.5°C↓ and May: 19.50±3.50°C, 2.0°C↓). Temperature values at zone III were usually higher than values recorded at zone II except during July, November, December, January and May (21.25± 3.75°C, 0.25°C↓; 17.50±0.50°C equal to ZII; 13.50±1.50°C, 1.0°C↓, 21.00±2.00°C, 1.0°C↓ and 19.50±3.50°C, 0.5°C↓ respectively)

Figure 2.19E & E\` shows the variation in salinity at transect I and transect II respectively.

TI (Figure 2.19E): The lowest salinity values measured were during September (ZI: 5.50±7.50‰, ZII: 52.00±6.00‰, ZIII: 46.50±3.50‰, Mean: 51.33±2.62‰), while the highest were in June 99 (ZI: 81.00±6.00‰, ZII: 67.50±11.50‰, ZIII: 64.00±6.00‰, Mean: 70.83±5.18‰). Zone I always had highest salinity values when compared with ZII and ZIII. The highest difference of 38%o in salinity between ZI and ZII was detected during July 98 (ZI: 97.5±42.70‰, ZII: 59.50±15.5‰). This difference gradually decreases to reach a minimum of 0.5%o during November (ZI: 66.50±‰1.50, ZII: 65.00±0.00‰), then gradually increases to reach a difference of 14%o in June 99. The difference between salinity recordings at ZI and ZIII ranged between 7-47.5%o. During July 98 the difference between the salinity values of both zones reached its highest (ZI: 97.50±42.50‰, ZIII: 50.0±12.0‰, difference: 47.5‰). The salinity difference then shows decreasing fluctuations till march 99, after which a gradual increase was noticed. Salinity recordings made at zone II were always higher than ZIII.

TII (Figure 2.19E\`): lowest mean salinity for the 3 zones was recorded during August 98 (ZI: 48.50±2.50‰, ZII: 43.00±1.00‰, ZIII: 42.50±1.5‰, Mean: 44.67±1.92‰), while the highest was recorded during June 99 (ZI: 62.50±7.50‰, ZII: 64.50±6.50‰, ZIII: 64.00±9.00‰, Mean: 63.67±0.60‰). Zone II always had values less than those of ZI except in November, January, February, May and June 99 where values were higher (59.50±1.50‰, 1.5‰↑; 52.50±2.50‰, 4.5‰↑; 62.50±7.50‰, 0.5‰↑ and 64.50±6.50‰, 2.0‰↑ respectively). Salinity values at ZIII were also mostly lower than those recorded at ZI except in November when they were similar (58.00±2.00‰), and during January (51.50±1.50‰), May (63.00±8.00‰) and June 99 (64.00±9.00‰), when they were higher by 4.5 %o, 1%o and 1.5%o respectively. Comparison of salinity recordings at ZII with those made at ZIII, show that recordings at zone II were always higher than or equal to recordings at ZIII, except during June 98, December and May when values were less (54.50±2.50‰, 2.5‰↓; 56.00±0.0‰, 0.5‰↓ and 62.50±7.50‰, 0.5‰↓ respectively).

Monthly variation in hydrogen ion concentration at TI and TII are represented in Figure 2.19F & F` respectively.

TI (Figure 2.19F): Recordings of pH at this transect show a decreasing trend from June 98 till September; then increase dramatically during October after which they were more or less constant. During June 98-September 98, values recorded at the 3 zones are similar. However, from October onwards a slight difference was seen between the zones, ZI had lower values than ZII, and zone III always showed the highest values.

TII (Figure 2.19F`): the same trends as seen in transect I occurred on this transect.

In summary, sediment surface temperature at transect II decreases down the shore, however at transect I, recorded temperature at zone I was greater than zone II, but measurements at zone III were equal to or greater than ZII (ZI > ZII ≤ ZIII). At both transects, temperatures at 25cm and 15cm below sediment surface were highest at ZI decreasing seawards down the intertidal gradient. Generally, sediment temperatures were highest during summer and lowest during winter. Both salinity and pH values recorded at both transects decreased with intertidal gradient. Both salinity and pH were highest during summer, however during winter salinity was lowest, while pH was lowest during autumn.

Figure 2.19

Physical and chemical parameters recorded within each of the 3 zones [Zone I —●— ; Zone II ---▲-- ; Zone III —■—] on each transect:

(A) Sediment surface temperature at the 3 zones within TI, and TII (A`)

(B) Temperature 15cm below sediment surface at 3 zones within TI, and TII (B`)

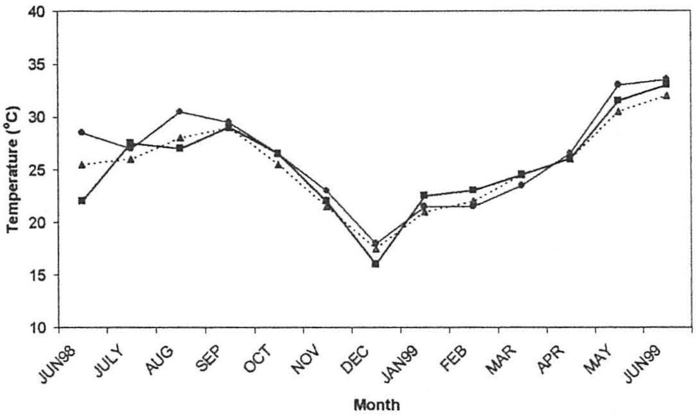
(C) Temperature 25cm below sediment surface at 3 zones within TI, and TII (C`)

(D) Temperature of water in pools at 3 zones within TI, and TII (D`)

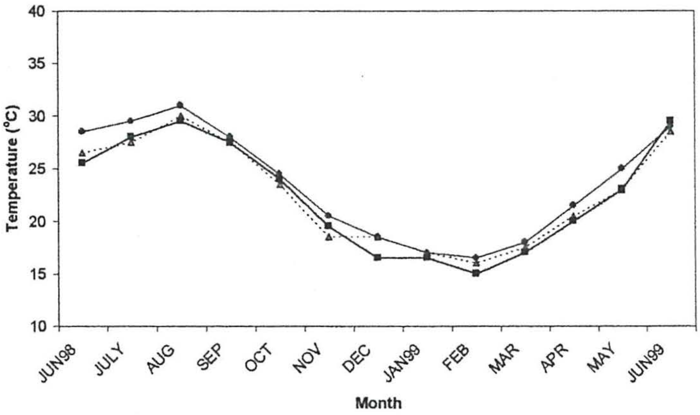
(E) Intertidal salinity at 3 zones within TI, and TII (E`)

(F) Hydrogen ion concentration at 3 zones within TI, and TII (F`)

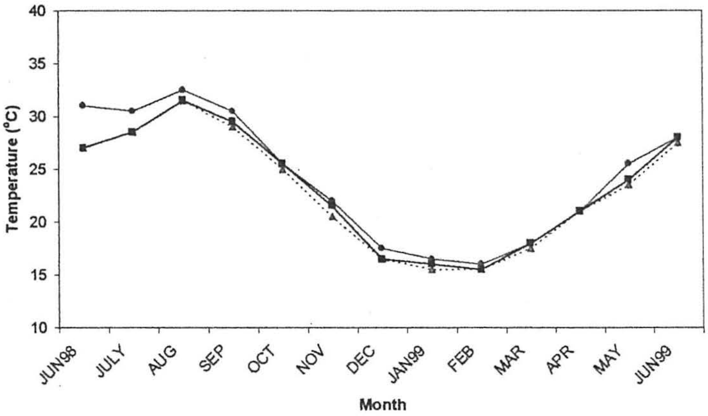
TI


40
35
30
25
20
15
10
Temperature (°C)
JUN98
JULY
AUG
SEP
OCT
NOV
DEC
JAN99
FEB
MAR
APR
MAY
JUN99
Month

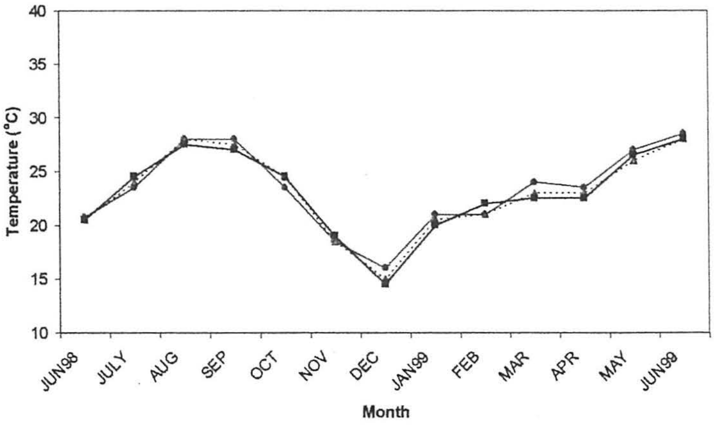
(A)


40
35
30
25
20
15
10
Temperature (°C)
JUN98
JULY
AUG
SEP
OCT
NOV
DEC
JAN99
FEB
MAR
APR
MAY
JUN99
Month

(B)

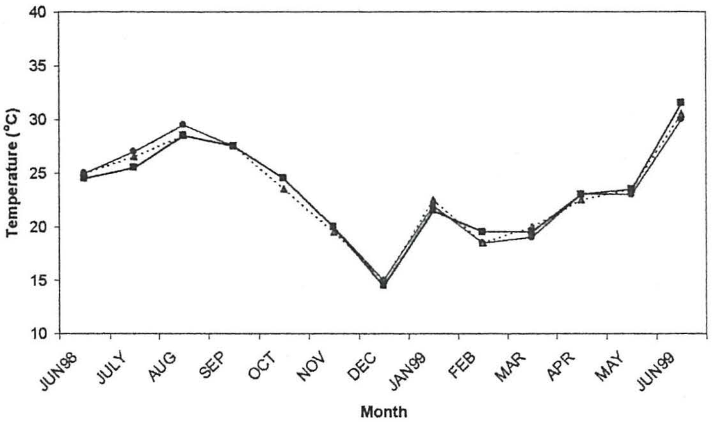

40
35
30
25
20
15
10
Temperature (°C)
JUN98
JULY
AUG
SEP
OCT
NOV
DEC
JAN99
FEB
MAR
APR
MAY
JUN99
Month

(C)

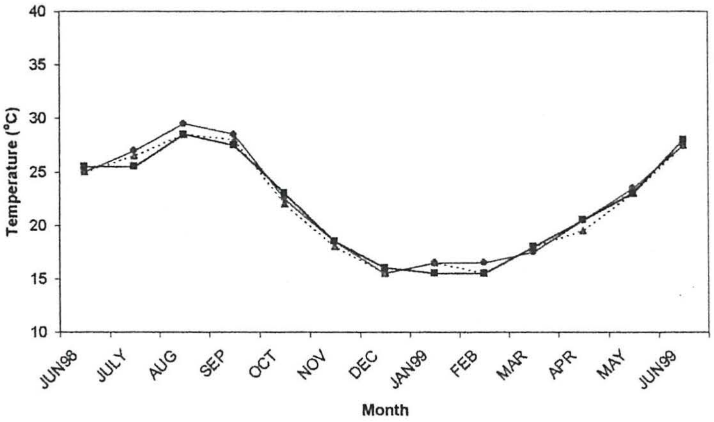

40
35
30
25
20
15
10
Temperature (°C)
JUN98
JULY
AUG
SEP
OCT
NOV
DEC
JAN99
FEB
MAR
APR
MAY
JUN99
Month

(D)

TII


40
35
30
25
20
15
10
Temperature (°C)
JUN98
JULY
AUG
SEP
OCT
NOV
DEC
JAN99
FEB
MAR
APR
MAY
JUN99
Month

(A`)


40
35
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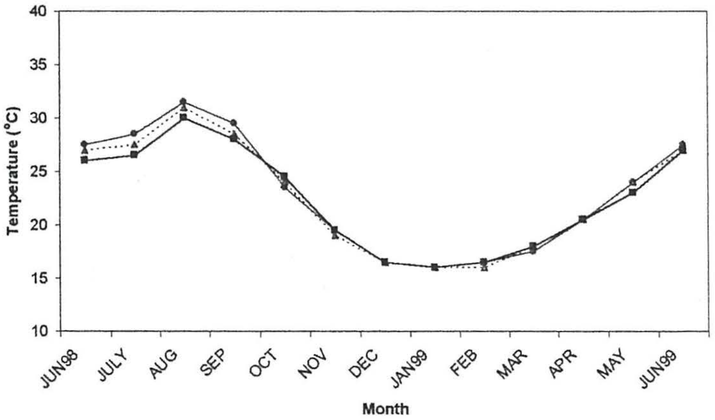
25
20
15
10
Temperature (°C)
JUN98
JULY
AUG
SEP
OCT
NOV
DEC
JAN99
FEB
MAR
APR
MAY
JUN99
Month

(B`)


40
35
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20
15
10
Temperature (°C)
JUN98
JULY
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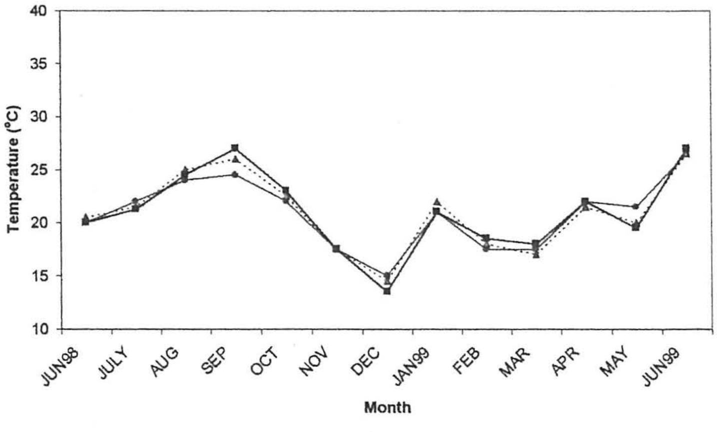
OCT
NOV
DEC
JAN99
FEB
MAR
APR
MAY
JUN99
Month

(C`)


40
35
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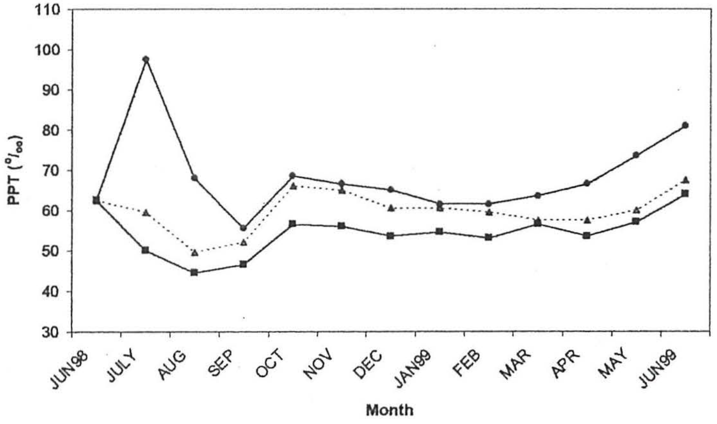
25
20
15
10
Temperature (°C)
JUN98
JULY
AUG
SEP
OCT
NOV
DEC
JAN99
FEB
MAR
APR
MAY
JUN99
Month

(D`)

TI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60
50
40
30
JUN98
JULY
AUG
SEP
OCT
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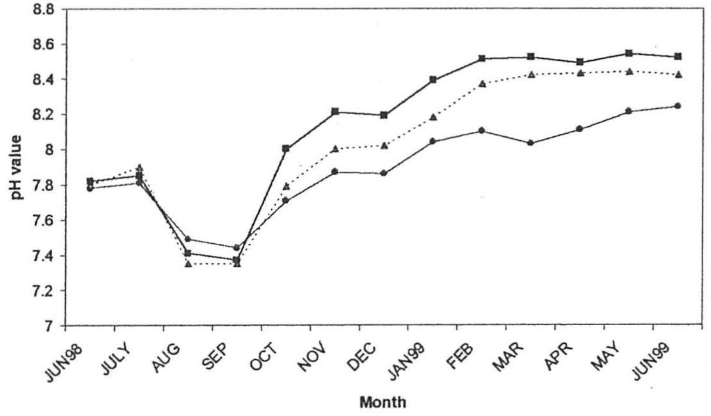
DEC
JAN99
FEB
MAR
APR
MAY
JUN99
Month

(E)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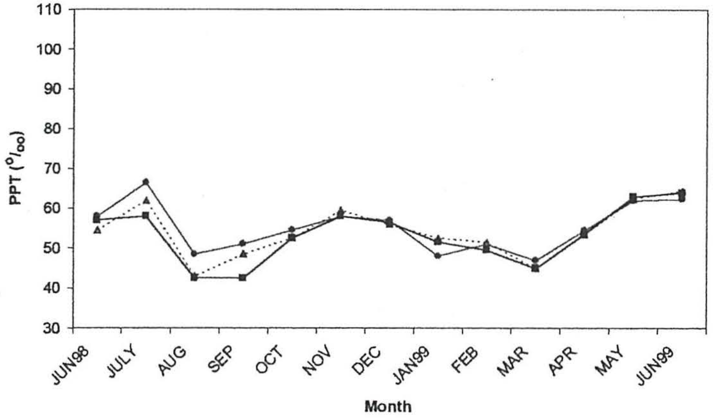
8.2
8
7.8
7.6
7.4
7.2
7
JUN98
JULY
AUG
SEP
OCT
NOV
DEC
JAN99
FEB
MAR
APR
MAY
JUN99
Month

(F)

TII


PPT (°/oo)
110
100
90
80
70
60
50
40
30
JUN98
JULY
AUG
SEP
OCT
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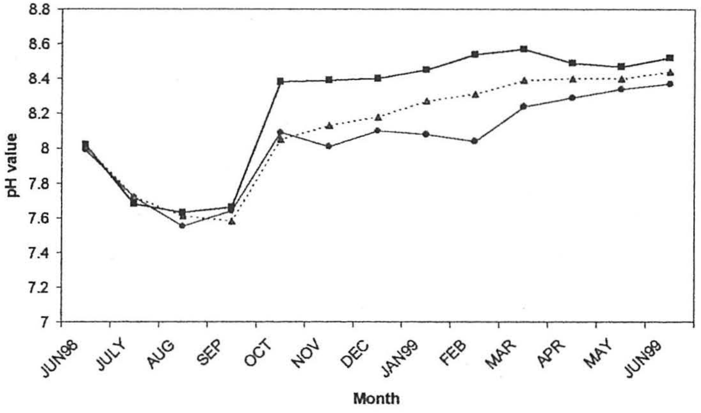
MAR
APR
MAY
JUN99
Month

(E`)


pH value
8.8
8.6
8.4
8.2
8
7.8
7.6
7.4
7.2
7
JUN98
JULY
AUG
SEP
OCT
NOV
DEC
JAN99
FEB
MAR
APR
MAY
JUN99
Month

(F`)

Sediment particle-size analysis

Appendix 2.3 shows the summary of the sedimentary characteristics of both transects, with the sediment texture classified according to the Wentworth scale. The modified textural classification of the sediment at both transects is summarised in Table 2.6.

According to the mud/sand ratio (MS), transect I is dominated by sand rather than mud, hence it being classified as muddy sand (35.82% mud), with zone I being the muddiest zone (52.27% mud = sandy mud). However, transect II is dominated by mud (66.12% mud) and accordingly classified as sandy mud, with zone III the muddiest zone of the 3 zones sampled (83.45% mud = slightly sandy mud).

When classifying the sediments according to the sand/silt/clay ratio (SSC), it appears that TI is classified as sand of a slightly silty nature, while the classification of transect II is more complex and accordingly termed as very silty sandy mud.

Table 2.6 Summary of textural classification of the sediment at transect I and II according to Flemming 2000, based on values presented in Appendix 2.3. MS ratio= Mud/Sand ratio, values between brackets indicate the percentage of mud; SSC ratio= Sand/Silt/Clay ratio, symbols in brackets represent the textural index.

	Transect I (Ashish Al-Doha)				**Transect II (Sulaibikhat)**			
	ZI	**ZII**	**ZIII**	**Mean**	**ZI**	**ZII**	**ZIII**	**Mean**
MS ratio	Sandy mud (52.27%)	Muddy sand (32.40%)	Slightly muddy sand (22.64%)	Muddy sand (35.82%)	Sandy mud (52.22%)	Sandy mud (57%)	Slightly sandy mud (83.45%)	Sandy mud (66.12%)
SSC ratio	Silty sandy mud (CIII)	Very Silty sand (BI)	Slightly silty sand (AI)	Very silty sand (BI)	Extremely silty sandy mud (CI)	Extremely silty sandy mud (CI)	Very silty slightly sandy mud (DII)	Very silty sandy mud (CII)

Biotic survey

Quantitative biological sampling

Species distribution and abundance: Appendix 2.4 details the infaunal abundance of the major species found in the bimonthly samples from the period June 98-June 99, on the different zones at both transects.

Four brachyuran species (*Tylodiplax indica*, *Ilyoplax stevensi*, *Nasima dotilliformis*, *Manningis arabicum*) and a gastropod (*Cerithidea cingulata*) dominated the sediment extract samples. The mean monthly abundance of total infaunal species found within the sediment extract at both transects I and II are shown in figure 2.20.

Tylodiplax indica

Mean monthly abundance of this species on the 3 zones as well as the mean monthly abundance ($\bar{x}$ of 3 zones) at transect I and II are shown in figures 2.20A and 2.20A` respectively.

TI: The monthly mean abundance of *Tylodiplax indica* on this transect was highest during February 99 (27.9 ± 21.6/0.05m^2), while the lowest abundance was during May 99 (11.39 ± 7.94/0.05m^2). Generally, highest abundance of this species occurred at zone II (36 ± 4.25/0.05m^2), while the lowest occurred at zone I (1.01± 0.43/0.05m^2). On ZI, the highest recorded abundance value was during June 99 (4.67 ± 3.0/0.05m^2), but this crab was frequently absent throughout most of the sampling periods (June 98-August 98; October 98-December 98, and May 99). On zone II highest abundance was during February 99 with a value of 71.0 ± 16.05/0.05m^2, however during July 98 the lowest abundance was recorded (15.0 ± 5.20/0.05m^2). The lowest intertidal zone sampled, (ZIII), had the highest abundance during August 98 (20.50 ± 7.58/0.05m^2), and the lowest during June 98 (0.67 ± 0.25/0.05m^2).

TII: the highest monthly mean abundance occurred during May 99 (5.50 ± 5.01/0.05m^2), however the crab was absent during June 98 – July 98, September 98 and March 99. Zone I shows the highest abundance (3.38 ± 1.30/0.05m^2), followed by ZIII (0.69 ± 0.45/0.05m^2). This crab reached 15.50 ± 6.50/0.05m^2 during May 99 at zone I, but was absent during June 98 – July 98, September 98 and March 99. No individuals were found at ZII during any of the sampling months. The highest value recorded at ZIII was in June 99 (5.50 ± 4.50/0.05m^2), and crabs were absent in June 98 – December 98, and February 99 till April 99.

Ilyoplax stevensi

Mean monthly abundance of this species on the 3 zones as well as the mean monthly abundance at transect I and II are shown in figure 2.20B and 2.20B` respectively.

TI: the highest mean abundance on this transect was recorded during February 99 with a value of 5.94 ± 3.62/0.05m^2, while the lowest was recorded during October 98 (1.22 ± 0.68/0.05m^2). Zone II had the highest mean abundance value for *I. stevensi* (6.02 ± 1.06/0.05m^2), followed by ZIII (2.51± 0.38/0.05m^2) then ZI (0.24 ± 0.14/0.05m^2). For zone I, the highest value of 1.83 ± 1.83/0.05m^2 was recorded during February 99, while the crab was absent during June 98-August98, October98 – December 98, March99, and April 99. At Zone II, the highest value for *Ilyoplax stevensi* was during February 99 (13.17 ± 3.53/0.05m^2), with the lowest during August 98 (1.33 ± 0.67/0.05m^2). During January 99, the highest abundance value was recorded at ZIII (6.17± 2.52/0.05m^2), and the lowest value for the same zone was recorded during November 98 (0.50± 0.22/0.05m^2).

TII: a high of 8.00 ± 1.26/0.05m^2 was recorded during June 99 for this transect. During October 98 a low of 1.0 ± 0.29/0.05m^2 was recorded. In general, ZI had highest abundance (7.54 ± 1.28/0.05m^2). This value gradually decreased at ZII (2.62 ± 0.58/0.05m^2) and reached lowest value (1.58 ± 0.53/0.05m^2)on ZIII. During January 99, the highest abundance of *I. stevensi* was recorded for ZI (17.0 ± 1.0/0.05m^2), whilst the lowest occurred during July 98 (1.0 ± 1.0/0.05m^2). Zone

II peaked at 7.0 ± 0.00/0.05m^2 during June 99, and a low abundance of 0.5 ± 0.5/0.05m^2 was recorded during October 98. The highest abundance at ZIII occurred in June 99 (6.50 ± 1.50/0.05m^2), but crabs were absent during August 98- September 98 and March 99.

Nasima dotilliformis

Mean monthly abundance of this species on 3 zones as well as the mean monthly abundance at transect I and II are shown in figure 2.20C and 2.20C` respectively.

TI: a value of 0.99 ± 0.92/0.05m^2 represents the highest abundance of *N. dotilliformis* which was recorded during March 99, however it was absent during august and September 1998. It was absent from zone III and was rare on ZI (0.23 ± 0.13/0.05m^2), and the highest mean abundance was recorded at ZII (0.73 ± 0.22/0.05m^2). During February 99, a high of 1.50 ± 1.50/0.05m^2 was recorded for zone I, but was absent during June 98-November 98, January 99 and April 99.The highest recorded abundance at ZII was during March (2.83 ± 2.26/0.05m^2), but this species was absent during June 98, August-September 98, and June 99. No individuals where found in the quadrat extracts taken at zone III during any of the months sampled.

TII: at this transect, the highest abundance was recorded during June 99 (1.67 ± 0.88/0.05m^2), while the crab was absent during September 98, November 98, and February 99- March 99. The mean abundance of this species gradually decreased further down the transect, with ZI having the highest value of 1.27 ± 0.64/0.05m^2, followed by ZII (0.58 ± 0.27/0.05m^2), and the lowest value of 0.08 ± 0.00/0.05m^2 occurring at ZIII. At zone I, the highest abundance value of 8.50 ± 8.50/0.05m^2 was recorded during October 98, but the crab was absent in July 98, September 98, and from January 99 till March 99. During June 99, the highest abundance was recorded for ZII (3.0 ± 3.0/0.05m^2), although the crab was absent during most of the sampling periods (August 98 – December 98, February 99- April 99). Only during June 98 did *Nasima* occur at ZIII (1.00 ± 1.00/0.05m^2).

Cerithidea cingulata

Mean monthly abundance of this gastropod on the 3 zones as well as the mean monthly abundance at transect I is shown in figure 2.20D.

TI: mean monthly abundance on this transect was lowest during November 98 (0.56± 0.56/0.05m^2), while peaked during June 99 reaching an abundance of 7.90 ± 7.90/0.05m^2. At both zone I and zone II, *C. cingulata* was absent, but it occurred at ZIII with an abundance of 10.37 ± 2.02/0.05m^2. During June 99, the highest abundance of 23.7 ± 12.8/0.05m^2 was recorded at zone III, and the lowest recorded value on the same zone was in November 98 (1.67 ± 1.48/0.05m^2). No cerithids were found in the sediment extracts obtained from any of the 3 zones at **TII**.

The rare infaunal brachyuran crab, *Manningis arabicum*, was occasionally found at TI, but was never found at TII. At transect I, it was confined to ZIII, with highest recorded abundance during July 98 (2.0 ± 2.0/0.05m^2), and was absent during the period from September 98-January 99 and from March 99- June 99.

Figure 2.20

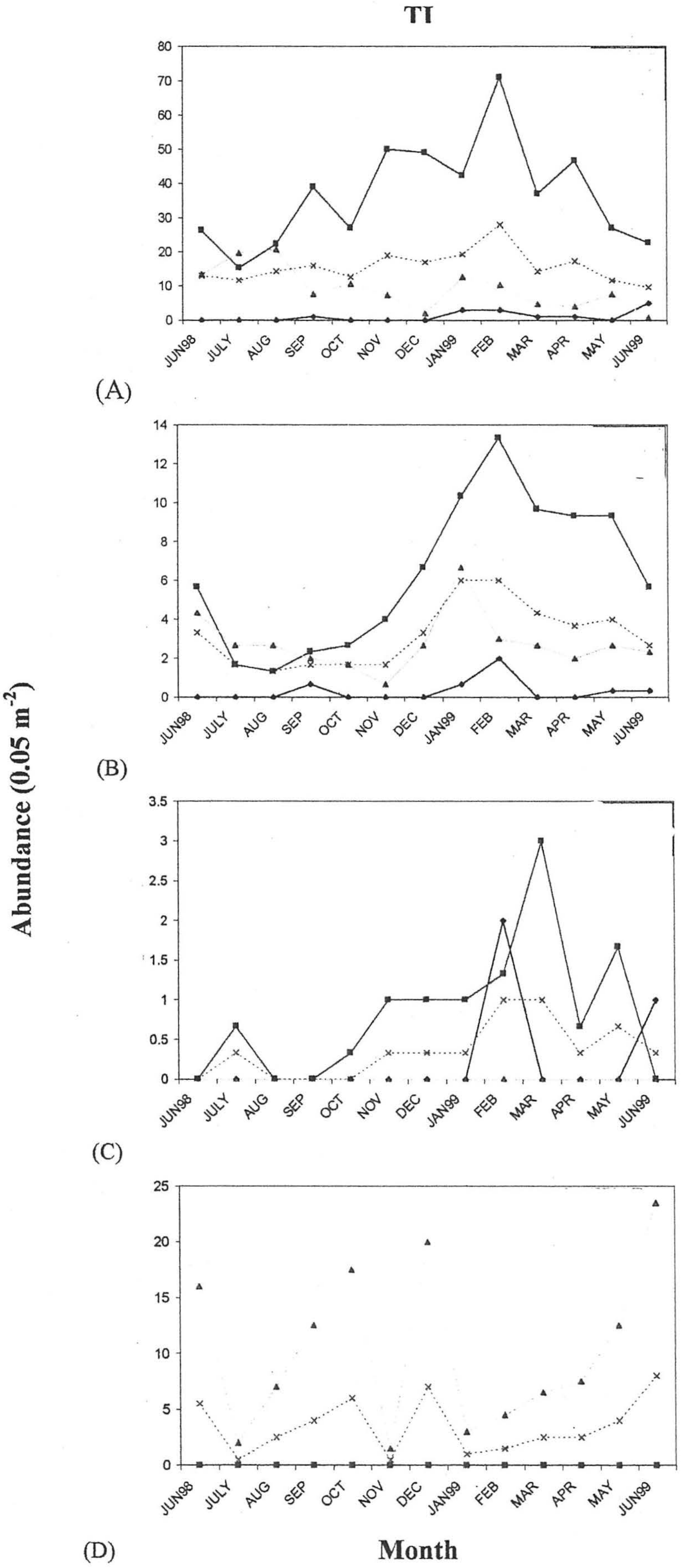
Abundance of dominant infaunal species obtained using a $0.05m^{-2}$ quadrat to a depth of 15cm, within each of the 3 zones [—◆— zone I; —■— zone II; ·····△····· zone III; - - -X- - transect mean] sampled at each transect:

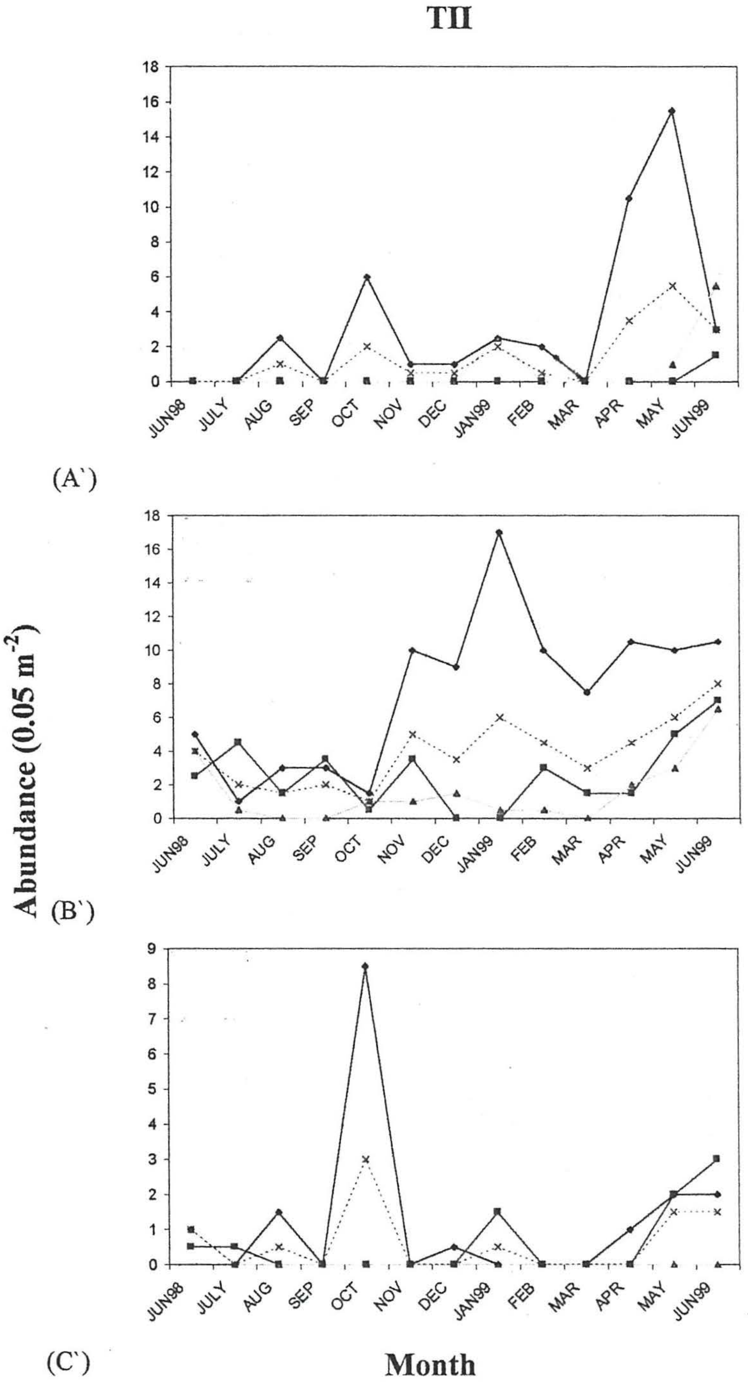
(A) Mean abundance of *Tyodiplax indica* at TI, and TII (A`)

(B) Mean abundance of *Ilyoplax stevensi* at TI, and TII (B`)

(C) Mean abundance of *Nasima dotilliformis* at TI, and TII (C`)

(D) Mean abundance of *Cerithidea cingulata* at TI.


TI
80
70
60
50
40
30
20
10
0
JUN98
JULY
AUG
SEP
OCT
NOV
DEC
JAN99
FEB
MAR
APR
MAY
JUN99
(A)
14
12
10
8
6
4
2
0
(B)
3.5
3
2.5
2
1.5
1
0.5
0
(C)
25
20
15
10
5
0
(D)
Abundance (0.05 m-2)
Month


TII
18
16
14
12
10
8
6
4
2
0
JUN98
JULY
AUG
SEP
OCT
NOV
DEC
JAN99
FEB
MAR
APR
MAY
JUN99
(A')
Abundance (0.05 m-2)
(B')
9
8
7
6
5
4
3
2
1
0
(C')
Month

Appendix 2.5 show abundance of macrofaunal species during each of the sampling periods. Three macrofaunal species were assessed for abundance via burrow counts in a $9m^{-2}$ within the 3 zones on both transects: the ocypodid *Leptochryseus kuwaitense*, and two gobies *Periophthlamus waltoni* and *Boleophthlamus boddarti* (Figure 2.21).

Leptochryseus kuwaitense

Figure 2.21A illustrates the mean abundance of this species on transect I. On **TI** the lowest abundance of 11.06 ± $11.10/9m^2$ was recorded during June 98, while the highest abundance was recorded during August 98 with a value of 24.30 ± $24.30/9m^2$. Zones II and III were devoid of *L. kuwaitense*, with ZI having an abundance of 50.71 ± $2.46/9m^2$. The highest recorded value at ZI was during August 98 (72.83 ± $9.55/9m^2$), while the lowest occurred in June 98 (33.17 ± $6.96/9m^2$). *Leptochryseus kuwaitense* was absent from all zones on **TII**.

Periophthalmus waltoni

Monthly abundance of this goby on the 3 zones at both transects is shown in Figures 2.21B and 2.21C.

On **TI** mean abundance was at its highest during August 98 with a value of 30.7 ± $17.10/9m^2$, and the lowest during June 98 (9.50 ± $3.38/9m^2$). The lowest value was recorded at ZIII (3.81± $0.29/9m^2$), followed by ZI with a mean abundance of 11.22 ± $1.59/9m^2$. The highest value recorded was at ZII with a mean of 56.19 ± $4.42/9m^2$. At zone I, the highest value was recorded during August 98 (27.2 ± $17.2/9m^2$), while the lowest occurred during July 98 (2.83 ± $1.56/9m^2$). During September 98 a high of 75.0 ± $37.0/9m^2$ was recorded for ZII, while the lowest was during July 98 with a value of 14.33 ± $3.95/9m^2$. For zone III, a high mean of 5.83 ± $0.54/9m^2$ was recorded in January 99, with the lowest value occurring during April and May 99 (2.67 ± $0.88/9m^2$)

On **TII** the highest mean monthly abundance (406.5 ± 45.1/9m^2) was recorded in January 99, while the lowest was recorded during June 98 (170.0 ± 4.38/9m^2). Abundance of *P. waltoni* decreases lower down the shore, with highest abundance at ZI (399.5± 27.4/9m^2), and the lowest at ZIII (264.1 ± 17.1/9m^2). During January 99, the highest abundance was recorded at ZI (486.0 ± 27.0/9m^2), but this decreased during June 98 in the same zone (177.0 ± 45.0/9m^2). Similarly, the highest abundance of 403.5 ± 1.50/9m^2 was recorded during January 99 for zone II, while the lowest was recorded during July 98 (133.5 ± 61.5/9m^2). At zone III, the highest abundance was also during January 99 (330.0± 15.0/9m^2), whilst the lowest was during July 98(121.5± 58.5/9m^2).

Boleophthlamus boddarti

Figure 2.21D shows the abundance of this mudskipper on the 3 zones at transect I. On **TI** highest abundance was 5.61 ± 2.85/9m^2 during October 98, while the lowest mean abundance occurred in June 99 at 2.67 ± 1.33/9m^2. The highest mean occurrence was at ZIII with a value of 6.17 ± 0.53/9m^2, followed by ZII (5.99 ± 0.39/9m^2), with the lowest abundance (0.08 ± 0.05/9m^2) recorded at ZI. At zone I, highest abundance was in August 98 (0.67 ± 0.67/9m^2), and absent from September 98 till June 99. During November 98, a high of 7.67 ± 1.09/9m^2 was recorded at ZII, while a low of 4.00 ± 0.52/9m^2 was recorded during June 99. The highest mean abundance of 9.33 ± 2.03/9m^2, for zone III, was recorded in October 98, with the lowest being 3.50 ± 2.08/9m^2 occurring July 98. *Boleophthalmus boddarti* did not occur in any of the 3 zones sampled on **TII**.

Figure 2.21

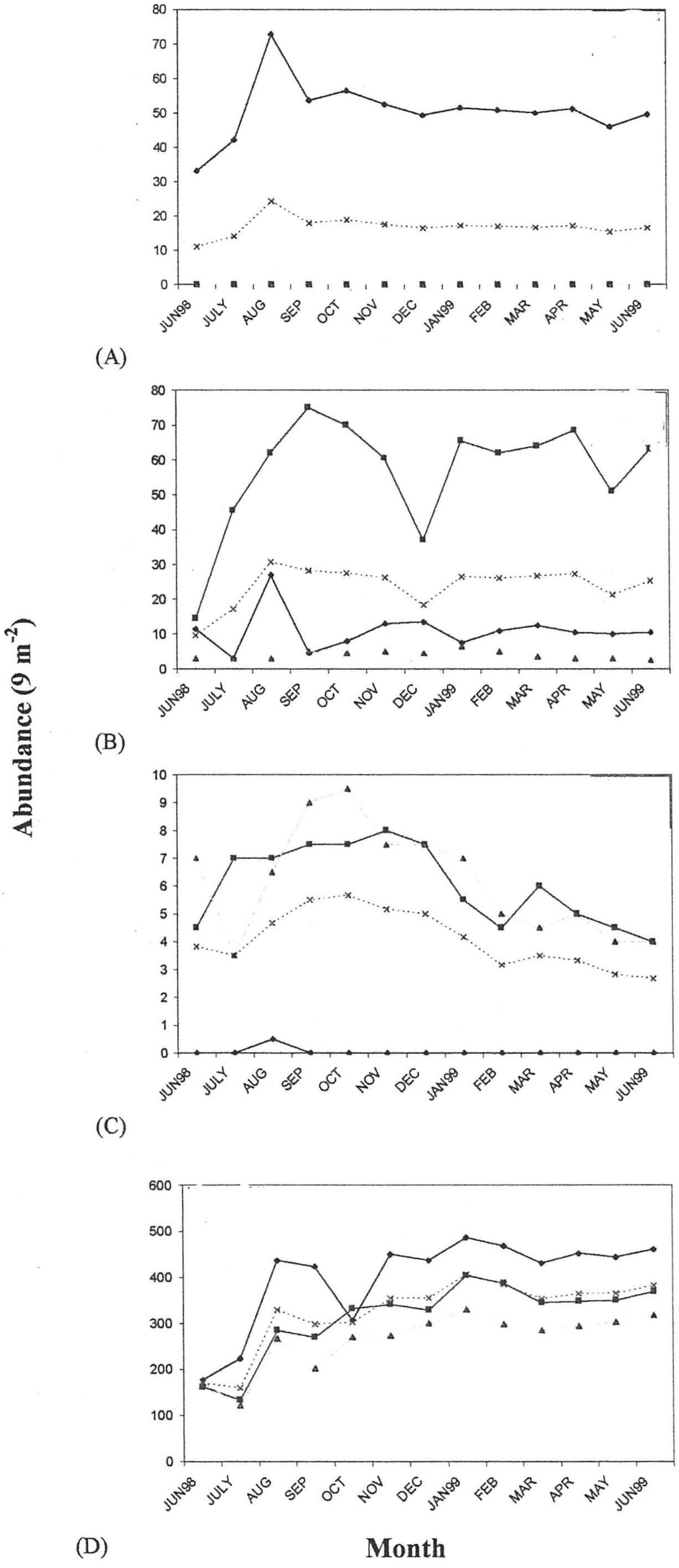
Abundance of dominant infaunal species obtained by calculating number of burrows in a $9m^{-2}$ quadrat, within each of the 3 zones [—◆— zone I; —■— zone II; ·····△····· zone III; - - -✕- transect mean] sampled at each transect:

(A) Mean abundance of *Leptochryseus kuwaitense* at TI.

(B) Mean abundance of *Periophthalmus waltoni* at TI.

(C) Mean abundance of *Periophthalmus waltoni* at TII.

(D) Mean abundance of *Boleophthalmus boddarti* at TI.


(A)
(B)
(C)
(D)
Abundance (9 m-2)
Month
0
10
20
30
40
50
60
70
80
1
2
3
4
5
6
7
8
9
10
100
200
300
400
500
600
JUN98
JULY
AUG
SEP
OCT
NOV
DEC
JAN99
FEB
MAR
APR
MAY
JUN99

Figures 2.22 and 2.23 compare the mean abundance of the dominant species within $9m^{-2}$ quadrats at transect I and transect II respectively.

At TI, *Tylodiplax indica* dominated other species, with a mean abundance of $555.3 \pm 48.6/9m^2$. *Cerithidea cingulata* followed with an abundance of $124.38 \pm 24.24/9m^2$. The lowest abundance on this transect was recorded for *Nasima dotilliformis* with a mean of $11.31 \pm 3.30/9m^2$.

At transect II, *Periophthlamus waltoni* was the most abundant species with a mean of $325.5 \pm 21.5/9m^2$ followed by *Ilyoplax stevensi* ($140.76 \pm 20.07/9m^2$). On this transect, the lowest abundance of $23.07 \pm 8.46/9m^2$ was again recorded for *Nasima dotilliformis.*

Tables 2.7 and 2.8 summarise the mean seasonal abundance of dominant species at TI and TII respectively.

On **TI,** it is evident that *C. cingulata* peaks during summer, while the remaining infaunal species (*T. indica, I. stevensi* and *N. dotilliformis*) reach their highest abundance during winter. *Leptochryseus kuwaitense, P. waltoni* and *B. boddarti* tend to reach highest abundance during autumn.

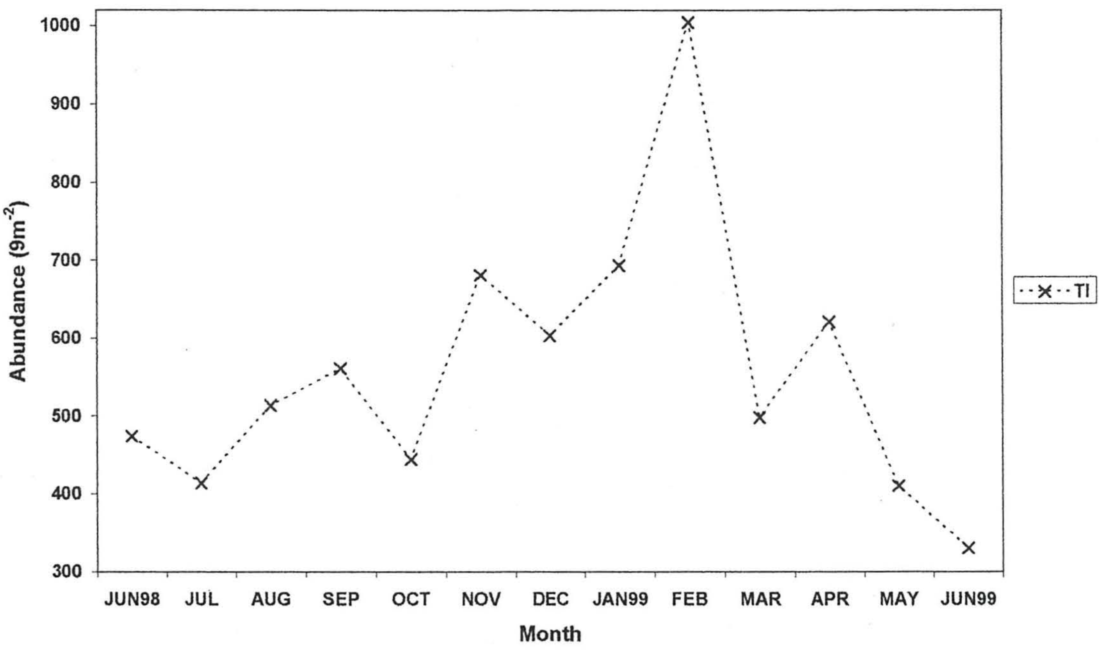
On **TII,** *Tylodiplax indica* shows a peak seasonal abundance in spring, however, *I. stevensi* peaks during winter and *N. dotilliformis* during summer. *P. waltoni* has a high abundance in winter, gradually decreasing to reach lowest values in summer.

Table 2.9 summarises the mean abundance of each species on both transects. Throughout the 13 months sampled at transect II, *C. cingulata, L. kuwaitense* and *B. boddarti* were absent. However, the abundance of *P. waltoni, I. stevensi* and *N. dotilliformis* at TII was higher than those at TI by ratios of 14:1, 1.3:1 and 2:1 respectively. *Tylodiplax indica* had a higher abundance at TI than TII by a ratio of 11:1.

Co-efficient of variation (CV) and Index of Dispersion (ID):

Table 2.10 gives the co-efficiencies of variation and indices of dispersion for the dominant species sampled at TI and TII. From the CV values it is evident that on TI *L. kuwaitense* and *C. cingulata* are most variable, while on TII, *T. indica* is the most variable in its abundance. However *P. waltoni* is least variable on both transects.

From the dispersion index values, it is clear that on TI both *L. kuwaitense* and *B. boddarti* are highly clumped, *T. indica* then *C. cingulata* are clumped, and *I. stevensi* is the least clumped. *Periophthlamus waltoni* is randomly dispersed, while *N. dotilliformis* shows a regular dispersion. On TII, *P. waltoni* is relatively clumped, with *I. stevensi*, then *T. indica* less clumped, while *Nasima dotilliformis* shows regular dispersion.



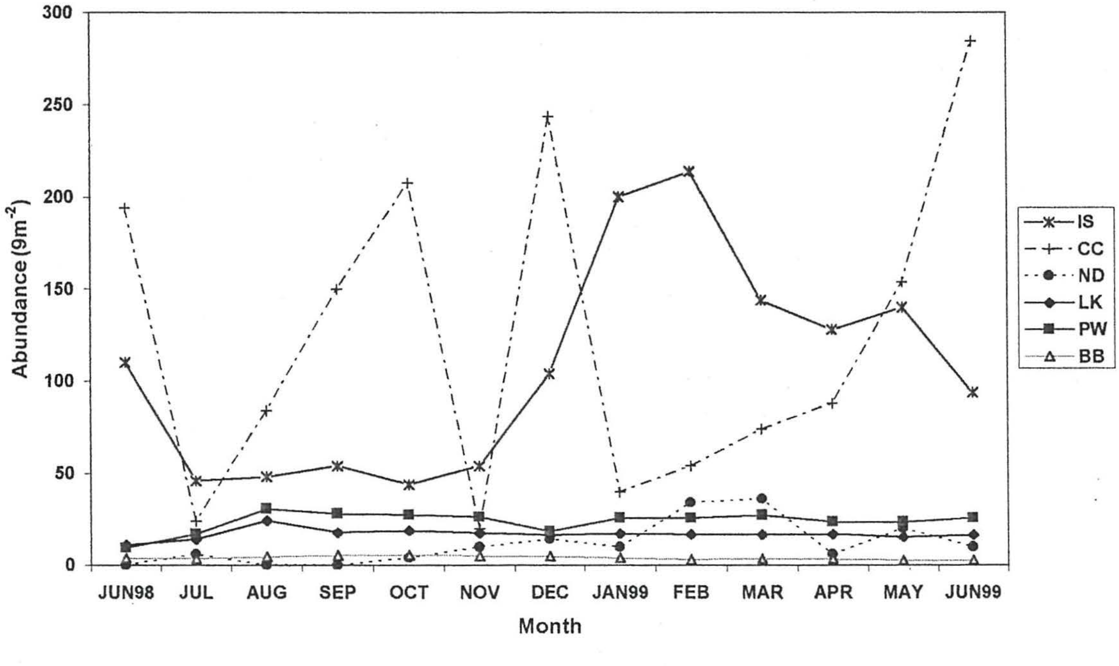


Figure 2.22 Mean abundance of total faunal species within $9m^{-2}$ at transect TI, Ashish Al-Doha. [TI, *Tylodiplax indica*; LK, *Leptochryseus kuwaitense*; PW, *Periophthlamus waltoni*; BB, *Boleophthlamus boddarti*; IS, *Ilyoplax stevensi*; ND, *Nasima dotilliformis*; CC, *Cerithidea cingulata*].

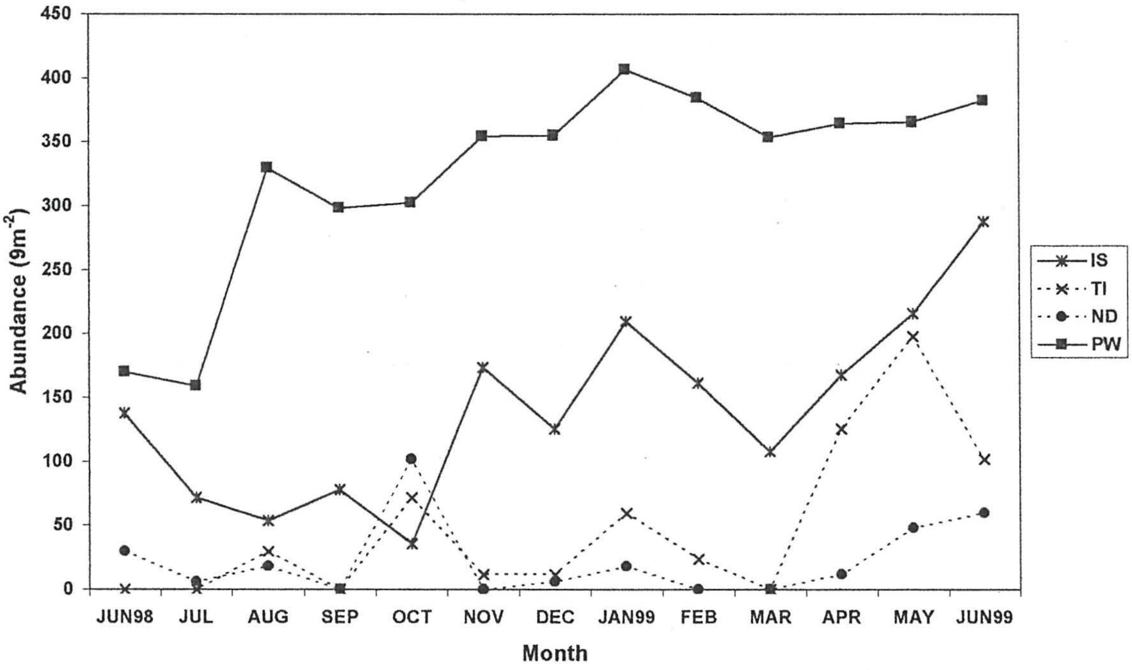


Figure 2.23 Mean abundance of total faunal species within $9m^{-2}$ at transect TII, Sulaibikhat [TI, *Tylodiplax indica*; PW, *Periophthlamus waltoni*; IS, *Ilyoplax stevensi*; ND, *Nasima dotilliformis*].

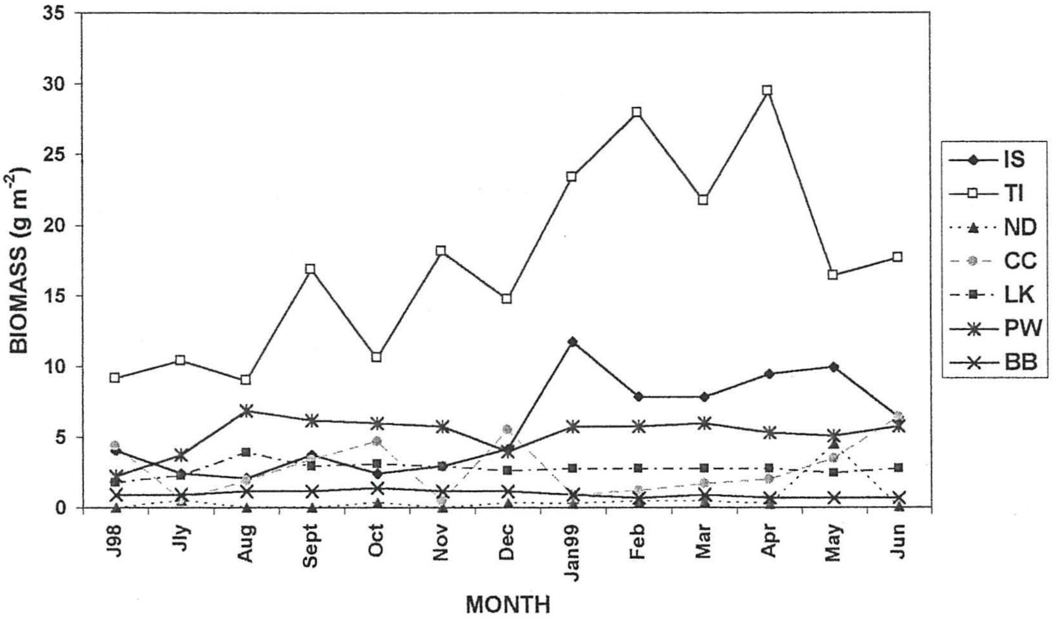


Figure 2.24 Monthly biomass (g AFDW m^{-2}) of key macrofaunal species collected at transect I – Ashish Al-Doha [TI, *T. indica*; LK, *L. kuwaitense*; PW, *P. waltoni*; BB, *B. boddarti*; IS, *I. stevensi*; ND, *N. dotilliformis*; CC, *C. cingulata*].

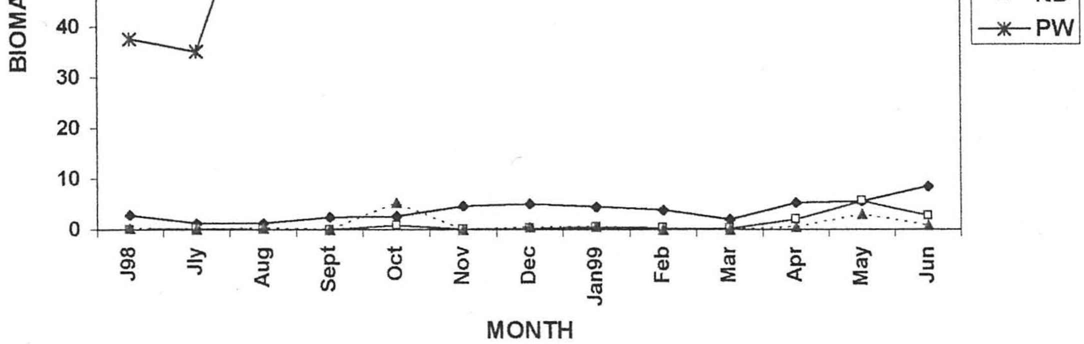


Figure 2.25 Monthly biomass (g AFDW m^{-2}) of key macrofaunal species collected at transect II – Sulaibikhat [TI, *T. indica*; PW, *P. waltoni*; IS, *I. stevensi*; ND, *N. dotilliformis*].

Table 2.7 Mean seasonal abundance of dominant faunal species found on TI, Ashish Al-Doha. [Summer: mean abundance of species found during June98-August98 and June99, Autumn: September98-November98, Winter: December98-February 99, Spring: March99-May99][CC, *Cerithidea cingulata*; PW, *Periophthlamus waltoni*; BB, *Boleophthlamus boddarti*; LK, *Leptochryseus kuwaitense*; TI, *Tylodiplax indica*; IS, *Ilyoplax stevensi*; ND, *Nasima dotilliformis*].

SPECIES	**MEAN ± S.E.**			
	SUMMER (n= 24)	**AUTUMN (n=18)**	**WINTER (n=18)**	**SPRING (n=18)**
CC ($0.05m^{-2}$)	5.28 ± 1.50	3.56 ± 1.88	2.50 ± 1.22	2.94 ± 1.19
PW ($9m^{-2}$)	22.44 ± 8.56	27.28 ± 7.16	25.06 ± 6.12	24.78 ± 6.32
BB ($9m^{-2}$)	3.36 ± 0.81*	5.44 ± 0.95	4.00 ± 0.72	3.22 ± 0.57
LK ($9m^{-2}$)	16.47 ± 8.42	18.06 ± 6.25	17.00 ± 5.83	16.39 ± 5.63
TI ($0.05m^{-2}$)	11.06 ± 3.54	15.67 ± 4.31	17.89 ± 5.24	13.33 ± 4.07
IS ($0.05m^{-2}$)	2.17 ± 0.79	1.39 ± 0.40	4.83 ± 1.07*	3.78 ± 0.97
ND ($0.05m^{-2}$)	0.19 ± 0.13	0.06 ± 0.06	0.67 ± 0.23	0.50 ± 0.32

$p<0.05$, except values with (*) where $p \geq 0.05$

Table 2.8 Mean seasonal abundance of dominant faunal species found an TII, Sulaibikhat. . [Summer: mean abundance of species found during June98-August98 and June99, Autumn: September98-November98, Winter: December98-February 99, Spring: March99-May99][PW= *Periophthlamus waltoni*, TI= *Tylodiplax indica*, IS= *Ilyoplax stevensi*, ND= *Nasima dotilliformis*].

SPECIE	MEAN ± S.E.			
	SUMMER (n= 24)	**AUTUMN (n=18)**	**WINTER (n=18)**	**SPRING (n=18)**
PW ($9m^{-2}$)	301.1 ± 31.2*	318.5 ± 22.1*	380.8 ± 16.1*	361.2 ± 15.2*
TI ($0.05m^{-2}$)	1.36 ± 0.64	0.78 ± 0.67	1.06 ± 0.39	3.00 ± 1.50
IS ($0.05m^{-2}$)	5.28 ± 1.03	2.67 ± 0.87	5.44 ± 1.67	4.56 ± 1.16
ND ($0.05m^{-2}$)	1.09 ± 0.65	0.94 ± 0.94	0.22 ± 0.17	0.33 ± 0.16

$p<0.05$, except values with (*) where $p \geq 0.05$

Table 2.9 Mean monthly abundance of dominant faunal species sampled on transect I (TI) and transect II (TII).

Species	**TI**	**TII**
Cerithidea cingulata ($0.05m^{-2}$)	3.46± 1.03	0.00
Periophthlamus waltoni ($9m^{-2}$)	23.74 ± 4.05	325.1 ± 15.7
Boleophthlamus boddarti ($9m^{-2}$)	4.08 ± 0.51	0.00
Leptochryseus kuwaitense ($9m^{-2}$)	16.90 ± 3.96	0.00
Tylodiplax indica ($0.05m^{-2}$)	15.49 ± 2.87	1.36 ± 0.51
Ilyoplax stevensi ($0.05m^{-2}$)	2.95 ± 0.54	3.91 ± 0.64
Nasima dotilliformis ($0.05m^{-2}$)	0.32 ± 0.09	0.64 ± 0.24

$n= 39$, $p \leq 0.05$

Table 2.10 Co-efficient of variation (CV) and Index of dispersion (ID) for the dominant faunal species found at both transects.

SPECIE	**TI (Ashish Al-Doha)**		**TII (Sulaibikhat)**	
	(CV)	**(ID)**	**(CV)**	**(ID)**
C. cingulata (0.05m^{-2})	173.21	9.92	-	-
P. waltoni (9m^{-2})	37.01	1.05	21.06	14.41
B. boddarti (9m^{-2})	156.34	50.35	-	-
L. kuwaitense (9m^{-2})	173.21	50.81	-	-
T. indica (0.05m^{-2})	117.23	19.95	115.37	1.94
I. stevensi (0.05m^{-2})	98.31	2.83	85.16	2.99
N. dotilliformis (0.05m^{-2})	116.53	0.44	93.39	0.56

Biomass

Biomass is represented as Ash free dry weight per square metre (g AFDW m^{-2}) for key macrofaunal species measured during the 13 month sampling period at both transects, and is shown in appendices 2.6 and 2.7 respectively. The monthly biomass for the dominant fauna found along transect I, and transect II are represented in figures 2.24 & 2.25 respectively.

TI: biomass of the crab *T. indica* fluctuated throughout the sampling period, showing highest values in April 99 (29.47g m^{-2}) and lowest in June 98 (9.15 g m^{-2}). From June 98 biomass of *I. stevensi* gradually decreased reaching lowest values during August and October 98 (2.09 g m^{-2}). It then gradually increased to reach a high of 11.79 g m^{-2} in January 99. *Nasima dotilliformis* was absent from mud samples obtained during June 98, August 98, September 98 and November 98, while highest biomass occurred in May (4.51 g m^{-2}). Biomass values for the gastropod *C. cingulata* fluctuated during the first half of the sampling period showing lowest value of 0.46 g m^{-2} in November 98, gradually increasing from February 99 onwards reaching highest total biomass in June 99 (6.44 g m^{-2}). The biomass of the endemic crab *L. kuwaitense* was almost constant throughout the sampling period, with lowest value of 1.78 g m^{-2} recorded during June 98, and highest during August 98 (3.89 g m^{-2}). Lowest biomass for the carnivorous goby, *P. waltoni* occurred in June 98 (2.21 g m^{-2}), while highest was in August 98 (6.86 g m^{-2}). This species showed a gradual decrease from September 98 to December 98. Biomass than gradually increased approaching March 99, slightly decreasing in April and May 99, and increasing again towards June 99. A high of 1.38 g m^{-2} was recorded for the herbivorous goby *B. boddarti* during October 98, while a low of 0.69 g m^{-2} was recorded during February 99, April – June 99.

TII: *T. indica* was absent during June and September 98, however highest biomass occurred during May 99 (5.60 g m^{-2}). Lowest biomass recorded for *I. stevensi* was during August 98 (1.26 g m^{-2}). A noticeable increase occurred from August 98 till December 98, followed by a gradually decrease from January 99 to March 99. During April 99, biomass of the same species increased to reach highest value of 8.44 g m^{-2} in June 99. *Nasima dotilliformis* showed highest biomass during October 98 (5.26 g m^{-2}), and was absent during September 98, November 98, February 99 and March 99. Lowest biomass value recorded for the carnivorous *P. waltoni* was during July 98 (35.14 g m^{-2}). The biomass gradually increased from September 98 to reach highest recorded value of 89.99 g m^{-2} in January 99. A decrease was noticed from February 99 to March 99, after which the biomass increased again.

Figure 2.26 shows the mean total biomass for dominant faunal species at both transects during the 13 month sampling period. At TI, the highest mean biomass of 17.37 ± 1.89 g m^{-2} was recorded for *T. indica*, followed by *Ilyoplax stevensi* (5.78 ± 0.91 g m^{-2}) and *P. waltoni* (5.25 ± 0.35g m^{-2}). *Leptochryseus kuwaitense* and *C. cingulata*, both had similar biomass values (2.74 ± 0.13g m^{-2} and 2.82 ± 0.55g m^{-2} respectively). *B. boddarti* had a low biomass value of 0.96 ± 0.06g m^{-2}, however lowest value was recorded for *N. dotilliformis* (0.54 ± 0.33 g m^{-2}).

Periophthalmus waltoni showed highest biomass throughout the sampling period (71.96 ± 4.77g m^{-2}) at transect II, followed by *I. stevensi* (3.85 ± 0.57g m^{-2}). Although both *T. indica* and *N. dotilliformis* had low and almost similar biomass values (1.01 ± 0.45g m^{-2} and 0.87 ± 0.43g m^{-2} respectively).

Table 2.11 gives mean seasonal biomass (g m^{-2}) of dominant faunal species on both transects. It is evident that *T. indica*, *Ilyoplax stevensi* and *N. dotilliformis* at TI all had highest biomass during spring. Although *T. indica* had lowest biomass in summer, both *I. stevensi* and *N. dotilliformis* had least during autumn. The mud snail *C. cingulata* showed an opposite trend to the above infaunal species, with lowest value during summer and highest in spring. *Leptochryseus kuwaitense* and *B. boddarti* both had low biomass during spring, however *P. waltoni* had its lowest in summer and highest in autumn.

At TII, *T. indica* had highest biomass in spring and lowest during autumn. Highest recorded biomass value was recorded during winter for *I. stevensi*, while during autumn the lowest was recorded. Both *N. dotilliformis* and *C. cingulata* had highest biomass values in autumn, however *I. stevensi* had lowest value in summer where *C. cingulata* showed least biomass in winter. During summer the biomass of the goby, *P. waltoni* was at its lowest during summer, while highest was during winter.

Generally mean seasonal faunal biomass at TI was lowest during summer gradually increased to reach highest biomass during spring. At TII, the biomass was also low in summer, however it gradually increased to reach highest recorded value in winter, slightly decreased in spring. Finally it is evident that total biomass over the 13 months sampled at TII is 2 fold higher than that recorded for TI.

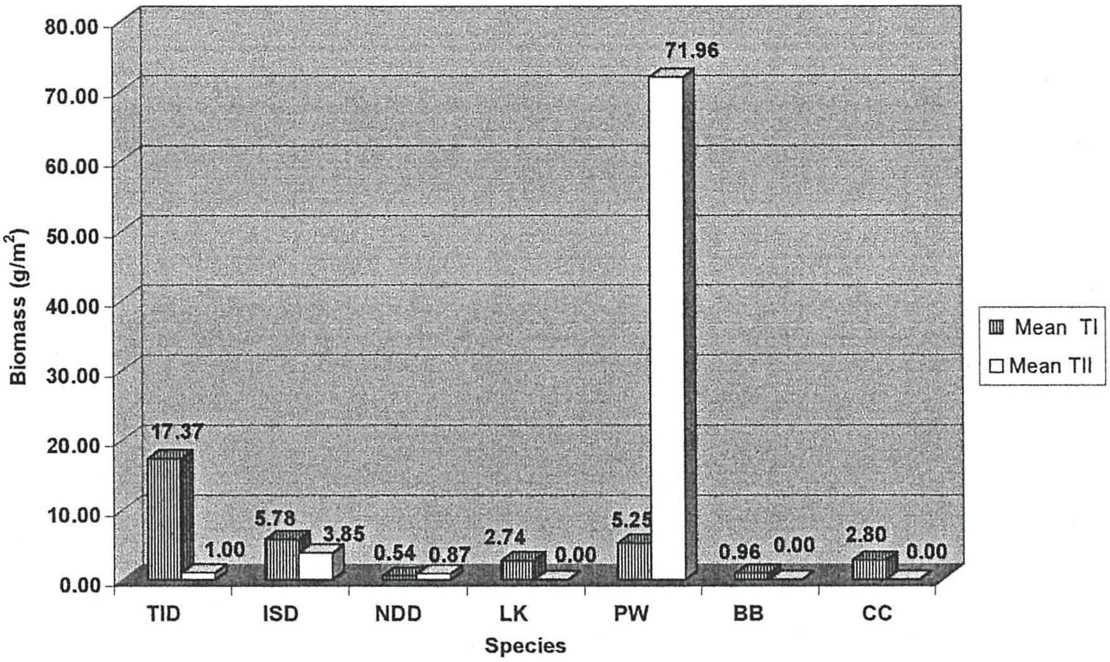


Figure 2.26 Mean biomass of faunal species collected during the 13 month sampling period at Ashish Al-Doha (TI) and Sulaibikhat (TII) [TI, *T. indica*; LK, *L. kuwaitense*; PW, *P. waltoni*; BB, *B. boddarti*; IS, *I. stevensi*; ND, *N. dotilliformis*; CC, *C. cingulata*].

Table 2.11 mean seasonal biomass (g AFDW m^{-2}) of infaunal and macrofaunal species at both transects. [Summer: (June98-August 98 and June 99), Autumn: (September 98-November 98), Winter: (December 98-February 99), Spring: (March99-May99)] [TI: *T. indica*, IS: *I. stevensi*, ND: *N. dotilliformis*, CC: *C. cingulata*, LK: *L. kuwaitense*, PW: *P. waltoni*, BB: *B. boddarti*].

	TI				**TII**			
	SUM	**AUT**	**WNT**	**SPR**	**SUM**	**AUT**	**WNT**	**SPR**
TI	11.57±2.07*	15.23±2.33	22.06±3.88	22.56±3.78	0.76±0.66*	0.33±0.27	0.39±0.08	2.63±1.57
IS	3.73±0.98	3.03±0.38	7.93±2.21	9.09±0.64	3.47±1.72	3.27±0.71	4.51±0.34	4.29±1.14
ND	0.13±0.12*	0.11±0.11	0.33±0.06	1.73±1.39	0.37±0.15	1.76±1.76	0.37±0.19	1.16±0.93
CC	3.32±1.31	2.86±1.26	2.56±1.49	2.39±0.56	0.0	0.0	0.0	0.0
LK	2.67±0.45	2.97±0.52	2.70±0.06	2.65±0.11	0.0	0.0	0.0	0.0
PW	4.64±1.03	5.97±0.13	5.16±0.59	5.46±0.26	57.56±12.44	70.53±3.99	84.53±3.33	79.94±0.87
BB	0.92±0.10	1.23±0.07	0.92±0.13	0.77±0.08	0.0	0.0	0.0	0.0
Total species mean	3.85±1.42	4.49±1.92	5.95±2.86	6.38±2.90	8.88±8.11*	10.84±9.94*	12.8±12.0*	12.6±11.20*
Seasonal mean	5.17 ± 0.59				11.28 ± 0.90			

Where (*) $p<0.005$

Qualitative biological sampling:

Tables 2.12 & 2.13 list the macrofaunal species found in the baited fish traps placed along transects I and II, during the 13 month sampling period, respectively. Note that occurrence is mentioned as on bimonthly basis as sampled.

The xanthid crab, *Eurycarcinus orientalis* occurred during all the sampling periods at TI, but only during October 98 at TII. In contrast, *Metaplax indica*, occurred quite frequently in fish traps at TII (Oct.98-June 99) but only once at TI (Feb. 99). The edible portunid crab, *Portunus pelagicus*, occurred 5 times during the monthly sampling at both transects (TI: June 98, Nov.98, March 99-May99; TII: Sept.98, February-May 99). The largest mud crab, *Macrophthalmus dentipes* caught at TI was not caught in any of the fish traps placed along TII, but at transect I it was found in fish traps during September 98 and March 99. Juveniles of the edible penaeid shrimp, *Metapenaeus affinis*, were caught during September 98, May and June 99 at TII, and during September 98 and April 99 at TI.

The edible fish species found at transect I include the silver sillago, *Sillago sihama*, the stripped piggy, *Pomadasys stridens* (= *Rhoniscus stridens*), the mullet, *Liza macrolepis*, the sea bream *Sparidentex hasta*, and the oriental sole *Euryglossa orientalis*, all of which occurred only once at TI (Aug.98, Sept.98, Sept.98 Nov.98 and Sept.98 respectively), but were never caught during any of the sampling periods at TII.

The goby *P. waltoni* occurred throughout the whole year except July 98. However, it was only caught during 5 months at TII (Oct. 98, Nov. 98, Jan. 99, March 99 and May 99). The intertidal goby, *B. boddarti* was found at TII during Sept.98, Jan.99 and May 99. At transect I, it was found during Dec.98-Feb.99 and may 99. The subtidal goby *Acanthogobius ornatus*, occurred repeatedly along TI (June 98- Sept. 98, Jan.99-Feb.99, and May 99), but only twice at TII (Oct.98 and May 99).

Tables 2.14 and 2.15 list the birds sighted from September 98 till June 99 at TI and TII respectively.

The grey Heron, *Ardea cinerea,* was sighted during Oct. 98, and through Dec. 98 to March 99 at TI, however at TII, it was seen during Oct. 98-Dec. 98, and Feb.99-March 99. The purple Heron, *Aredea pupurea* was seen only twice at both transect I and transect II (Dec.98 & Jan.99, and Dec.98 & March 99 respectively). At TII, the pink flamingo, *Phoenicopterus ruber* was sighted during the period from Nov.98-Dec.98 and From April 99 to May 99, but there was no sign of the flamingos during any of the sampling periods at TI. The plover *Charadrius* sp. occurred only once at TI (March 99), but twice at TII (Nov.98 & March 99). Although both the crested lark, *Galerida cristata* and the stork *Ciconia ciconia* were seen only once at TII (March 99), both were absent from TII. At both transects the seagull *Larus genei* was sighted during the same periods (Dec.98-Feb.99). On transect I, the sand piper *Actitis* sp. was seen during Nov.98, Jan 99 and June 98, but at TII it was seen during Nov. 98 and December 98.

Table 2.16 summarises the macrobiota found on both transects during June 98-June 99. The species included in this table are species either obtained by qualitative sampling, or by collection (hand, fish traps) and observation. Figures 2.27 and 2.28 illustrate the zonation pattern and distribution of the major macrobiotic components on TI and TII respectively. Both table and figures give an overall view of the species on both transects, and reveals that transect I is more species rich than transect II.

Table 2.12 Macrofauna caught by fish traps placed along the transect line at SI, during period from June 98 till June 99

	Sampling period (month and date)	**JJ98**	**J**	**A**	**S**	**O**	**NV**		**DC**		**J99**	**FB**		**MR**		**AR**		**M**	**JJ**	
	Species	**II**	**II**	**II**	**II**	**II**	**I**	**II**	**I**	**II**	**I**	**I**	**II**	**I**	**II**	**I**	**II**	**II**	**I**	**II**
Crustacea (Decapoda: crabs & shrimp)																				
1	*Eurycarcinus orientalis*	x	x	x	x	x	x	x	x	x	x		x	x		x		x	x	
2	*Portunus pelagicus*		x				x							x		x	x	x		
3	*Metaplax indica*											x								
4	*Macrophthalmus pectinipes*				x									x						
5	*Metapenaeus affinis* (Shrimp Juv.)				x											x				
Osteichthyes (Gobies)																				
6	*Periophthlamus waltoni*	x		x	x	x	x		x	x	x	x	x	x		x	x	x		
7	*Boleophthlamus boddarti*								x		x	x	x					x		
8	*Acentrogobius ornatus*	x	x	x	x						x		x					x		
Osteichthyes (Fish)																				
9	*Sillago sihama*			x																
10	*Rhoniscus stridens*				x															
11	*Lisa macrolepis*				x															
12	*Acanthopagarus cuvieri*						x													
13	*Synaptura orientalis*				x															

Table 2.13 Macrofauna caught by fish traps placed along the transect line at SII, during period from June 98 till June 99.

	Sampling period (month and date)	JJ98	J	A	S	O	NV		DC		J99	FB		MR		AR		M	JJ	
	Species	II	II	II	II	II	I	II	I	II	I	I	II	I	II	I	II	II	I	II
Crustacea (Decapoda: crabs & shrimp)																				
1	*Eurycarcinus orientalis*					x														
2	*Portunus pelagicus*				x								x		x	x		x		
3	*Metaplax indica*					x	x	x	x	x	x	x	x		x	x		x	x	x
4	Macrophthlamus pectinipes																			
13	*Metapenaeus affinis* (Shrimp Juv.)				x													x	x	x
Osteichthyes (Gobies)																				
5	*Periophthlamus waltoni*					x		x			x							x	x	x
6	*Boleophthlamus boddarti*				x						x							x		
7	*Acentrogobius ornatus*					x												x		
Osteichthyes (Fish)																				
8	*Sillago sihama*																			
9	*Rhoniscus stridens*																			
10	*Lisa macrolepis*																			
11	*Acanthopagarus cuvieri*																			
12	*Synaptura orientalis*																			

Table 2.14 Birds on Ashish Al-Doha mudflats (SI), Sulaibikhat Bay, sighted during each sampling period from September 1998 till June 1999.

		SE.98		**OCT.**		**NOV.**		**DEC.**			**JA.99**		**FEB.**		**MAR.**		**APR.**		**MAY**		**JUNE**	
		A	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**C**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
1	*Ardea cinerea* (Grey Heron)			x					x	x	x	x		x	x							
2	*Ardea purpurea* (Purple Heron)								x		x											
3	*Phoenicopterus ruber* (Pink Flamingo)																					
4	*Charadrius* sp. (Plover)														x	x						
5	*Galerida cristata* (Crested Lark)														x							
6	*Larus genei* (Sea Gull)								x	x	x	x		x								
7	*Ciconia ciconia* (Stork)															x						
8	*Actitis* sp. (Sandpiper)						x				x	x									x	

Table 2.15 Birds on Sulaibikhat area mudflats (SII), Sulaibikhat Bay, sighted during each sampling period from September 1998 till June 1999.

		SE.98		OCT.		NOV.		DEC.			JA.99		FEB.		MAR.		APR.		MAY		JUNE	
		A	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**C**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
1	*Ardea cinerea* (Grey Heron)			x	x	x			x	x			x	x	x							
2	*Aredea purpurea* (Purple Heron)								x	x					x							
3	*Phoenicopterus ruber* (Pink Flamingo)					x	x		x								x	x		x		
4	*Charadrius* sp. (Plover)					x									x							
5	*Galerida cristata* (Crested Lark)																					
6	*Larus genei* (Sea Gull)							x	x		x	x	x									
7	*Ciconia ciconia* (Stork)																					
8	*Actitis* sp. (Sandpiper)					x		x														

Table 2.16 Biota found at both transects (TI: Ashish Al-Doha; TII: Sulaibikhat) during the sampling period June 98 - June 99.

Species	Transect I	Transect II
FLORA		
Microbial mat (a) [Cyanophyta dominated)	X	-
Microbial mat (b) {diatom dominated]	X	X
Salicornia herbacea	X	X
Schanginia aegyptiaca	-	X
Halconemon strobilacea	X	-
FAUNA		
Sipunculoida		
Ikeda taenioides	X	-
Mollusca		
Gastropoda		
Potamididae		
Cerithidea cingulata	X	X
Bivalvia		
Veneridae		
Amiantis umbonella	X	-
Crustacea		
Penaeidae		
Metapenaeus affinis	X	X
Grapsidae		
Metapograpsus messor	-	X
Xanthidae		
Eurycarcinus orientalis	X	X
Portunidae		
Portunus pelagicus	X	X
Ocypodidae		
Leptochryseus kuwaitense	X	-
Manningis arabicum	X	-
Metaplax indica	X	X

Cont^{d}.

Macrophthlamus dentipes	X	X
Macrophthlamus depressus	-	X
Nasima dotilliformis	X	X
Uca annulipes albimana	X	-
Uca sindensis	X	X
Ilyoplax stevensi	X	X
Tylodiplax indica	X	X
Osteichthyes		
Gobiddae		
Periophthlamus waltoni	X	X
Boleophthlamus boddarti	X	X
Acentrogobius ornatus	X	X
Haemulidae		
Pomadasys stridens	X	-
Mulidae		
Liza macrolepis	X	-
Sillaginidae		
Sillago sihama	X	-
Soleidae		
Euryglossa orientalis	X	-
Sparidae		
Sparidentex hasta	X	-
Avians		
Actitis sp.	X	X
Aredea cinerea	X	X
Areda purpurea	X	X
Charadrius sp.	X	X
Ciconia ciconia	X	-
Galerida cristata	X	-
Larus genei	X	X
Phoenicopterus ruber	-	X
Total species number	**34**	**24**

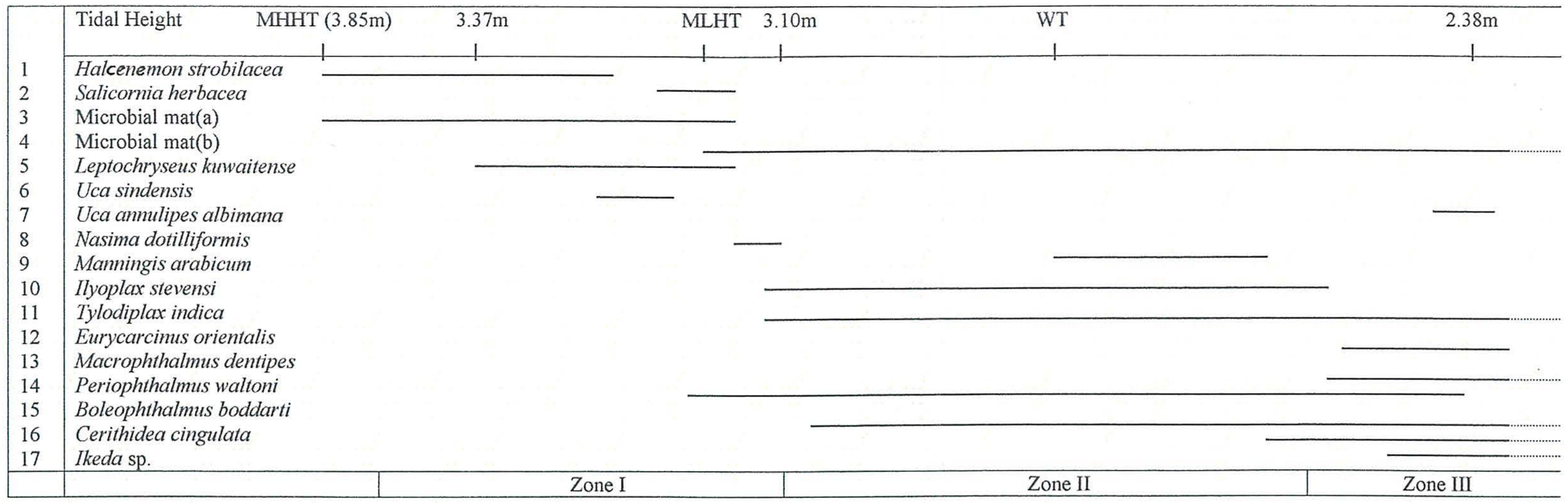
Figure 2.27

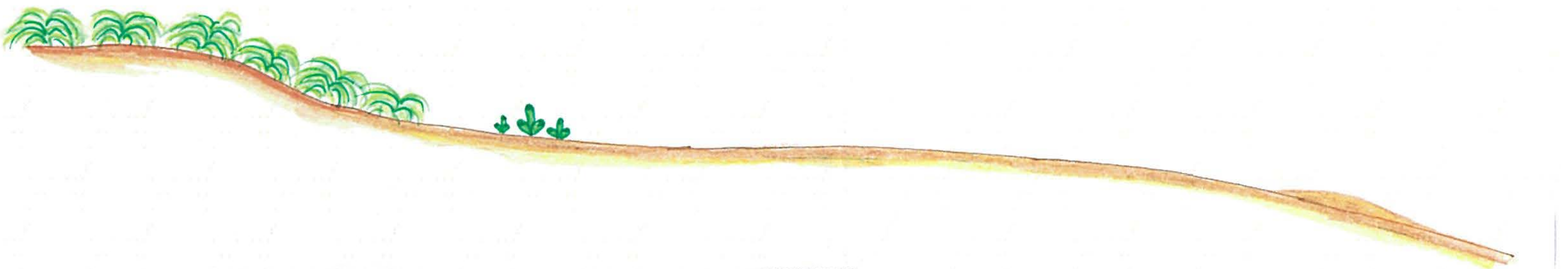
Distribution and zonation pattern of intertidal macrobiota along Transect I, Ashish Al-Doha- Mudflats of Sulaibikhat Bay.

A → D Sediment appearance along the transect:

A. Zone I (ZI)
B. Lower end of ZI till highest point at Zone II (ZII)
C. Mid-point at ZII till highest point at Zone III (ZIII)
D. Beyond ZIII

(Numbers on pictures correspond with numbers on zonation scheme)





A.

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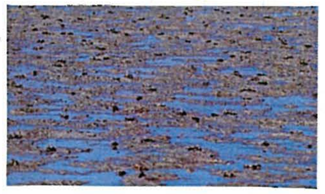

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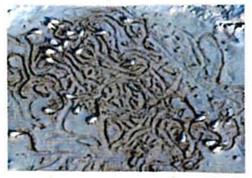

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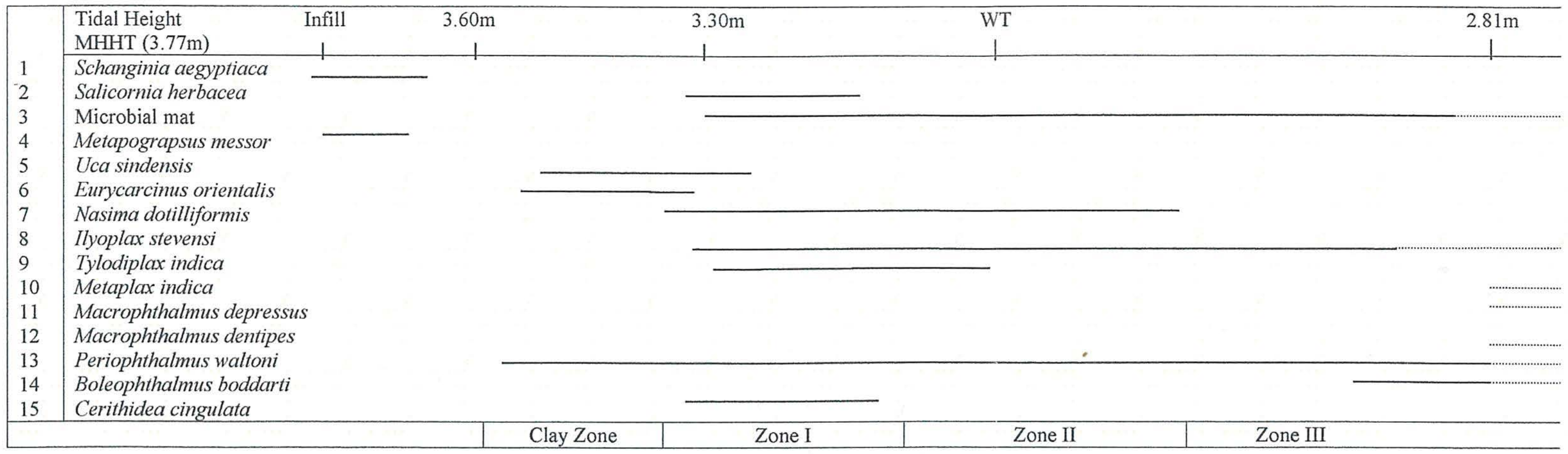
Figure 2.28

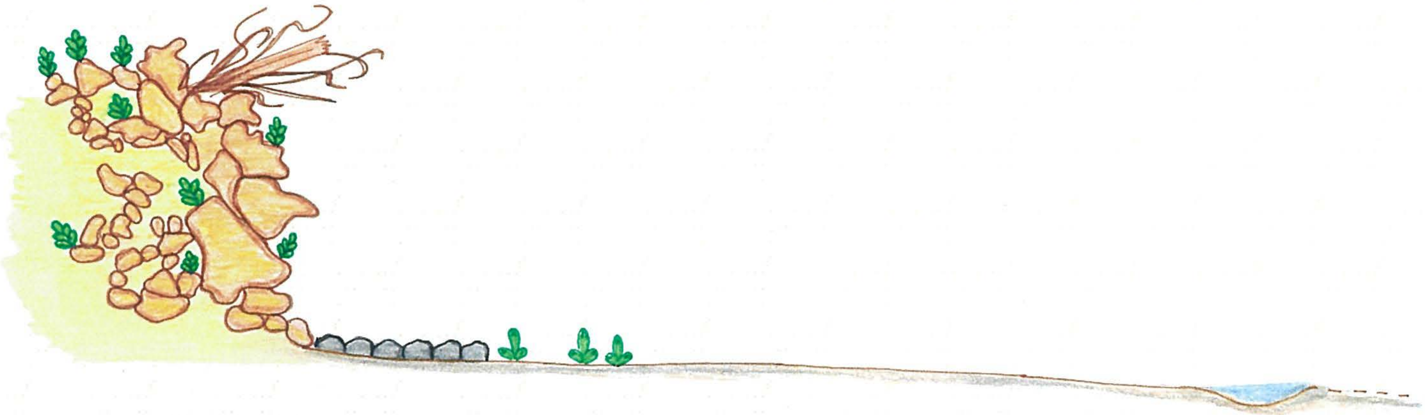
Distribution and zonation pattern of intertidal macrobiota along Transect II, Sulaibikhat- Mudflats of Sulaibikhat Bay.

A → D Sediment appearance along the transect:

A. Clay zone
B. Zone I (ZI) and Zone II (ZII)
C. Zone III (ZIII)
D. Beyond ZIII

(Numbers on pictures correspond with numbers on zonation scheme)





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B.

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DISCUSSION

A basic ecological description of the distribution and abundance of benthic fauna is presented here for a semi-tropical mudflat in the northwestern Arabian Gulf (Kuwait), Sulaibikhat Bay. The distribution of benthic organisms at two transects is compared, and generally seen to be a combined effect of several factors.

Abiotic Environment

Environmental factors fluctuate rapidly in mudflat habitats due to changes in atmospheric weather, all of which must remain within tolerable limits if the organism is to survive. If any one factor varies beyond the tolerated range, the species will be eliminated even though all other factors remain suitable. Temperature and salinity are important factors that not only affect abundance and distribution, but are also the most important environmental factors which govern all physiological processes for marine organisms represented in growth and reproduction. Other factors such as the duration of emergence and submergence, influence of weather, and sediment composition, indirectly effect temperature and salinity, thus determining the abundance and distribution of benthic fauna both spatially and seasonally. Intertidal mudflats at both transects frequently experience a much wider range of temperature than other coastal habitats. This is due in part to their relatively large surface area/volume ratios, allowing heating and cooling more rapidly under prevailing atmospheric conditions (Boaden and Seed, 1996).

The ambient temperature of Sulaibikhat Bay is characterised by large annual fluctuations ranging between 12.5°C and 35°C (Anonymous, 1983). During this present investigation similar fluctuations were also noticed (Figure 2.14), with lowest values recorded in December 98 and highest in June 99, for temperature recordings of the sediment and pool water. Sediment temperatures reached maximum in summer and minimum in winter, coinciding with the hottest and coldest months of the year. Temperature recordings of the sediment at TI are relatively higher than recordings at TII, decreasing horizontally down the shore across the intertidal gradient, while increasing vertically with sediment depth.

Sand represents a larger percentage of the sediment at transect I, and coarse sediments have less interstitial water, so that with a rise in shore temperature when the sun is shining the sediment tends to dry rapidly. However, because TII is dominated by silty mud, characterised by high capillarity and associated interstitial water, evaporation is less when the tide is out (Eltringham, 1973). Because the top of the shore is dry with rapid drainage during low tide, in comparison to the lower end of the beach where the sediment is wet with frequent standing pools keeping it cool (Gray, 1981), similar horizontal intertidal gradients in sediment temperature at both transects were present.

Seasonal atmospheric changes in temperature also affect the vertical temperature gradient within the sediment, causing stratification in temperature at different depths. In general, mean sediment temperature is positively correlated with depth throughout the sampling period (25cm > 15cm > 0cm). The sediment surface is exposed to various fluctuations in atmospheric and environmental conditions including weathering (wind), degree of exposure to sun, and submersion during high tide. Such factors play a significant role in reducing temperature at the surface, while deeper layers within the sediment are less affected, and the temperature attained during the day remains constant. Nevertheless, on a seasonal level, the sediment temperatures at different depths at transect II showed similar trends to the mean sediment temperature, but fluctuated at TI. This is associated with the particle size and thixotropy of the soil, as well as the atmospheric environment. During summer months the shores of Kuwait are only exposed when air temperatures are lowest (dusk till dawn), while in winter when night temperatures are low the shore is covered by the tide (Jones, 1986a). During this investigation, sampling took place in the early morning hours (4am) during summer in association with low tidal levels, when air temperature and solar exposure were low, which might explain the observed trend. Fluctuations during the remaining seasons and the inverse correlation between temperature and sediment depth might be related to the fact that sampling was conducted later in the day when sun exposure was at its highest.

Pool water temperatures given in figure 2.16 were lower than the surface seawater temperatures given by EPA (Environmental Public Authority). These differences may be because the measurements were taken at different times of the day and/or month.

Salinity recordings in the present study were lowest at TII due to the sediment high porosity. Because both transects are exposed to evaporation and desiccation during low tide, they both exhibit salinity values higher than recorded by EPA for surface seawater. According to Tait and Dipper (1998), the lowest temperature frequently coincides with the lowest salinities because in winter the outflow of freshwater may be greatly increased by rainfall reducing salinity in adjacent coastal habitats. In summer, high temperatures and high salinities co-exist together when drought periods reduce the amount of freshwater at the same time as insolation is heating and evaporating the water. However, this was not the present case. Although highest salinity was recorded in June 99 for both transects, lowest was also during the previous summer at transect I and transect II (September 98 and August 98, respectively). In 1992, Iraq created what is known as the Third River, capturing all the water reaching the surrounding marshes. Since the completion of this manipulation the salinity along the northern coast of Kuwait has changed significantly (Al-Yamani *et al.*, 1997a). Mean salinity recorded for Khor Al-Sabiya waters in the north of Kuwait was 31.7‰ during a 1995-1998 survey (Al-Yamani and Khan, 2002), as compared to the higher salinity of 36.6‰ recorded during 1981-1982 (Anonymous, 1983). Al-Yamani and Khan (2002) also noticed a clear ascending trend from low salinity in Kuwait's northern waters to a higher salinity in the southern waters. This anthropomorphic alteration may increase run-off from rivers into the Gulf, even during the summer, leading to the reduction in the salinity observed during this study.

Measurements and interpretation of seawater pH is considered to be difficult due to changes in temperature and salinity values, which are inversely correlated with pH (Meadows and Campbell, 1988). The hydrogen ion concentration at both transects varied slightly, showing relative stability throughout the sampling period, generally within extreme range of seawater (7.5-8.4; Meadows and Campbell, 1988; Nybakken, 2001). In summer (98) lowest pH concentration was recorded, correlated with high temperature and associated salinity. Lower down on the shore, at both transects, pH increased. This is also associated with decreasing temperature and salinity down the intertidal gradient, linked to increased water retention.

In the current study mudflats occur in the sheltered area of Sulaibikhat Bay where wave action is generally low. It is evident from the steepness and the dominating sediment particle size at TI, that it is relatively more exposed to wave action in comparison to TII which is flatter and muddier. Within each transect grain size and sorting varied over distances as small as a few centimetres (Gray, 1981). The strong foul smell at TII during low tide indicates the presence of high concentrations of hydrogen sulphide within the sediment. A few millimetres (1-2mm) below the surface, the colour of the mud is bluish grey to black. The nature of the sediment, with grains tightly packed together, precludes the presence of interstitial fauna, but traps organic matter which in the presence of bacterial activity has led to it becoming anoxic.

Biotic Environment

Community structure of Sulaibikhat Bay

Two sites within Sulaibikhat Bay were assessed biologically: a virtually pristine natural site, Ashish Al-Doha, and a physically modified site, Sulaibikhat. The outcome of the assessment conducted on the two sites (TI, Ashish Al-Doha; TII, Sulaibikhat) was compiled to give an overall view of the faunal diversity and, for the first time, the faunal abundance and biomass of key species occurring on its mudflats. It revealed 33 macrofaunal species occurring within the accessible upper intertidal region, of which 14 were crustacean species, 2 molluscs, 1 sipunculoid, 8 fish species and 8 avian species. Only 8 of the 33 macrofaunal species were assessed quantitatively (abundance and biomass), while the remaining were assessed qualitatively.

Brachyurans, belonging to the family Ocypodidae, dominated the faunal assemblage within the area and represented approximately 40% of the total faunal assemblage sampled both quantitatively and qualitatively during this study. The dominance of crustaceans in the intertidal zone of Kuwait has also been found by Jones (1986a), Clayton (1986), Al-Zaidan, *et al.* (1999) and Al-Mohanna *et al.* (in prep.), and along the western coast of the Arabian Gulf by Basson *et al.* (1977), Al-Khayat (1996) and Apel (1996). This agrees with Alongi (1987), who stated that in general tropical soft-sediment shores are usually dominated by decapod crustaceans, in contrast to similar habitats in temperate latitudes where gastropods and polychaetes dominate. Recent studies confirm that brachyuran crustaceans are an important and dominant element within faunal assemblages of soft sediment intertidal habitats in the Arabian Gulf, with maximum number of species occurring in Kuwait and UAE (Apel and Türkay, 1999). The apparent success of crustaceans in the tropics is attributed to their motility and ability to escape or avoid high temperatures and salinity or desiccation (Alongi, 1990).

Of the 8 fish species obtained during the study, 2 were intertidal inhabitants of the mudflats (gobies), while the remaining 6 were tidally-migrating species. Of the 6 migrant species, 5 were juveniles of commercially important species belonging to the families Haemulidae, Sparidae, Sillaginidae, Mugilidae and Soleidae. Numerous studies have documented the species composition of demersal fish in tropical estuaries (UNESCO, 1981; Longhurst & Pauly, 1987). Lowe-McConnell (1987) pointed out that the great majority of fish found in tropical estuaries are juveniles and adults of species which are also found on adjacent coastal waters. Several families, namely the Belonidae, Engraulidae, Mugilidae, Gobidae and Soleidae, in addition to several other fish species are important constituents of many demersal estuarine assemblages in the tropics and subtropics (Alongi, 1990). Findings by Jones (1986a,b), Clayton (1986), Abou-Seedo (1992) and Wright *et al.* (1996) also reported the occurrence of such families on the soft-shores of Kuwait. One of the reasons, which brings individuals of such species ashore, is food. Several species feed on the rich concentration of benthic fauna or the microalgal film on the sediment surface when the tide is in (Jacob and Qasim, 1974; Boaden & Seed, 1996; Little, 2000; chapter 4).

when the tide is in (Jacob and Qasim, 1974; Boaden & Seed, 1996; Little, 2000; chapter 4).

The unique ornithological position of Kuwait at the head of the Arabian Gulf has led to diverse wildlife including shorebirds. Although such habitats are generally characterised by extreme atmospheric and environmental conditions, some 60 shorebird species have been reported, of which 46 species occur on mudflats of Sulaibikhat Bay (Al-Sdirawi, 1989). In the current investigation 8 species of residents and migrants, were occasionally sighted at MHLW during the 13-month sampling period. These species were also perceived within the Arabian Gulf region by Jennings, (1981), Al-Sdirawi, (1984, 1989), and Clayton, (1986). Similar species have also been sighted on mudflats of Khor Dubai, UAE (Richardson, 1990). Highest abundances occurred during the winter season, in agreement with Al-Sdirawi, (1984) who suggested that vast numbers of waders are attracted to Kuwait's intertidal mudflat areas during winter. These birds migrate from areas which are likely to become harsh in winter to more favourable areas where survival is substantially enhanced. In addition to favourable climatological conditions, the intertidal fauna of the mudflats provides a substantial food source for waders. In many food chains they are ranked as top predators (Boaden and Seed, 1996), and on average consume between 5 and 15% of the macrozoobenthos biomass throughout the year (Petersen & Exo, 1999).

The distribution of major macrofauna taxa, genera and even species was generally in good agreement with records from other tropical and sub-tropical tidal flats (Haines, 1976; Basson *et al.*, 1977; Rodelli *et al.*, 1984; Incze *et al.* 1982; Dittmann, 2000). Abundance of most macrofaunal groups quantitatively sampled within Sulaibikhat Bay fluctuated significantly over time, but with no distinct seasonality. However, for the overall macrofaunal abundance, a significant increase occurred during winter reaching a mean of 304 individual m^{-2}, while during summer and autumn the abundance was approximately one third less than winter. Correspondingly, the estimated biomass in the bay ranged from 3.8 and 12.9g AFDW m^{-2}, with a mean of 8.3g AFDW m^{-2}, with the goby *P. waltoni* and the crab *T. indica* as the dominant contributors (39.2 and 9.5 g AFDW m^{-2}

respectively). Peak mean biomass was observed during winter and spring (9.4 and 9.5g AFDW m^{-2} respectively), while lowest biomass was recorded during summer (6.41g AFDW m^{-2}). The most comprehensive study of intertidal communities for the dry tropics has been conducted in North Queensland, Australia (Alongi, 1987, 1988, 1990). These studies also found that lowest faunal densities and associated biomass occur during the hottest months of the year. Comparison of present macrofaunal abundance with reported values from other tropical mudflats reveals Sulaibikhat Bay is as rich as similar habitats at different geographical locations, and richer than similar habitats within the Arabian Gulf region (Table 2.17). However, biomass values within the Bay were higher than those reported from similar tropical areas (Table 2.18). This high biomass suggests a high-energy flow from the habitat to nearby coastal areas which may support high pelagic productivity within the Bay.

The seasonal dynamics (abundance and biomass) of macrofaunal species is influenced not only by environmental conditions (González-Oreja & Saiz-Salinas, 1999), but also by the availability of food and the presence of predators (Sardá *et al.*, 1995). Vohra, (1971) suggested that reduction in exposure to sun, increase in moisture and a more continuous food supply effects the distribution along the intertidal gradient seawards, and that relatively low environmental stress may promote higher biodiversity and abundance at mid- and low intertidal levels of tropical shores. The lower intertidal mudflat region was not accessible in present work due to the thixotropy of the substratum, but visual inspection and observation suggest the presence of several macrofaunal communities, other than those sampled quantitatively, lower down the shore. Hence, it is postulated that the biodiversity, abundance and seasonal dynamics of the macrobenthic community of Sulaibikhat Bay is likely to be greater than presently calculated.

Table 2.17 Community structure of macrofauna in some tropical soft-sediment habitats at different geographical locations, in comparison with the current study.

Location	Mean abundance m^{-2} (Range)	Mean Species No. (Range)	Dominant Organism	Reference
Selangor, India	**305** (129-480)	**18** (16-19)	Bivalve & Gastropod	Broom, 1982
Surinam, S. America	**245**	-	Decapod	Swennen *et al.*, 1982
Sunderbans, India	**125** (68-329)	**15** (12-17)	Gastropod & Polychaete	Nandi & Choudhury, 1983
Saudi Gulf, Saudi Arabia	**241** (67-421)	**34** (15-51)	Polychaete	Coles & McCain, 1990
Sulaibikhat Bay, Kuwait	**304** (123-523)	**7** (1-17)	Decapod & Goby	Current Study

Table 2.18 Macrofaunal biomass in some tropical mudflat habitats at different geographical locations, in comparison with the current study.

Location	**Mean Biomass g DW m^{-2} (Range)**	**Reference**
Florida Keys, USA	**6.4** (5.3-7.90)	Holm, 1978
Gujarat Estuaries, India	**2.4** (0.3-4.10)	Govindan *et al.*, 1983
Gulf of Nicoya, Costa Rica	**2.0** (0.0-11.0)	Maurer & Vargas, 1984
Saudi Gulf, Saudi Arabia	**3.6** (0.9-7.20)	Coles & McCain, 1990
Sulaibikhat Bay, Kuwait	**8.24** (3.9-12.9)	Current study

Spatial and temporal variation within the Bay

In Sulaibikhat Bay, species composition, total abundance and total biomass varied both spatially and temporally. The community structure was noticeably different among the two sampling sites during the 13-month sampling period. On the whole, both species composition and total abundance were greater at the pristine site (TI, Ashish Al-Doha) than at the disturbed site (TII, Sulaibikhat), while total biomass was greater at the latter (Table 2.19). Seasonal dynamics of macro-infaunal species, quantitatively assessed at both transects, did not directly correspond. It is suggested that variation among the two sites assessed during this investigation reflects different levels of stress due to interrelated physiochemical and biological factors.

In regions where rainfall is sporadic, such as Kuwait, high temperatures and desiccation are one of the factors influencing seasonality of intertidal benthos. When the tide is out, the littoral habitat is exposed to the atmospheric weather. Temperature of the shore can be limiting if it rises due to insolation, however death from high temperatures is rare. Elevated temperatures may not affect the inhabitants of depositing shores as their burrowing activity mitigates the worst of climatic extremes. However, substrate type and gradients in associated physical and chemical factors are known to play an important role in the distribution, abundance and biomass of benthic infauna (Gray, 1981; Diaz and Schaffner, 1990). Death through high temperature can arise from a decrease in oxygen supply within the sediment, since both oxygen and temperature are inversely proportional to each other (Eltringham, 1973). Salinity is also known to strongly influence benthic infaunal communities. Coles and McCain (1990) assessed the species composition and abundance of benthic organisms along the Saudi Arabian coastline, and found that both infaunal biodiversity, and abundance significantly decreased with increase in sediment salinity and grain size. Newell (1965) has shown that abundance of a species can vary considerably even between areas few hundred yards apart, and concluded that particle size governs the intertidal distribution of fauna. Sardá *et al.* (1995) found that fauna at exposed sites with coarse grains, or extreme reducing conditions, are characterised by low species composition and biomass, while sites with moderate erosion and intermediate sediment organic content exhibit higher species composition and biomass.

The distribution of sedimentary organic carbon is related to water depth, grain size, terrestrial run-off, and hydrography (Romankevich, 1984). According to Premuzic *et al.* (1982), a carbon ratio generally less than 8% indicates a marine origin, whereas higher values suggest some terrestrial input. Recent studies conducted at the present sites revealed a sediment organic content ratio of 5.5% for the pristine site, while the disturbed site had a ratio of 12% (Al-Zaidan, 1999). This high level of organic carbon at the disturbed site, and the anoxic sediment, suggests increased organic enrichment associated with anthropogenic disturbance (sewage/industrial discharge). Grizzle (1984) assessed the effect of physiochemical changes on the macrobenthos of two lagoons in Florida USA, over a period of 24 months, comparing a sewage-polluted, moderately enriched site with a less-polluted site. The sewage-polluted, enriched site had less biodiversity and lower abundances than the less-polluted site. Ahn *et al.* (1995) assessed the influence of industrial effluents on intertidal benthic communities within a mudflat-dominated Bay in Korea, subject to rapid and heavy industrialisation. The area closest to the effluent source was devoid of macrofauna and was extremely anoxic, and even at a distance of 5km, traces of biological activity noticeably decreased over time (from 22 species in 1984, to 4 in 1992).

Anthropogenic disturbance, resulting in oxygen depletion causes hypoxia (O_2: 2.0- 0.0 ml l^{-1}) and anoxia (beyond 0.0 ml l^{-1}), and is considered to be the major stress factor in many enriched areas causing depletion of marine fauna (Pearson & Rosenberg, 1978; Santos & Simon, 1980a,b; Diaz and Rosenberg, 1995), and Sulaibikhat Bay is no exception. At the anthropogenically disturbed site (TII) several sewage outlets occur. Domestic wastewater discharged into the Bay is of high concentration and is often septic due to low flow rates, long retention periods and high temperatures (Al-Muzaini *et al.*, 1991). In addition, as Kuwait has a major problem with inefficient pumping stations, raw sewage is often discharged into the sea in emergency situations. Water near a major sewage outlet located close to Shuwaikh Port within the Bay has shown depleted dissolved oxygen (> 1 mg l^{-1}) and high H_2S values (6.1 mg l^{-1})(KISR, 1985). Discharges and the nature of the sediment result in the depletion of infauna. This is seen not only for total abundance of the macro-infaunal community, but also for fish populations migrating in with high tide. During the whole sampling period, no commercially important fish species were encountered at this site. It is likely that the chemical cue (H_2S) associated with anoxic conditions in the sediment may cause the overlying water during high tide to also become deoxygenated. Hypoxia is known to cause massive faunal mortality (Diaz & Rosenberg 1995). However, some species respond to low oxygen by escaping hypoxic areas through emigration (Baden *et al.*, 1990; Pihl *et al.*, 1991), or decreasing their metabolism (Hagerman, 1998; Sagasti *et al.*, 2001). Reduced oxygen conditions may also act as an important density-independent factor regulating the supply of postlarvae and survivorship of post-settlement crabs. Tankersley & Wieber (2001) studied the physological response of post-larval and juvenile blue crabs *Callinectes sapidus* to hypoxia and anoxia. They found that the crabs were generally very sensitive to hypoxia and that metamorphosis decelerated. Hence, difference in the spatial and temporal variation in the community structure within the bay may reflect active avoidance or tolerance/adaptation of faunal species to oxygen depletion represented by hypoxia and anoxia.

Although there was lower biodiversity and abundance at the disturbed site (TII), biomass was twice as much as that calculated for the natural site (TI). Community biomass has a tendency to increase with animal body size (González-Oreja & Saiz-Salinas, 1999). *Periophthlamus waltoni* dominated in high numbers at this site (TII), and had relatively larger body size than individuals occurring on the pristine site (TI). This carnivorous goby feeds on the minute brachyurans *T. indica* and *I. stevensi* (Chapter 4). These crab species graze on microbial mats (chapter 5) which are denser at TII than TI, due to increased organic input associated with sewage discharge. Such increase in mat productivity is reflected in the size of both *T. indica* and *I. stevensi* (Chapter 3), which may explain the increased biomass of *P. waltoni* at TII, since increased energy flow within a system is directly proportional to biomass (Poff *et al.*, 1993).

Physical modification of the upper littoral at Sulaibikhat site (TII) associated with infilling during the early 1980's has led to the disappearance of macro-infaunal niches, which in turn has caused extreme overlap and crowding between Zone I and II. Under these conditions, the occurrence of large numbers of the carnivorous goby *P. waltoni*, may have increased predatory risk and/or disturbed sediment stability for other borrowers such as the brachyuran community, resulting in lower species biodiversity (Desroy *et al.*, 1998).

Responses to disturbances by opportunistic species, as well as those of other species, can be quite variable and unpredictable. Zajac & Whitlatch (1982), found that monopolisation of space and/or food by 2 spionids in Alewife Cove, USA, inhibited the invasion of *Capitella* during the initial stages of succession. Richter and Sarnthien (1977) also found that for bivalves, the first larval species to arrive at a disturbed site may occupy all niches preventing settlement of later-arriving species. These are some of the many reasons that may explain the spatial and temporal variation within the Bay, and the dominance of *P. waltoni* at transect II, rather than the naturally-dominant species *Tylodiplax indica* and *Ilyoplax stevensi* (Snowden *et al.*, 1991, 1994).

The physical and biological processes discussed above are not the only factors that could cause variations in response to disturbance. They are however, examples of how fluctuations in physical factors and their effects on estuarine infauna can account for the spatial and temporal fluctuations observed in this study. The environmental conditions measured during this study, with exception of summer salinity, show no significant variation with measurements in previous studies conducted within the Bay (Anonymous, 1983; Snowden *et al.*, 1991; Snowden *et al.*, 1994). As inhabitants of these shores mitigate and adapt to the worst of climatic conditions, it is likely that anthropogenic disturbance associated with urbanisation and development, is probably responsible for the variation in community structure between the two sites. Sulaibikhat Bay serves as an important settlement and refuge site for commercially and ecologically important species, and present results indicate that disturbance may inflict serious changes upon the environmental quality of the bay, reducing its suitability as a nursery area by affecting the composition and abundance of benthic macrofauna, and altering the trophic interactions that lead to the top consumer, man.

Table 2.19 Total species (TS) Number, seasonal Abundance and Seasonal biomass at both transects within Sulaibikhat Bay.

	(Ashish Al-Doha) **TI**	**(Sulaibikhat)** **TII**
TS Number	**34**	**24**
Flora	4	3
Fauna		
Quantitative sampling	8	4
Qualitative sampling		
Fish traps	11	5
Bird sighting	7	6
Intertidal inspection	4	6
TS Seasonal Abundance (m^{-2})	**360**	**131**
TS Seasonal Biomass (g AFDW m^{-2})	**5.2**	**11.28**

CHAPTER III

DETECTION OF ENVIRONMENTAL CHANGE WITHIN SULAIBIKHAT BAY USING COMMON SPECIES AS BIO-INDICATORS

INTRODUCTION

While all intertidal areas are valuable ecological entities with a productive flora and fauna, mudflat habitats occurring within such intertidal areas are places of extraordinary biological interest, home to immense diversity of plants and animals, and may support some of the highest rates of primary production in the world (Jones *et al.*, 2002a). Such characteristics cause them to be highly sensitive and vulnerable to environmental modifications (Al-Bakri, 1996). Nevertheless, because these habitats are visually unappealing, they are often selected by coastal zone planners for reclamation associated with urban expansion, coastal development, and/ or industrialisation. Such activities strongly affect the habitat inflicting severe environmental modifications reducing biological diversity, abundance of natural resources, and quality of life in these habitats if not managed correctly (Clark, 2001). In order to predict the response of mudflats to environmental and anthropogenic pressures a greater scientific understanding of this productive habitat is required.

One approach to this understanding involves the detection of changes in the system through repeated observations "monitoring", by evaluating the condition of key groups of species "bio-indicators" within the environment in which they are found. A bio-indicator is an organism that signals not only direct chemical exposure and accumulation, but also potential ecologically adverse effects. They should be relatively sedentary or resident to the area of interest, easy to identify, abundant, long lived, be available for sampling all year and have a wide distribution (Rainbow, 1995). Ecologists frequently focus on the determination of population dynamics within an ecosystem as an index of biotic integrity (Begon *et al.*, 1996: Dobson *et al.*, 1998), by concentrating research on a single species, either of high conservation interest, or so common that its absence or presence has a major repercussion in the community. This may allow an explanation as to why its population within the community changes in abundance through time and space.

The marine environment of the Arabian Gulf is becoming increasingly important in fulfilling social economic development and strategic objectives of its member states. Recent industrialisation and urbanisation in western coastal countries has increased the use of coastal seas for waste discharge, oil transportation, desalination, the building of marinas and resorts, and expansion of residential areas. Coastal uses and other human activities inevitably impinge on the marine environment and its inhabitants.

Although soft sediment tidal flats dominate the western coast of the Arabian Gulf (Basson *et al.*, 1977; Jones, 1986a; Price *et al.*, 1993: Carpenter, 1997), and are considered to be vulnerable (Al-Bakri, 1996) but highly productive and important ecosystems (Basson *et al.*, 1977; Jones, 1985; Clayton, 1986; Jones *et al.*, 2002a,b), they have been given little priority either at the research level or by coastal planners. Although they harbour many juvenile stages of commercial species (Wright, 1988; Bishop, 2002) as well as species endemic to the Gulf (Jones & Clayton, 1983; Collins *et al.* ,1984; Apel and Türkay, 1999), no action has yet been made to monitor such areas and their associated biota for changes although they have been subjected to impact and modification.

Benthic invertebrates are typical inhabitants of coastal ecosystems, where they play an important ecological role in transferring energy through food webs. Brachyuran crustaceans, mainly Ocypodidae, often dominate the macrobiota of tropical and subtropical habitats, including the intertidal mudflat communities along the Western coast of the Arabian Gulf. Apel and Türkay, (1999) confirm that the western part of the Gulf has several endemic brachyuran species, although similar habitats do occur elsewhere, and that maximum grapsid and ocypodid crab diversity in the Arabian Gulf is found in Kuwait. Despite the presence of endemic species, information on their biology and ecology is still lacking in comparison to brachyuran genera elsewhere. A few studies deal with taxonomy (*Cleistostoma*, de Haan and *Paracleistostoma*, de Man; Jones and Clayton, 1983), re-classification (*Nasima dotilliformis*; Manning, 1991)(*Leptochryseus kuwaitense* and *Manningis arabicum*; Al-Khayat and Jones, 1996), and species biodiversity and distribution (Apel and Türkay, 1999). Even fewer studies have dealt with the ecology and biology of crabs in the region. Snowden *et al.*, (1991, 1994) initiated ecological studies on *Ilyoplax stevensi* (Kemp, 1919) and *Tylodiplax indica* (Alcock, 1900) demonstrating possible effects of temperature and salinity. In contrast, several other species of *Ilyoplax* have recently received intense ecological investigation worldwide (Wada, 1993, 1994; Wada *et al.*, 1995, 1996; Kitaura *et al.*, 1998; Aizawa, 1998, 2000).

Results of the present study described in chapter 2 (Table 2.11, Figure 2.23-2.24) describe the zonation and species composition of some brachyuran species found along the intertidal mudflats located within the southern coast of Kuwait Bay, as well as their abundance and biomass. The study revealed that two ocypodid crabs, *Ilyoplax stevensi* (Kemp, 1919) and *Tylodiplax indica* (Alcock, 1900), are common and highly abundant along the coastline of the Bay (chapter 2). These crabs form a major source of nutrition for many carnivorous and omnivorous species inhabiting the mudflats, as well as for tidal immigrants (Jones, 1986a; Al-Mohanna, pers. comm.; chapter 4).

Since decapod crustaceans are known to be effective bio-indicators (Rainbow, 1990), and dominate the fauna on the mudflats of Kuwait Bay, it is hypothesised that such macrofaunal species are likely to act as bio-indicators of environmental stress. Present research concentrates on their population dynamics, breeding patterns and recruitment in both un-impacted and modified mudflat habitats along the coast of Sulaibkhat Bay, from June 98 to June 99. These results are then compared to evaluate the impacts on crab population associated with habitat modification, to establish a baseline for future comparison and bio-monitoring.

METHODOLOGY

Research was conducted along the two transects located in Sulaibikhat Bay (see chapter 2 for details), that were sampled bimonthly over a period of 13 months, from June 98 till June 99. During each visit, 7 random sediment extracts (each $0.05m^2$, 15cm depth; total individuals/$0.35m^2$) were obtained from each transect. Extracts were individually placed in a labelled container and transferred to the laboratory, where they were washed through a 500 micron sized mesh, and all infaunal species retained by the mesh were removed and stored in a freezer for processing.

Prior to processing, each sample was left at room temperature to thaw. Required species were then removed from each sample and their maximum carapace width [CW] was measured to the nearest 0.5mm using a micrometer under a binocular microscope, and sexed by checking the abdomen. Females were checked for presence of eggs on the abdomen (sexable crabs: males [M], non-oviparous females [NOF], ovigerous females [OF]). Individuals with a carapace width <3mm were difficult to sex and were arbitrarily classed as juveniles ([J] = non-sexable crabs).

MINITAB was used to conduct statistical description analysis on the data obtained. Depending on the nature of the data, either a 2-sample quantitative analysis (parametric: 2-sample t-test), or a non-parametric statistical analysis (Moods median test) was conducted.

RESULTS

Seasonal Distribution

Monthly abundance of non-sexable and sexable crabs of both species, occurring at both sites (TI: Ashish Al-Doha, TII: Sulaibikhat), is shown in table 3.1.

Ilyoplax stevensi

Figure 3.1 illustrates a comparison between the population abundance of *Ilyoplax stevensi* at both Transect I (Ashish Al-Doha) and transect II (Sulaibikhat) within Sulaibikhat Bay.

At TI, the total population obtained during the 13 month sampling period was slightly higher than that at TII (725 and 690 individuals respectively). However, upon comparing the mean monthly abundance at both transects no significant difference was detected (TI= 55.77±9.03 ind./m^2, TII= 53.08±7.96 ind./m^2; T= 0.22, $p>0.10$). The highest population was recorded during January 99 at TI with a value of 118 ind.m^2, and during June at TII (112 ind./m^2). During September/October 98, the lowest population of *I. stevensi* was obtained at both transect I and transect II (22 and 12 ind./m^2 respectively).

Figure 3.2 shows a comparison between the monthly abundance of non-sexable (juveniles) and sexable (males and females) crabs at both transects.

Juveniles: non-sexable crabs (<3mm CW) were collected in abundance at both transects (TI= 36 individuals, TII= 19 individuals). Juveniles occurred during 7 months of the 13 month sampling period at TI, but were absent during July 98-November 98 and May 99. However, at transect II they only occurred during 2 months: December 98 & January 99. The maximum juvenile frequencies occurred during January 99 at both TI and TII (18 ind./m^2, and 12 ind./m^2 respectively).

Sexable crabs (> 3mm in carapace width [CW]) occurred commonly at both transects. Ratio of males to females was approximately 1:0.8, with female frequencies 10% less than those of males. Both sexes showed high abundance during the second half of the sampling period, specifically during winter season (December 98-February99), while had the lowest during the summer season (June 98-August 98).

Males: total male population obtained during the 13 month sampling period was slightly higher at transect I (382 individuals) than transect II (365 individuals). The mean abundance value of 29.38 ± 4.26 ind./m^2 recorded for TI was almost similar to that recorded at TII (28.08 ± 5.21 ind./m^2), with t-test results showing no significant difference between the two values (T= 0.19, $p>0.10$). The lowest abundance of males recorded at both transects was during August 98 (TI= 10 ind./m^2, TII= 5 ind./m^2). Another minimum level was recorded at both transects during October 98 (TI= 12 ind./m^2, TII= 8 ind./m^2). During February 99, male abundance reached a high of 59 ind./m^2 at TI, however at TII, the highest abundance value of 71ind./m^2 was recorded in June 99.

Females: total female population obtained throughout the whole sampling period was almost identical at both transect I and transect II (307 and 306 individuals respectively). Hence, there was no significant difference between the mean monthly abundance for both transects (TI= 23.62 ± 3.78 ind./m^2, TII= 23.54 ± 3.30 ind./m^2; T= 0.02, $p>0.10$). During July & November 99, the lowest abundance was recorded at TI (9 ind./m^2), while the highest was during January 99 with a value of 47 ind./m^2. At transect II, lowest female abundance occurred during October 98 with a value of 4 ind./m^2. The highest abundance value of 41 ind./m^2 was recorded during June 99.

Figure 3.3 shows the monthly abundance of non-ovigarous and ovigarous females at both TI and TII.

At both transects the ratio of non-ovigarous females to ovigarous females was approximately similar (TI→ 1:0.4, TII→ 1:0.3) showing no significant difference ($p>0.10$). At both transects, ovigarous females represented a high 75% of the total female population during September 98. However the lowest percentage of ovigerous females was recorded during June 99 at TI (10%), and during July & August 98 at TII (0%).

The abundance of non-ovigerous females did not differ significantly from each other at both transect I and II (17.23 ± 3.15 and 18.23 ± 2.91 ind./m^2 respectively; T= -0.23, $p>0.05$). The highest abundance value of 40 ind./m^2 was recorded in February 99 for TI, and during June 99 for TII (39 ind./m^2). Both transects showed lowest abundance during September and October 98 (TI= 3 ind./m^2, TII= 2 ind./m^2).

Two sample t-test showed that the mean monthly abundance of ovigarous females at both transects did not differ significantly (TI= 6.38 ± 1.67 ind./m^2, TII= 5.31 ± 1.28 ind./m^2; T= 0.51, $p>0.10$). During January 99, ovigerous female abundance reached a high of 25 ind./m^2 at TI, and a high value of 16 ind./m^2 during February 99 at TII. Lowest abundance occurred during November 98 & June 99 at TI (2 ind./m^2), however at transect II, no ovigarous females where obtained during July & August 98.

Tylodiplax indica

Figure 3.4 compares total population abundance of *T. indica* at TI, Ashish Al-Doha and TII, Sulabikhat.

Total population obtained during the survey period at transect I was approximately 18 times greater than that at TII (3608 and 204 individuals respectively). The non-parametric Moods median test revealed that the mean population at both transects differed significantly (TI= 277.5 ± 23.9 ind./m^2, TII= 15.69 ± 5.87 ind./m^2; χ^2 [chi-square] =26.00, $p<0.001$). During February 99, the highest population was recorded at TI (501 ind./m^2), and during May 99 at TII (75 ind./m^2). The lowest population value of 164 ind./m^2 was obtained during June 99 at TI. At TII, *Tylodiplax indica* was absent during June 98, July 98, September 98 and March 99.

Abundance of sexable non-sexable crabs (juveniles) and (males & females) at both transects is illustrated in figure 3.5.

Juveniles: during the entire survey period, non-sexable crabs reached a value of 202 individuals at TI. No juveniles were recorded at transect II. Juvenile crabs at transect I occurred during almost all of the 13 sampling periods except July 98, reaching a high of 49 ind./0.9m^2 during November 98.

At TI, sexable crabs occurred more frequently and were more numerous than at transect II. However at both transects, the male to female ratio was the same (1:0.9), with females approximately 5% less than males. Both males and females at TI showed high abundance during winter season (December 98-February 99), while the lowest occurred during summer 98 (June 98-August 98). At transect II, both sexes showed high abundance in spring 99 (March 99-May 99), with summer 98 having the lowest recorded abundance.

Males: During the entire survey, the total male population at TI had a value of 1777 ind./m^2, which was 16.5 times higher than that obtained from TII (108 ind./m^2). A mean monthly abundance value of 136.7 ± 12.1 ind./m^2 was recorded for TI, while a mean value of 8.31 ± 3.08 ind./m^2 was obtained for TII, thus both values differed significantly (mood median test: χ^2= 26.00, $p<0.001$). During February 99, the highest male abundance was recorded at TI (256 ind./m^2), while the lowest was recorded in June 99 (78 ind./m^2). at TII, the species was absent during June 98, July 98, September 98 and March 99, however a high of 39 ind./m^2 occurred during May 99.

Females: at transect I, 1629 individuals were collected throughout the 13 month sampling period, which was much greater than that obtained at TII (83 individuals). It was evident from the mean values at both transects that a significant difference occurs between abundances at both transects (TI= 125.3 ± 11.2 ind./m^2, TII=7.38 ± 2.90 ind./m^2; χ^2=26.00, $p<0.001$). At TI, lowest abundance was during June 99 (74 ind./m^2), while highest was during February 99

(227 ind./m^2). Females were absent at TII during June 98-September 98, and March 99, with highest abundance recorded during May 99 (36 ind./0.9m^2).

The monthly abundance of non-ovigerous and ovigerous females at both transects is shown in figure 3.6.

Non-ovigerous females to ovigerous females represented a ratio of 1:0.25 at TI, and a ratio of 1:0.16 at TII, with no significant difference between ratios ($p>0.05$).

The mean monthly abundance of non-ovigerous females at transect I was 15.7 times higher than that occurring at TII (99.9 ± 14.1 and 6.38 ± 2.42 ind./m^2 respectively), hence the occurrence of significant difference between both values ($\chi^2=26.00$, $p<0.001$). Non-ovigerous females reached a high abundance during February 99 (221 ind./m^2), and a low value of 48 ind./m^2 during July 98 at TI. At transect II, a high of 29 was recorded in May 99, however low abundance was represented by their absence from June 98-September 98 and March 99.

During July 98, ovigerous females represented a high of 51% of the total female population at TI, while non where recorded in December 98. At transect II, ovigerous females appeared for the first time during April 99 (11%), gradually increased through May (19%), reaching a high of 50% of total female population recorded during June 99.

Table 3.1 Monthly abundance of non-sexable and sexable crabs of both species, occurring at both sites (TI, Ashish Al-Doha; TII, Sulaibikhat) during the 13-month sampling period. [M, males; NOF, non-ovigerous females; OF, ovigerous females; J, juveniles].

	ILYOPLAX									
	Ashish Al-Doha (TI)					Sulaibikhat (TII)				
month	**M**	**NOF**	**OF**	**J**	**TOTAL**	**M**	**NOF**	**OF**	**J**	**TOTAL**
JUN98	32	20	4	1	**57**	36	16	2	0	**54**
JLY	14	6	3	0	**23**	11	12	0	0	**23**
AUG	10	11	3	0	**24**	5	15	0	0	**20**
SEP	17	3	9	0	**29**	19	2	6	0	**27**
OCT	12	3	7	0	**22**	8	2	2	0	**12**
NOV	18	7	2	0	**27**	37	22	7	0	**66**
DEC	33	13	4	4	**54**	23	8	9	7	**47**
JAN99	53	22	25	18	**118**	30	26	11	12	**79**
FEB	59	40	6	8	**113**	24	21	16	0	**61**
MAR	35	31	5	3	**74**	13	25	4	0	**42**
APR	34	25	5	1	**65**	35	24	6	0	**65**
MAY	40	25	8	0	**73**	53	25	4	0	**82**
JUN99	25	18	2	1	**46**	71	39	2	0	**112**
TOTAL	**382**	**224**	**83**	**36**	**725**	**365**	**237**	**69**	**19**	**690**
	TYLODIPLAX									
JUN98	116	75	47	1	**239**	0	0	0	0	**0**
JLY	109	48	50	0	**207**	0	0	0	0	**0**
AUG	147	59	39	14	**259**	11	0	0	0	**11**
SEP	153	88	25	15	**281**	0	0	0	0	**0**
OCT	101	91	5	25	**222**	15	11	0	0	**26**
NOV	152	140	1	49	**342**	2	2	0	0	**4**
DEC	124	126	0	25	**275**	2	2	0	0	**4**
JAN99	148	169	5	26	**348**	8	13	0	0	**21**
FEB	256	221	6	18	**501**	2	6	0	0	**8**
MAR	127	81	40	3	**251**	0	0	0	0	**0**
APR	161	82	64	8	**315**	17	16	2	0	**35**
MAY	105	66	27	6	**204**	39	29	7	0	**75**
JUN99	78	53	21	12	**164**	12	4	4	0	**20**
TOTAL	**1777**	**1299**	**330**	**202**	**3608**	**108**	**83**	**13**	**0**	**204**

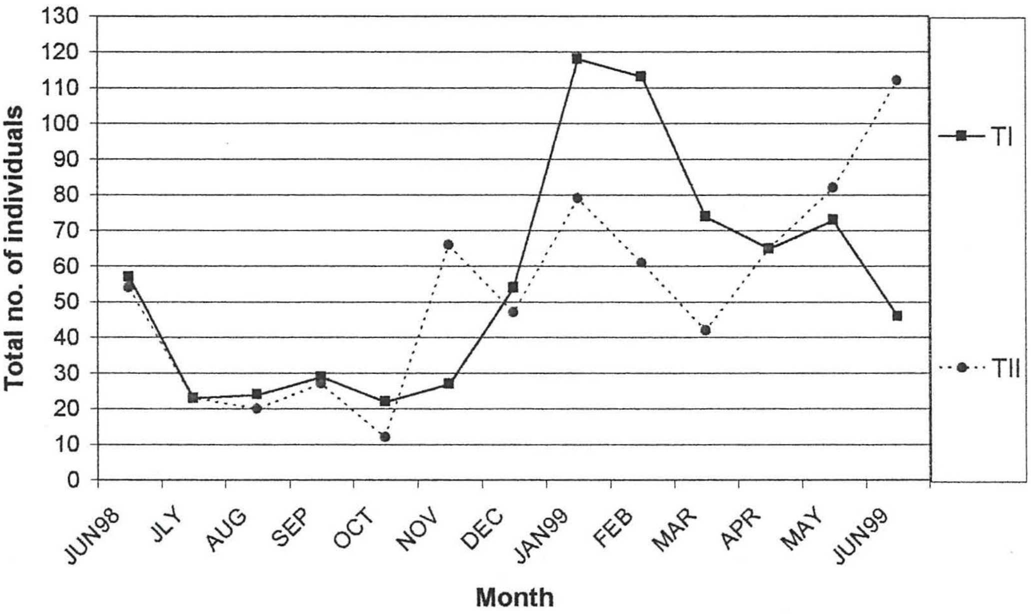


Figure 3.1 Abundance of *Ilyoplax stevensi* at both TI (Ashish Al-Doha) and TII (Sulaibikhat) during the survey period (June 98-June 99)

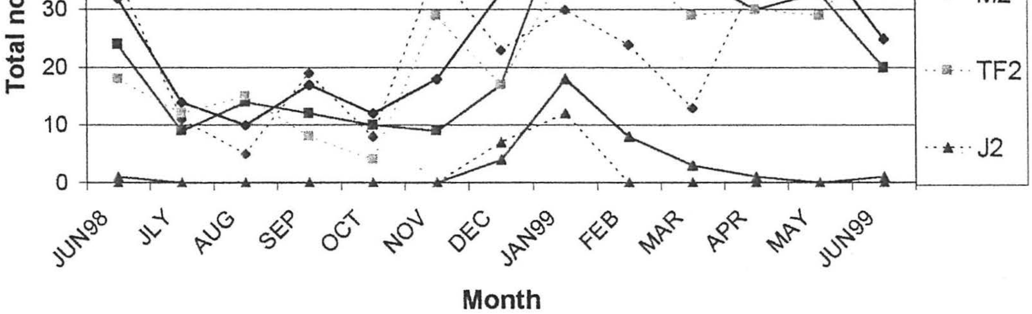


Figure 3.2 Abundance of non-sexable and sexable *Ilyoplax stevensi* at both TI (Ashish Al-Doha) and TII (Sulaibikhat) during the survey period (June 98-June 99) [M1=males at TI, TF1=total female at TI, J1=juveniles at TI; M2=males at TII, TF2=total females at TII, J2=juveniles at TII].

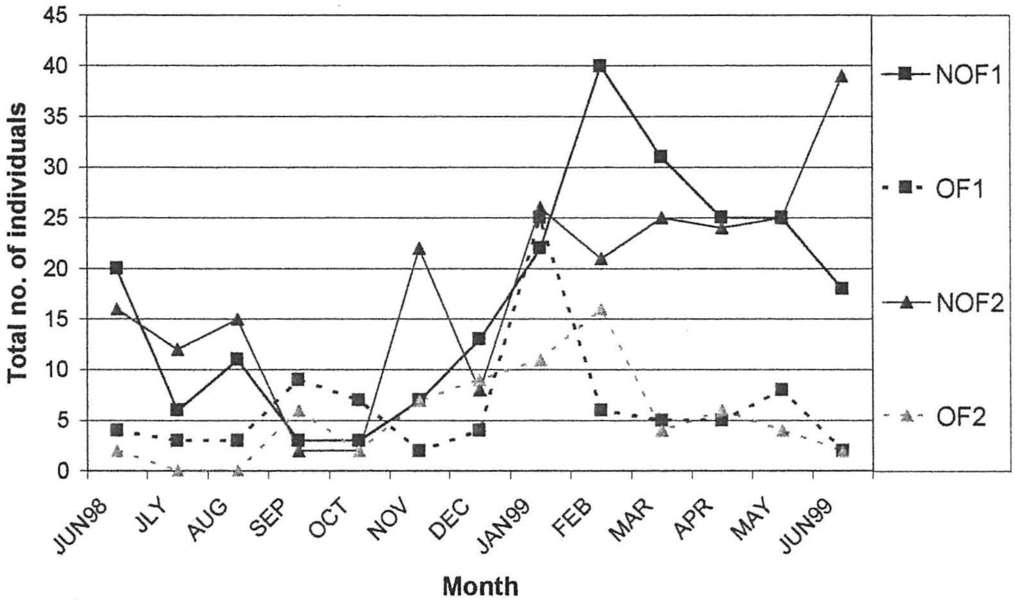


Figure 3.3 Abundance non-ovigerous and ovigerous *Ilyoplax stevensi* at both TI (Ashish Al-Doha) and TII (Sulaibikhat) during the survey period (June 98-June 99) [NOF1= non-ovigerous females at TI, OF1=ovigerous females at TI; NOF2=non-ovigerous females at TII, OF2=ovigerous females at TII].

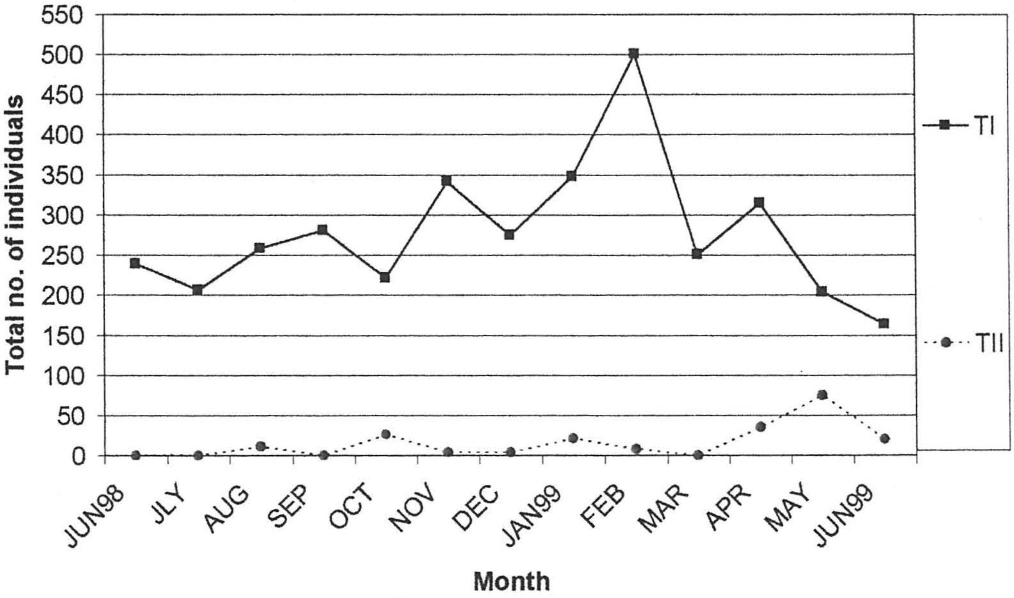


Figure 3.4 Abundance non-sexable and sexable *Tylodiplax indica* at both TI (Ashish Al-Doha) and TII (Sulaibikhat) during the survey period (June 98-June 99).

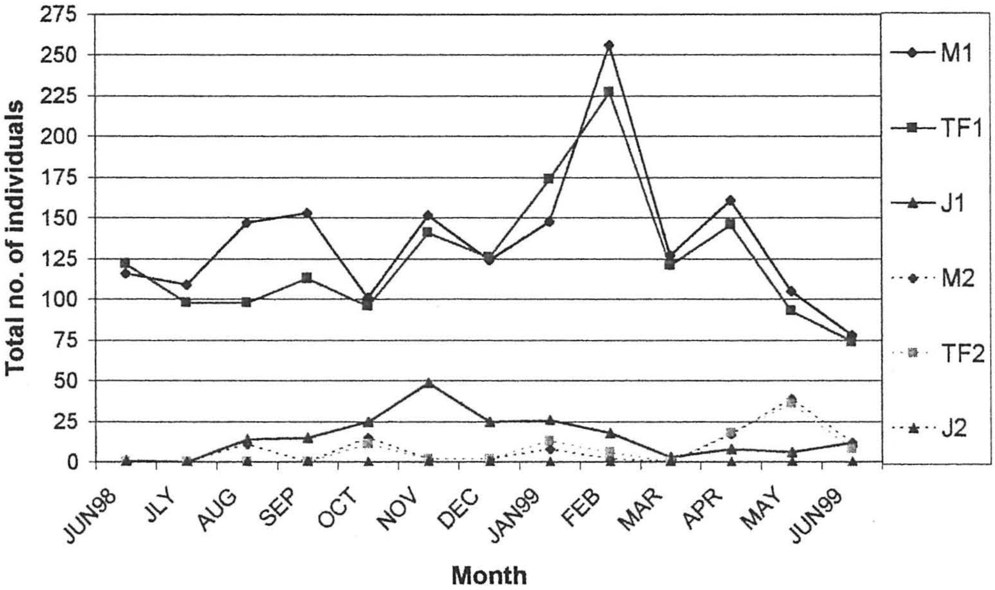


Figure 3.5 Abundance non-sexable and sexable *Tylodiplax indica* at both TI (Ashish Al-Doha) and TII (Sulaibikhat) during the survey period (June 98-June 99) [M1=males at TI, TF1=total female at TI, J1=juveniles at TI; M2=males at TII, TF2=total females at TII, J2=juveniles at TII].

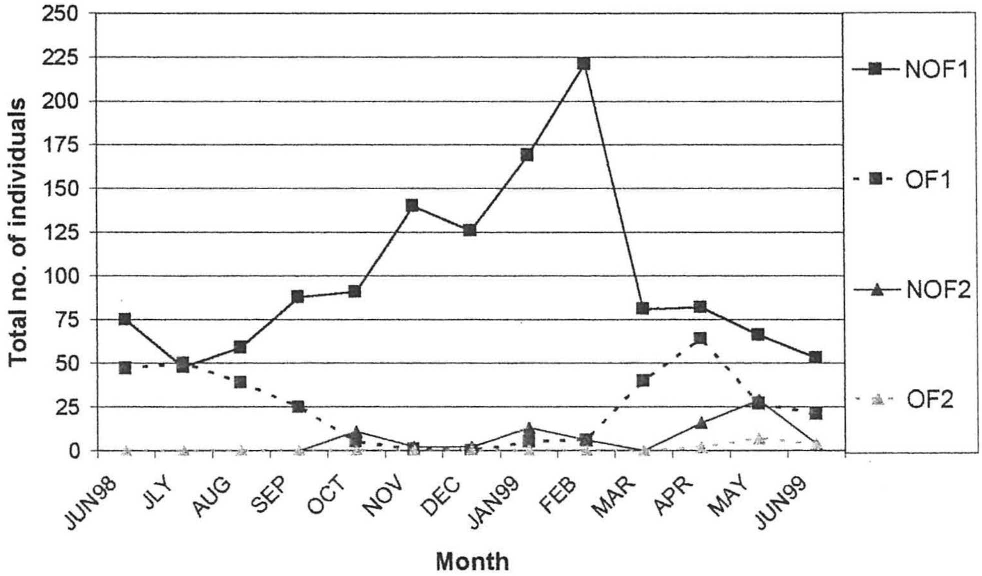


Figure 3.6 Abundance non-ovigerous and ovigerous *Tylodiplax indica* at both TI (Ashish Al-Doha) and TII (Sulaibikhat) during the survey period (June 98-June 99) [NOF1= non-ovigerous females at TI, OF1=ovigerous females at TI; NOF2=non-ovigerous females at TII, OF2=ovigerous females at TII].

Seasonal Population Structure

Ilyoplax stevensi

Figures 3.7 and 3.8 show the total carapace width frequency distribution of males, non-ovigerous females, ovigerous females and juveniles collected during the survey at TI and TII respectively.

TI: There was a single mode at 6mm CW of all males collected, with size ranging between 3 to 9mm (figure 3.7a). There was 1 mode for non-oviGarous females at 4mm, with carapace width ranging between 3 to 8.5mm (figure 3.7b). Size of ovigerous females collected during the survey at TI ranged between 4.5 and 10mm CW, having a single mode at 6.5mm (figure 3.7c). Non-sexable crabs (=Juveniles<3mm in carapace width [CW]) ranged in size from 2 to 2.5mm, and had a single mode at 2.5mm (figure 3.7d).

TII: males collected during the survey ranged between 3 and 9.5mm, having a single mode at 7mm (figure 3.8a). Non-ovigerous females also exhibited a single mode, at 5mm and, ranging in size from 3 to 9mm (figure 3.8b). There was a single mode at 8mm for ovigerous females, with size ranging between 5.5 and 8.5mm (figure 3.8c). Juveniles had a single mode at 2.5mm CW, ranging in size between 2 and 2.5mm (figure 3.8d).

Figures 3.9 & 3.10 show the monthly carapace width frequency distribution of males and non-ovigerous females respectively, during each of the 13 sampling periods at TI. The monthly carapace width frequency distribution of males and non-ovigerous females at TII are illustrated in figures 3.11 and 3.12 respectively.

TI: The carapace width frequency distribution of males and non-ovigerous females show a varying number of modes throughout each of the 13 sampling periods. Both male and non-ovigerous female populations tend to be mostly concentrated in the mid-size (5.5-7.5mm) during the first 6 months of the survey (June 98- November 98). However, during the remaining months (December 98-

February 99) the size class reaches low ranges (3 to 5mm), gradually reaching mid-range size class towards the end of the survey period.

TII: the carapace width frequency distribution of males and non-ovigerous females at this transect also showed a varying number of modes. In general, the male population tended to be concentrated within the mid-size (5.5 to 7.5mm) and large size class range (8 to 10mm) during most of the sampling periods, except during November 98, January 99-March 99 and June 99, where the modes where located within the low class range. During June 98-August 98, the non-ovigerous female population was concentrated within the mid-range size class. During November 98, half of the population was concentrated in the low class range, however from January 99 till June 99, most of the population was concentrated within the low size class, in some cases having two modes, one at low-range and another at mid-range.

Tylodiplax stevensi

Total carapace width frequency distribution of males, non-ovigerous females, ovigerous females and juveniles collected throughout the survey period at both TI and TII are illustrated in figures 3.13 & 3.14 respectively.

TI: (figure 3.13a) size of males collected during the survey ranged between 3 and 9.5mm, having a single mode at 5mm. There was a single mode at 6mm for non-ovigerous females, with carapace size ranging from 3 to 9.5mm (figure 3.13b). Ovigerous females ranged in size from 4 to 9mm, with a single mode at 6.5mm (figure 3.13c). Juveniles ranged in size from 2 to 2.5mm, with a mode at 2.5mm (figure 3.13d).

TII: (figure 3.14a) males had 2 modes, at 3.5 and 6mm, ranging in size between 3mm and 12mm CW. Non-ovigerous females collected during the survey had a single mode at 6.5mm, with carapace width ranging from 3.5 to 9.5mm (figure 3.14b). Ovigerous females ranged in size from 9 to 15mm, having a single mode at 15mm (figure 3.14c).

Figure 3.15 & 3.16 shows the monthly carapace width frequency distribution of *Tylodiplax indica* males and non-ovigerous females respectively during each of the 13 sampling periods at TI. The monthly carapace width frequency distribution of males and non-ovigerous females at TII are represented in figure 3.17 & 3.18 respectively.

TI: carapace width frequency distribution of males and non-ovigerous females shows a varying number of modes throughout each of the 13 sampling periods. During the beginning of the survey (June-July 98), the male population was concentrated within the mid class size range (5.5-7.5mm CW). From August 98-February 99, most of the male population tended to be concentrated within the low class range (3-5mm CW). From June 98-January 99, non-ovigerous females were mostly concentrated within the mid-range size class. However, during February 99, approximately the same number of individuals were present within both low and mid-range class. Within the period from March 99-June 99, individuals from low-range class slightly out-numbered those within the mid-range class.

TII: a varying number of modes were noticed for males and non-ovigerous female carapace width frequency distributions at this transect. During August 98, November 98 and February 99, all male population was concentrated within the low range class, however during December 98-January 99 the male population was totally within the mid-range class. During April, male individuals classified within low-range dominated. Mid-range sized male crabs dominated during May 99, while individuals within the high-range class (>8mm CW) dominated during June 99. Non-ovigerous females of mid-range size prevailed during most months when population occurred. However, individuals from low-range size class represented over 95% of the non-ovigerous population during April 99.

Reproduction

Ilyoplax stevensi

Figures 3.19 and 3.20 represent monthly abundance of juveniles and ovigerous females at both transect I and transect II respectively.

It is evident that the frequencies of ovigerous females fluctuates during the 13 month sampling period at TI, showing a peak during January 99, and dropping to 0.25 of the peak in February 99. Juveniles appear in June 98, re-appearing after a 5 month absence in December 99, reach a peak in January 99, then drop to a third of peak value in February 99, and gradually decrease disappearing in May. However at TII, frequencies of ovigerous females show a gradual increase from October 98, reaching a peak during February 99, then dropping to 0.25 of the peak in March 99. Juveniles at TII are absent throughout the 11 months of the sampling period, first appearing in December 98, reaching its peak in January 99.

Figure 3.21 represents size-frequency distribution of *Ilyoplax stevensi*, combined from June 98 to June 99, within Sulaibikhat Bay (TI and TII).

It appears that young males and females (non-breeding, ≤ 5mm) occur throughout the whole sampling period reaching lowest occurrence during summer season (specifically Aug. 98), and highest during winter season (Jan. 99). It is probable that those recruiting in as juveniles and young males and females during summer (June 98), grow rapidly to form the breeding population during September (autumn season). Off-spring from the September breeding population seem to recruit during winter, giving a high number of recruits which may form the mature (breeding) population during the spring season.

Tylodiplax indica

Figures 3.22 and 3.23 represent monthly abundance of juveniles and ovigerous females at both transect I and transect II respectively.

Frequencies of ovigerous females and absence of juveniles fail to present an obvious reproductive pattern at TII. Two peaks for ovigerous females occur at transect I. the 1st peak occurred in July 98, values gradually decreased till disappearing in December 98. Ovigerous females re-appeared in January 99, gradually increasing to reach a second larger peak during April 99, followed by a gradual decrease. Juveniles appeared in August 98 following the first ovigerous female peak, and then gradually increased to reach a maximum during November 98. A gradual increase then occurred with juveniles reaching their minimum in March 99, showing a fluctuating increase after the second ovigerous female peak. Since no juveniles were found, and the fact that ovigerous females only appeared during the last 3 months of the survey period at transect II, no trend was detectable.

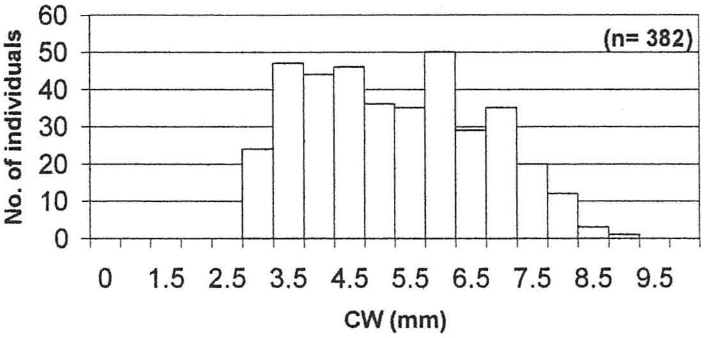
Figure 2.24 represents the size-frequency distribution of *Tylodiplax indica*, combined from June 98 to June 99, within Sulaibikhat Bay (TI and TII).

Breeding period mainly takes place throughout spring and summer seasons, with peak spawning during April. Offspring from the summer breeding population seem to contribute to the new recruits which reach their high numbers during February 99.

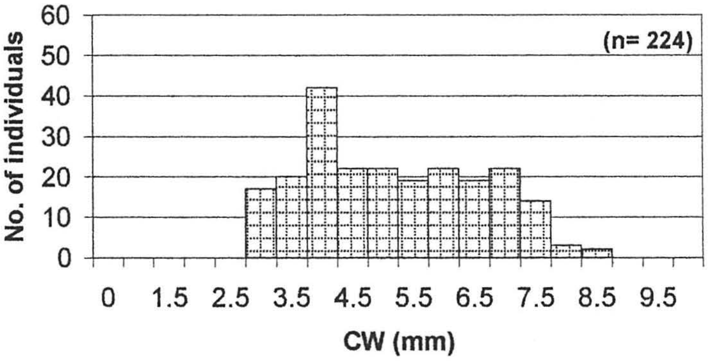
Figure 3.7

Carapace width total-frequency distribution of sexable and non-sexable *Ilyoplax stevensi* at TI Ashish Al-Doha.

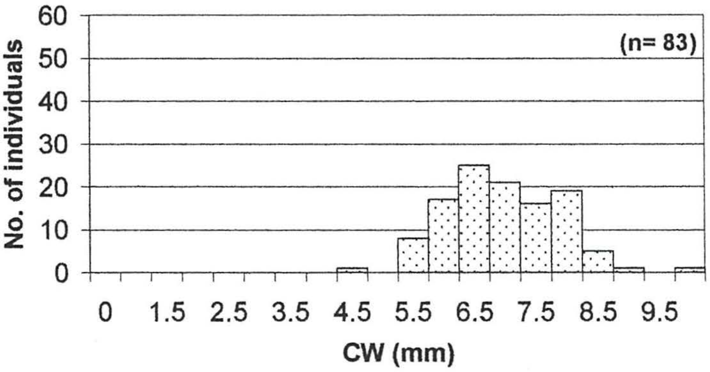
a. Males
b. Non-ovigerous females
c. Ovigerous females
d. Juveniles


(n= 382)
No. of individuals
0
10
20
30
40
50
60
0
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
CW (mm)

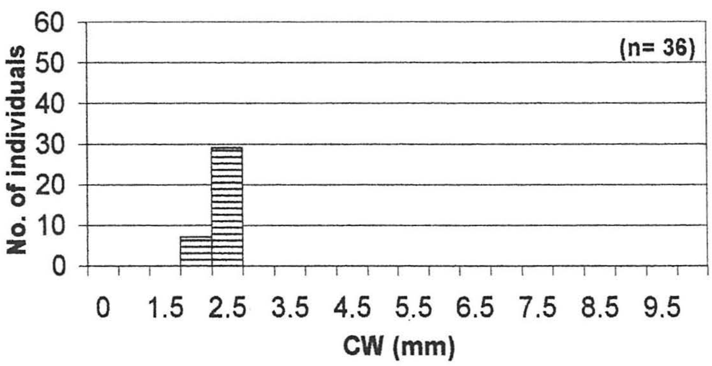
a.


(n= 224)
No. of individuals
0
10
20
30
40
50
60
0
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
CW (mm)

b.


(n= 83)
No. of individuals
0
10
20
30
40
50
60
0
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
CW (mm)

c.

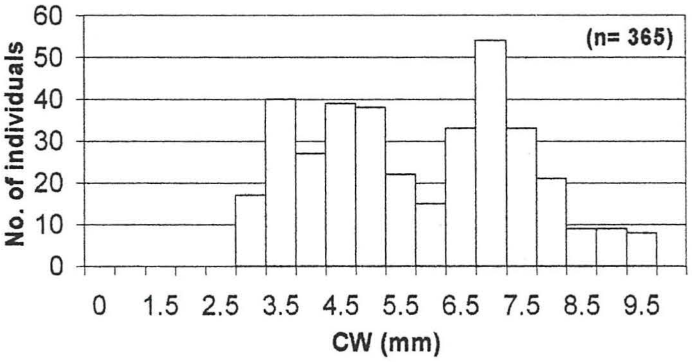

(n= 36)
No. of individuals
0
10
20
30
40
50
60
0
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
CW (mm)

d.

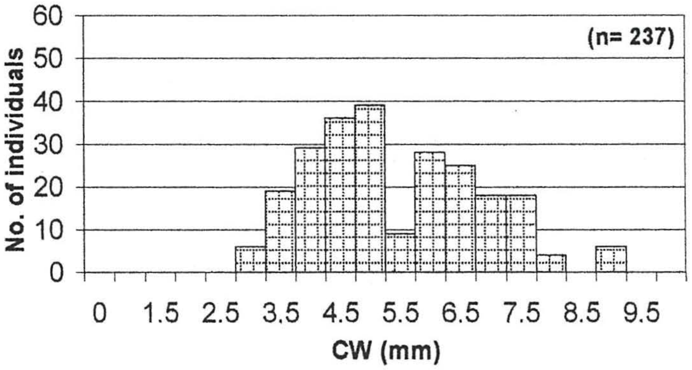
Figure 3.8

Carapace-width total-frequency distribution of sexable and non-sexable *Ilyoplax stevensi* at TII, Sulaibikhat.

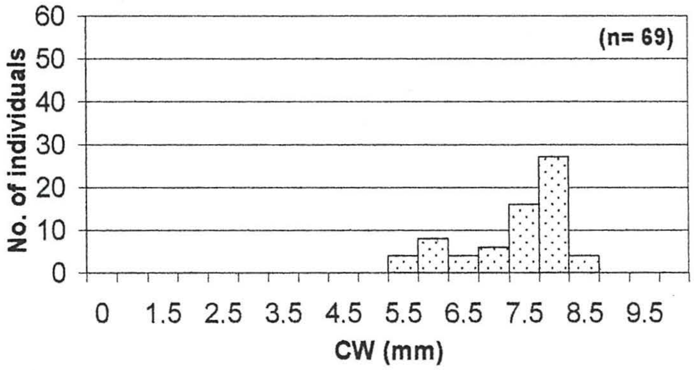
a. Males
b. Non-ovigerous females
c. Ovigerous females
d. Juveniles


(n= 365)
No. of individuals
60
50
40
30
20
10
0
0
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
CW (mm)

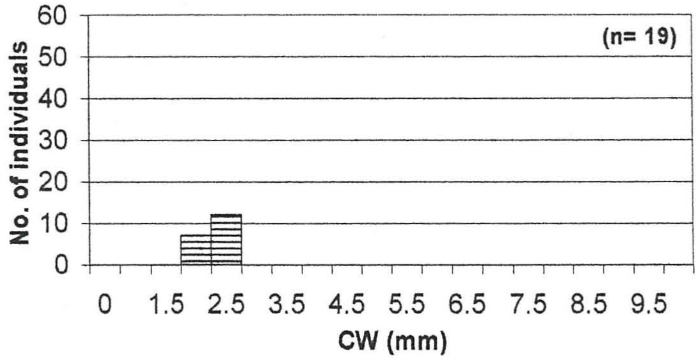
a.


(n= 237)
No. of individuals
60
50
40
30
20
10
0
0
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
CW (mm)

b.


(n= 69)
No. of individuals
60
50
40
30
20
10
0
0
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
CW (mm)

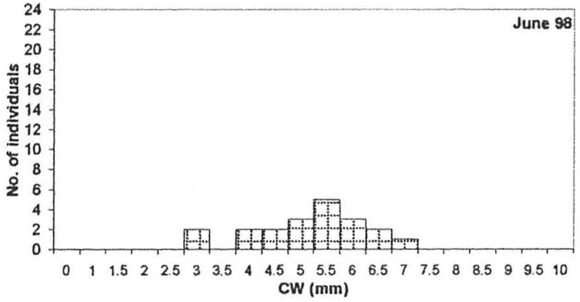
c.

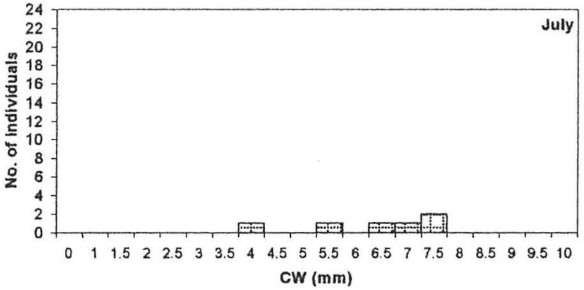

(n= 19)
No. of individuals
60
50
40
30
20
10
0
0
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
CW (mm)

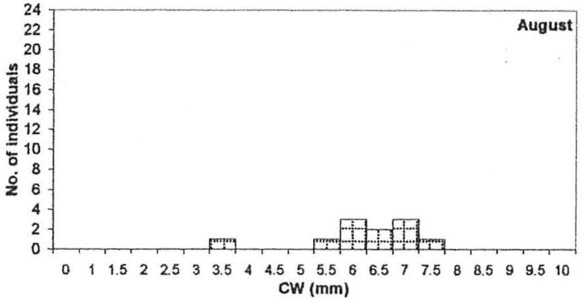
d.

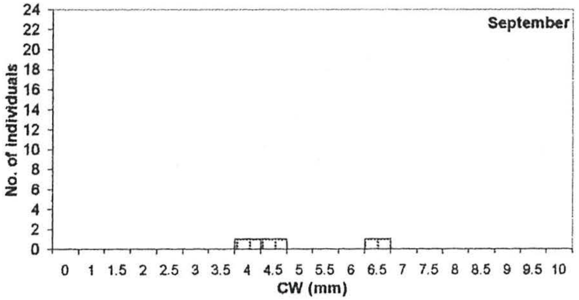
Figure 3.9

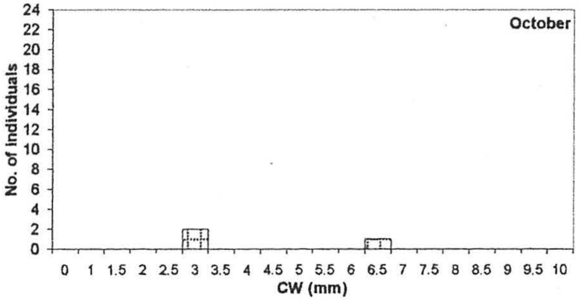
Monthly carapace-width frequency distribution of male *Ilyoplax stevensi* at TI (Ashish Al-Doha), during each of the 13 sampling periods.

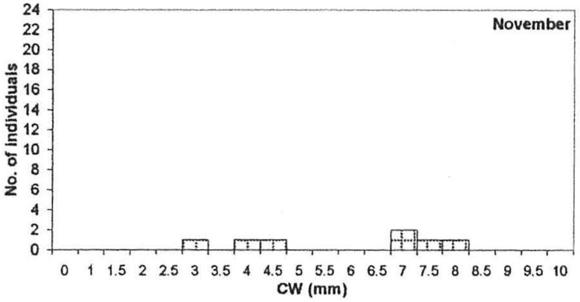

June 98
No. of individuals
0 2 4 6 8 10 12 14 16 18 20 22 24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

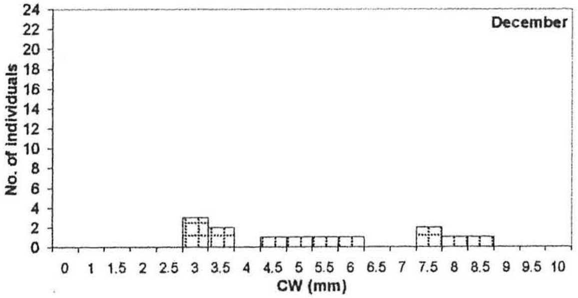

July
No. of individuals
0 2 4 6 8 10 12 14 16 18 20 22 24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

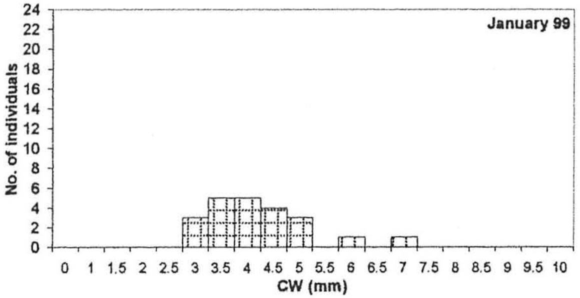

August
No. of individuals
0 2 4 6 8 10 12 14 16 18 20 22 24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

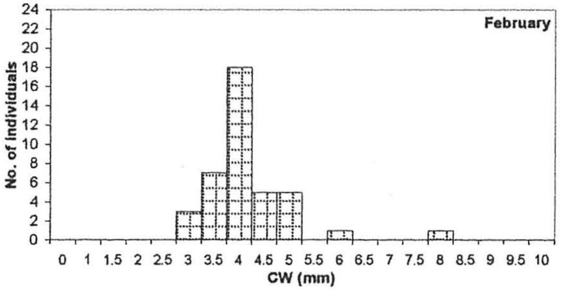

September
No. of individuals
0 2 4 6 8 10 12 14 16 18 20 22 24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

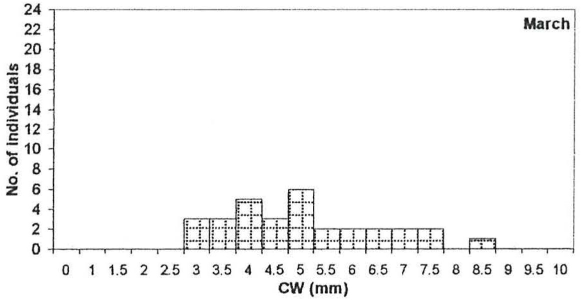

October
No. of individuals
0 2 4 6 8 10 12 14 16 18 20 22 24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

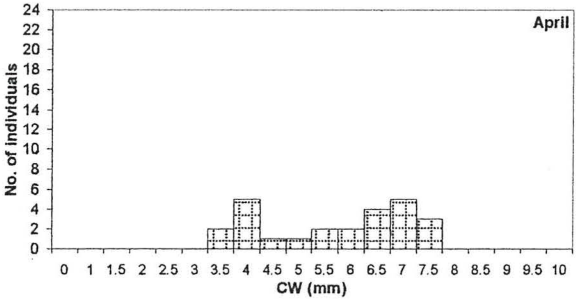

November
No. of individuals
0 2 4 6 8 10 12 14 16 18 20 22 24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

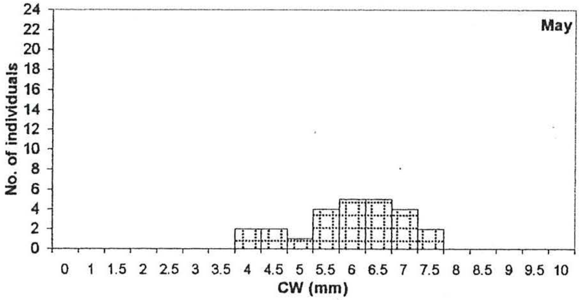

December
No. of individuals
0 2 4 6 8 10 12 14 16 18 20 22 24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


January 99
No. of individuals
0 2 4 6 8 10 12 14 16 18 20 22 24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


February
No. of individuals
0 2 4 6 8 10 12 14 16 18 20 22 24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


March
No. of Individuals
0
2
4
6
8
10
12
14
16
18
20
22
24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


April
No. of Individuals
0
2
4
6
8
10
12
14
16
18
20
22
24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


May
No. of individuals
0
2
4
6
8
10
12
14
16
18
20
22
24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

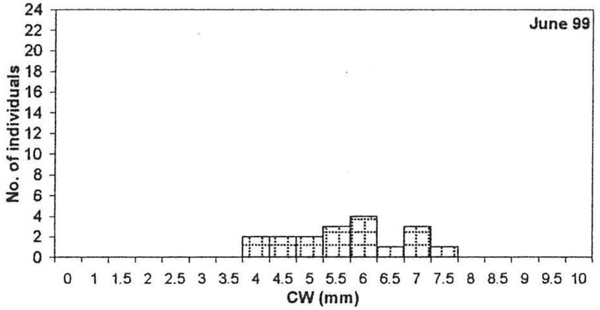
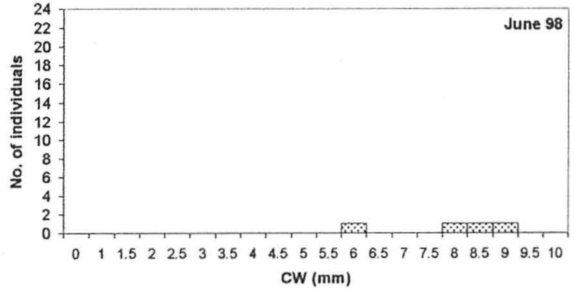
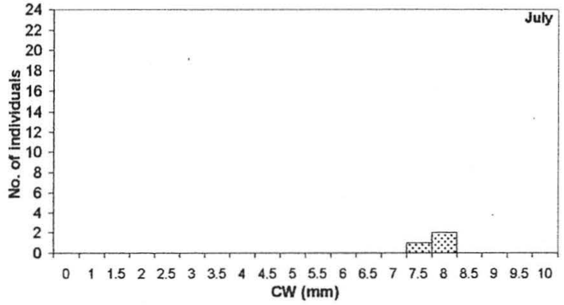
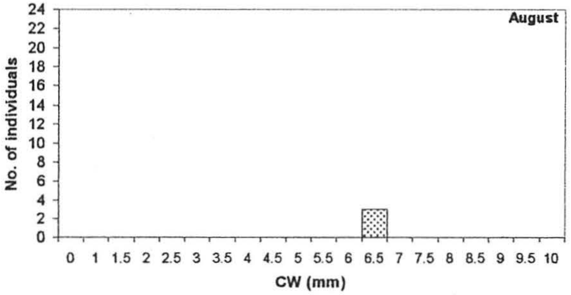

June 99
No. of individuals
0
2
4
6
8
10
12
14
16
18
20
22
24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

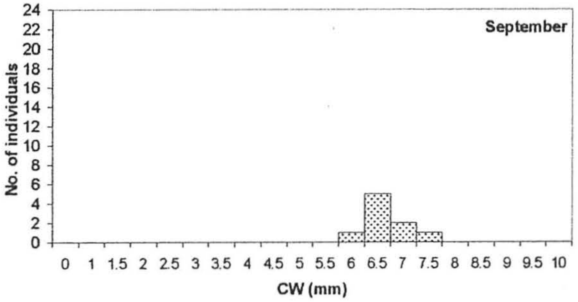
Figure 3.10

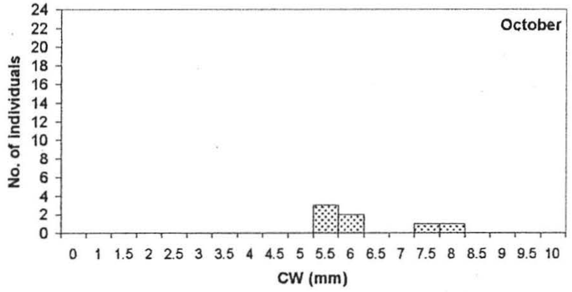
Monthly carapace-width frequency distribution of non-ovigerous female *Ilyoplax stevensi* at TI (Ashish Al-Doha), during each of the 13 sampling periods.

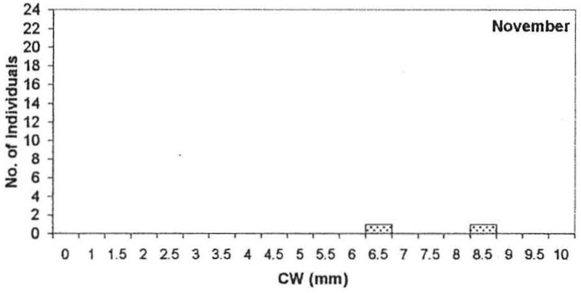

June 98
No. of individuals
24 22 20 18 16 14 12 10 8 6 4 2 0
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

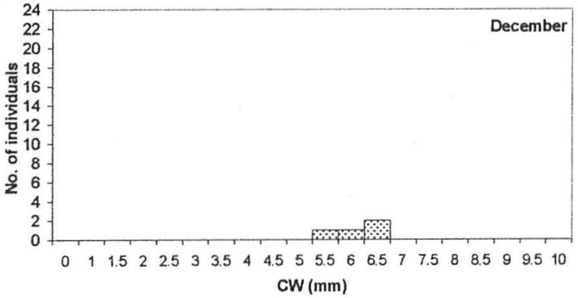

July
No. of individuals
24 22 20 18 16 14 12 10 8 6 4 2 0
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

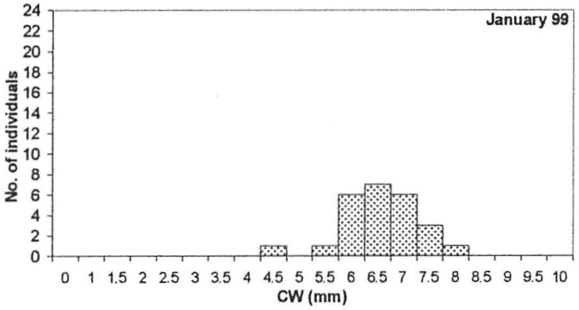

August
No. of individuals
24 22 20 18 16 14 12 10 8 6 4 2 0
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

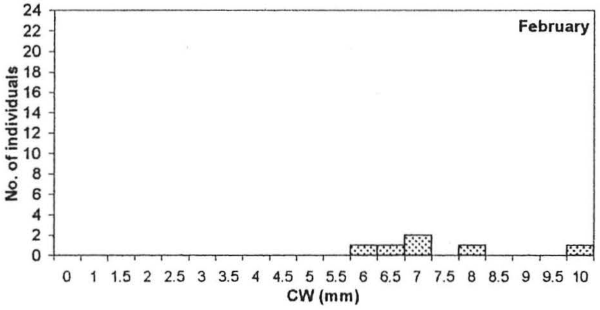

September
No. of individuals
24 22 20 18 16 14 12 10 8 6 4 2 0
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

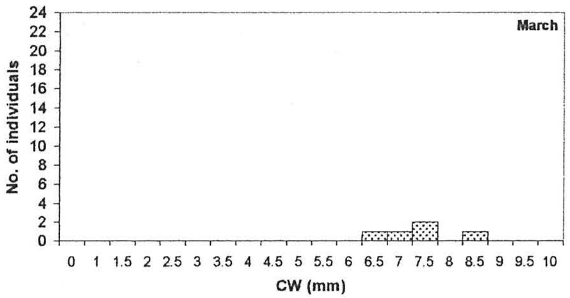

October
No. of individuals
24 22 20 18 16 14 12 10 8 6 4 2 0
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

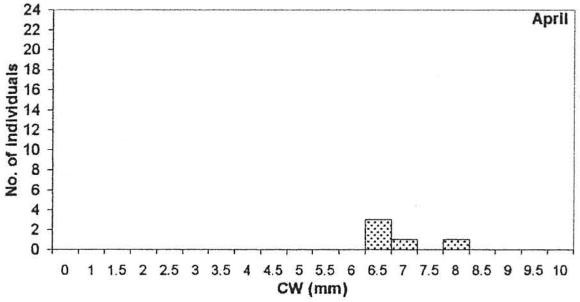

November
No. of individuals
24 22 20 18 16 14 12 10 8 6 4 2 0
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

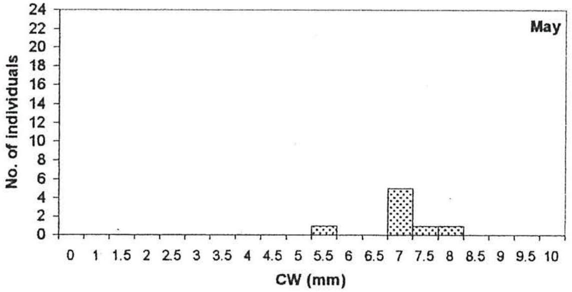

December
No. of individuals
24 22 20 18 16 14 12 10 8 6 4 2 0
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


January 99
No. of individuals
24 22 20 18 16 14 12 10 8 6 4 2 0
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


February
No. of individuals
24 22 20 18 16 14 12 10 8 6 4 2 0
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


March
No. of individuals
0
2
4
6
8
10
12
14
16
18
20
22
24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


April
No. of individuals
0
2
4
6
8
10
12
14
16
18
20
22
24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


May
No. of individuals
0
2
4
6
8
10
12
14
16
18
20
22
24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

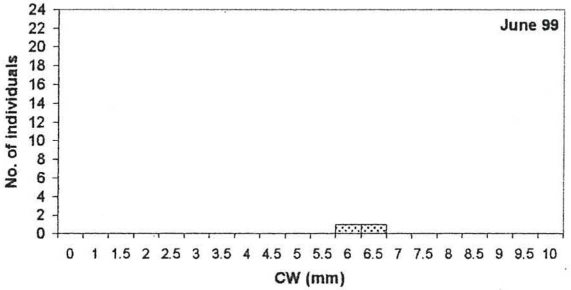
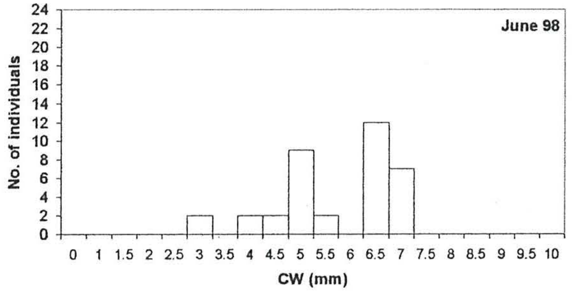
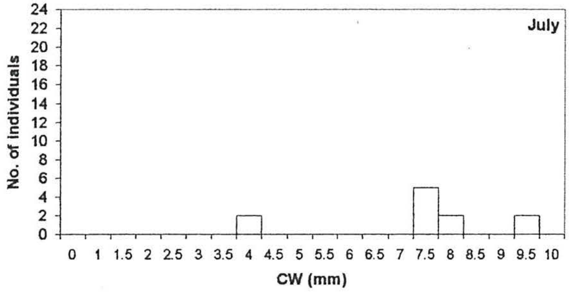
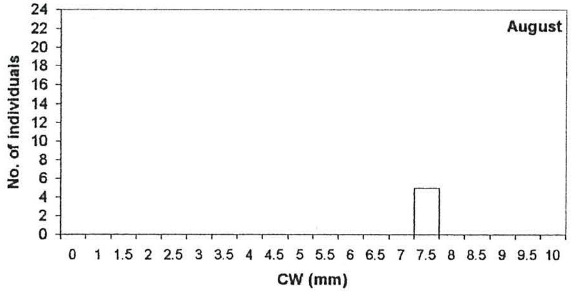

June 99
No. of individuals
0
2
4
6
8
10
12
14
16
18
20
22
24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

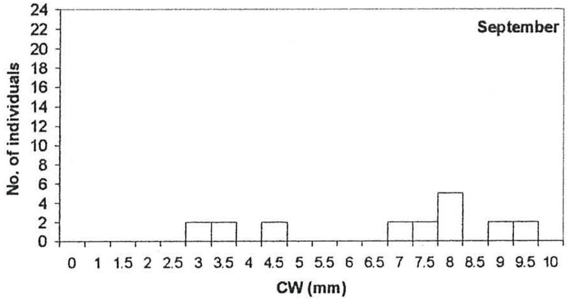
Figure 3.11

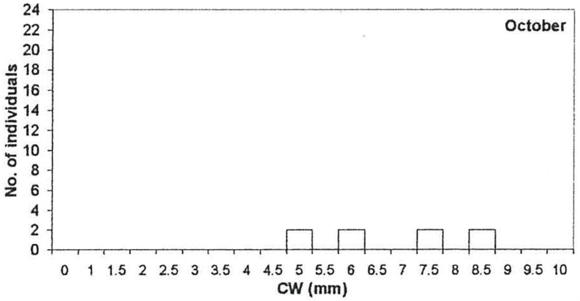
Monthly carapace-width frequency distribution of male *Ilyoplax stevensi* at TII (Sulaibikhat), during each of the 13 sampling periods.

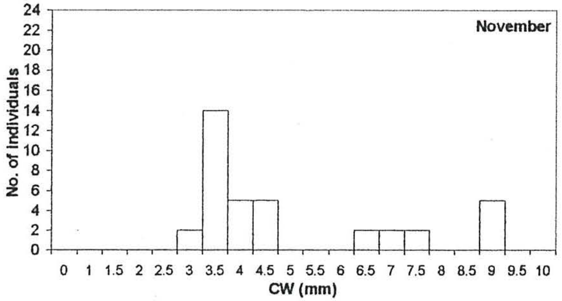

June 98
No. of individuals
0 2 4 6 8 10 12 14 16 18 20 22 24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

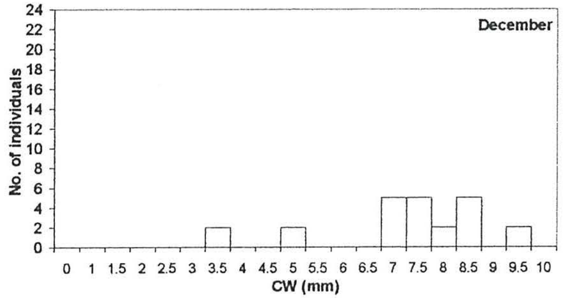

July
No. of individuals
0 2 4 6 8 10 12 14 16 18 20 22 24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

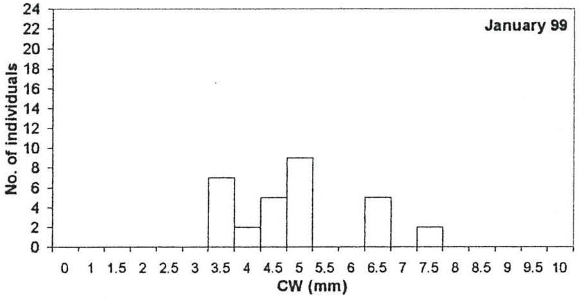

August
No. of individuals
0 2 4 6 8 10 12 14 16 18 20 22 24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

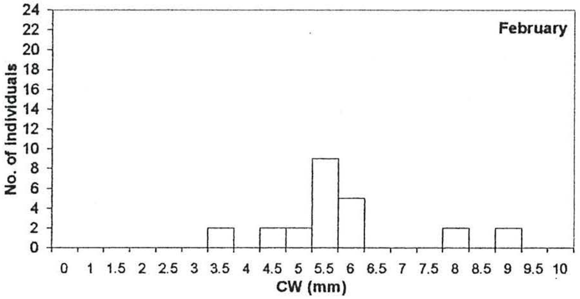

September
No. of individuals
0 2 4 6 8 10 12 14 16 18 20 22 24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

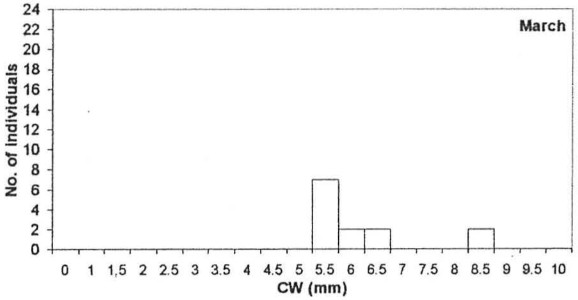

October
No. of individuals
0 2 4 6 8 10 12 14 16 18 20 22 24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

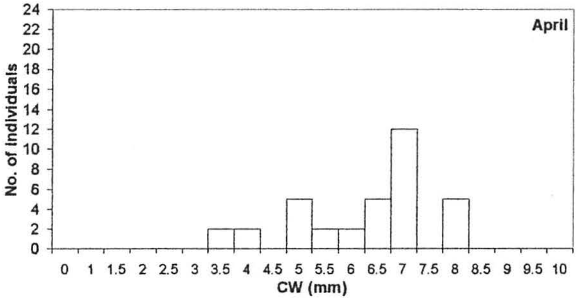

November
No. of Individuals
0 2 4 6 8 10 12 14 16 18 20 22 24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

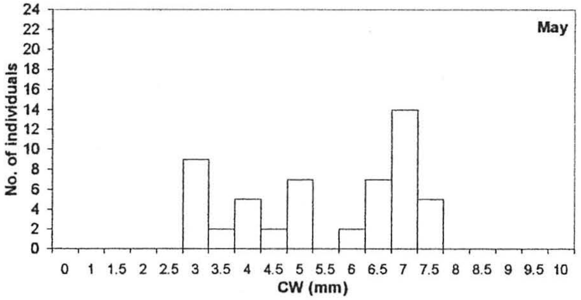

December
No. of individuals
0 2 4 6 8 10 12 14 16 18 20 22 24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


January 99
No. of individuals
0 2 4 6 8 10 12 14 16 18 20 22 24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


February
No. of Individuals
0 2 4 6 8 10 12 14 16 18 20 22 24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


March
No. of individuals
0
2
4
6
8
10
12
14
16
18
20
22
24
0 1 1,5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


April
No. of individuals
0
2
4
6
8
10
12
14
16
18
20
22
24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


May
No. of individuals
0
2
4
6
8
10
12
14
16
18
20
22
24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

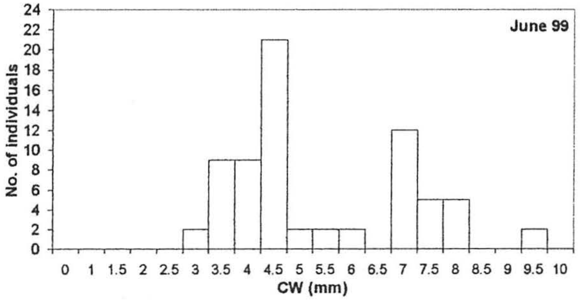
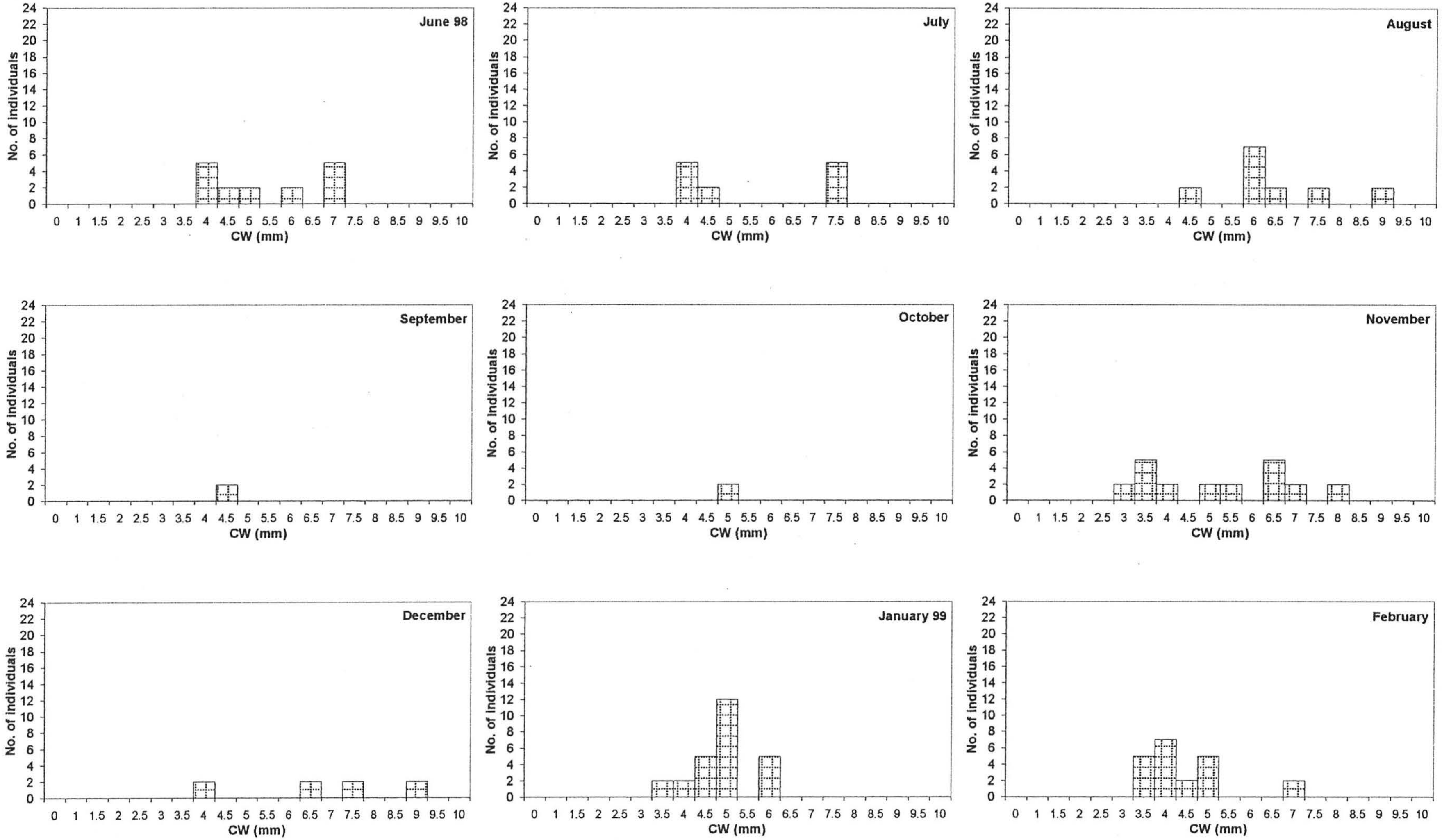
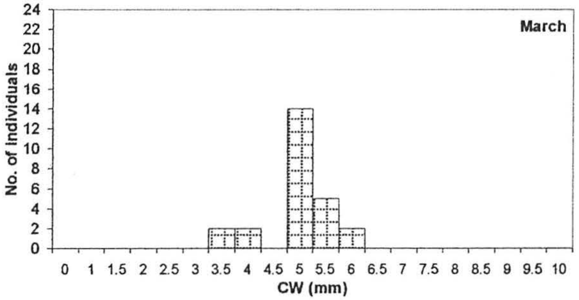
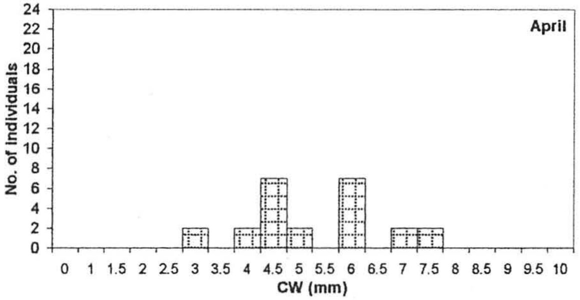

June 99
No. of individuals
0
2
4
6
8
10
12
14
16
18
20
22
24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

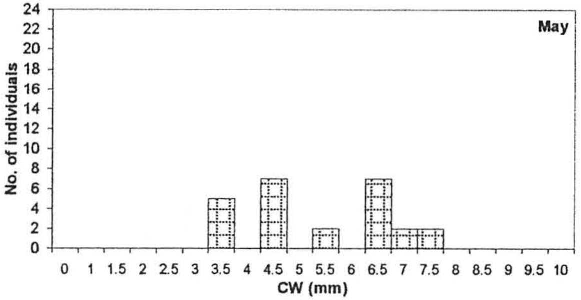
Figure 3.12

Monthly carapace-width frequency distribution of non-ovigerous female *Ilyoplax stevensi* at TII (Sulaibikhat), during each of the 13 sampling periods.


June 98
July
August
September
October
November
December
January 99
February
No. of individuals
0
2
4
6
8
10
12
14
16
18
20
22
24
CW (mm)
0
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10


March
No. of Individuals
0 2 4 6 8 10 12 14 16 18 20 22 24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


April
No. of Individuals
0 2 4 6 8 10 12 14 16 18 20 22 24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


May
No. of Individuals
0 2 4 6 8 10 12 14 16 18 20 22 24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

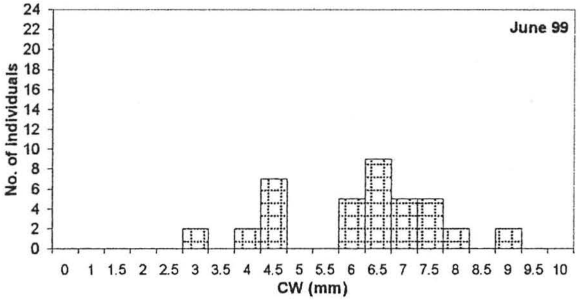
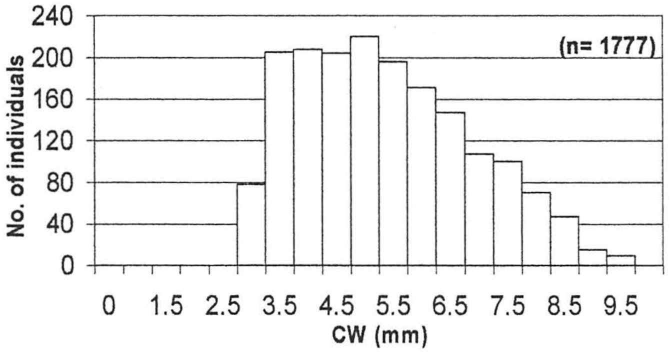

June 99
No. of Individuals
0 2 4 6 8 10 12 14 16 18 20 22 24
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

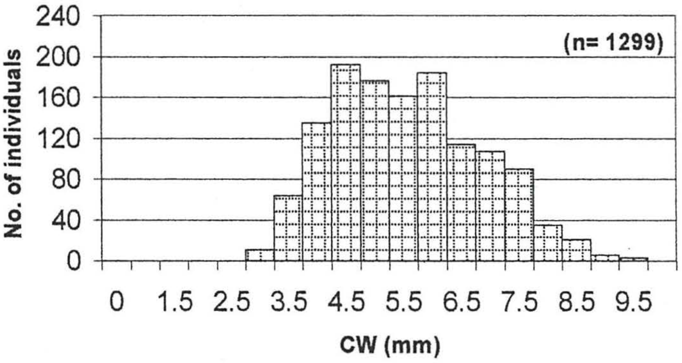
Figure 3.13

Carapace-width total-frequency distribution of sexable and non-sexable *Tylodiplax indica* at TI, Ashish Al-Doha.

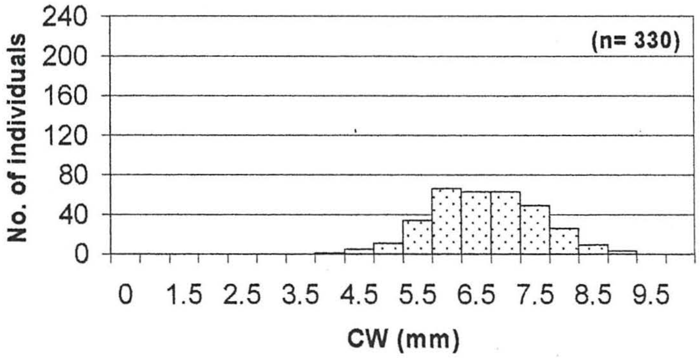
a. Males
b. Non-ovigerous females
c. Ovigerous females
d. Juveniles


(n= 1777)
No. of individuals
0
40
80
120
160
200
240
0
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
CW (mm)

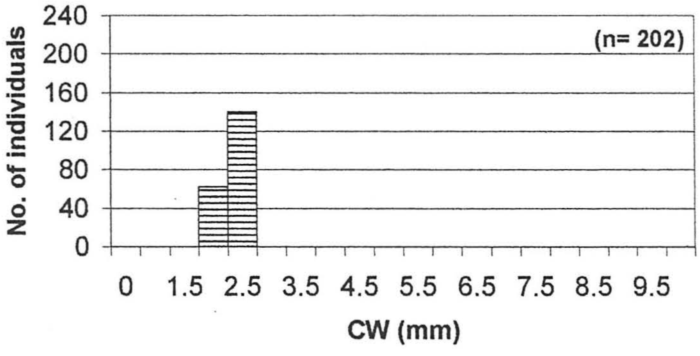
a.


(n= 1299)
No. of individuals
0
40
80
120
160
200
240
0
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
CW (mm)

b.


(n= 330)
No. of individuals
0
40
80
120
160
200
240
0
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
CW (mm)

c.

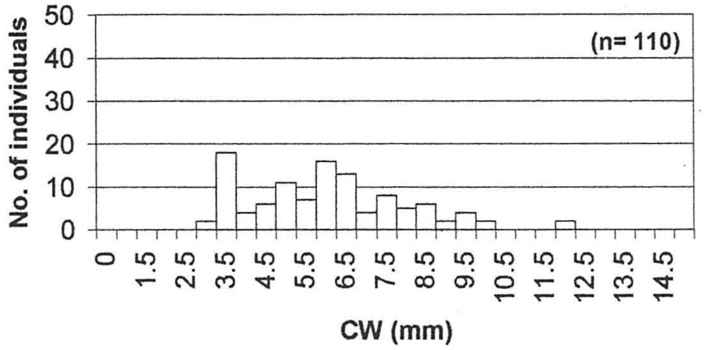

(n= 202)
No. of individuals
0
40
80
120
160
200
240
0
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
CW (mm)

d.

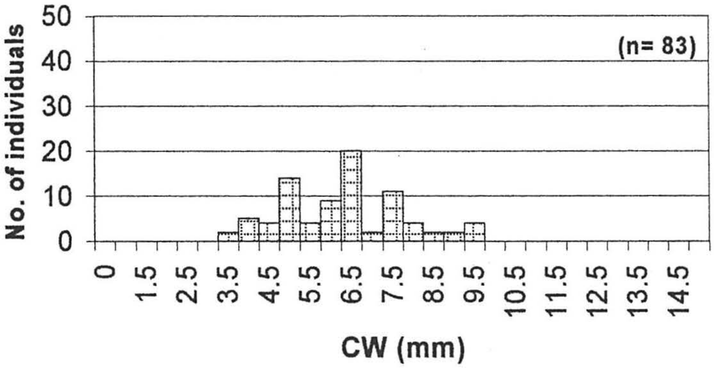
Figure 3.14

Carapace-width total-frequency distribution of sexable and non-sexable *Tylodiplax indica* at TII, Sulaibikhat.

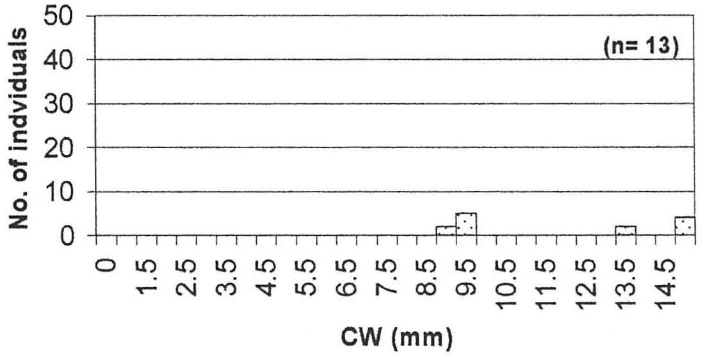
a. Males
b. Non-ovigerous females
c. Ovigerous females
d. Juveniles


No. of individuals
50
40
30
20
10
0
(n= 110)
0
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5
14.5
CW (mm)

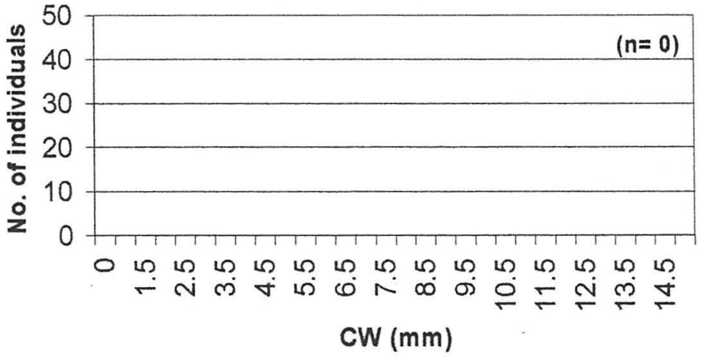
a.


No. of individuals
50
40
30
20
10
0
(n= 83)
0
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5
14.5
CW (mm)

b.


No. of indviduals
50
40
30
20
10
0
(n= 13)
0
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5
14.5
CW (mm)

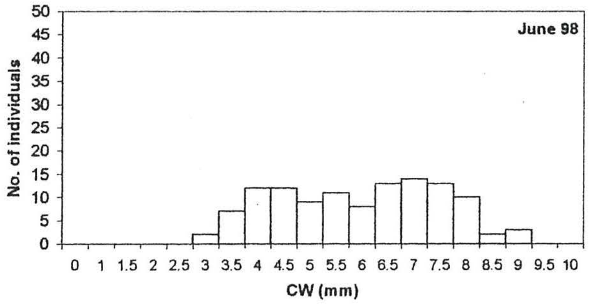
c.

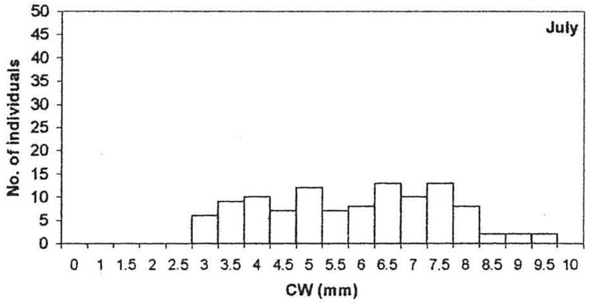

No. of individuals
50
40
30
20
10
0
(n= 0)
0
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5
14.5
CW (mm)

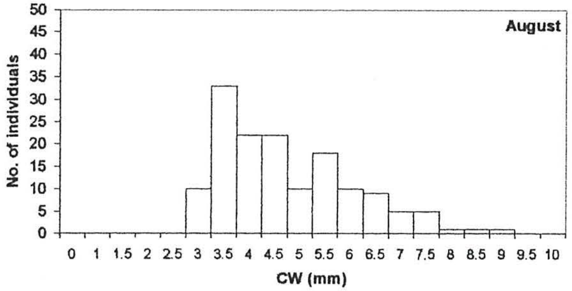
d.

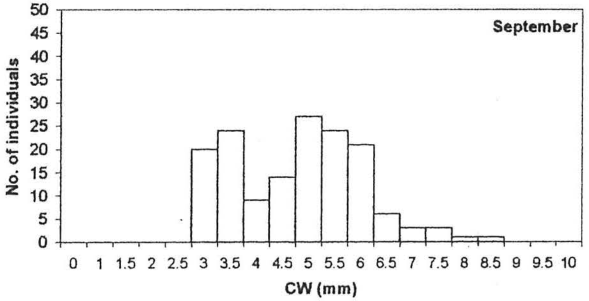
Figure 3.15

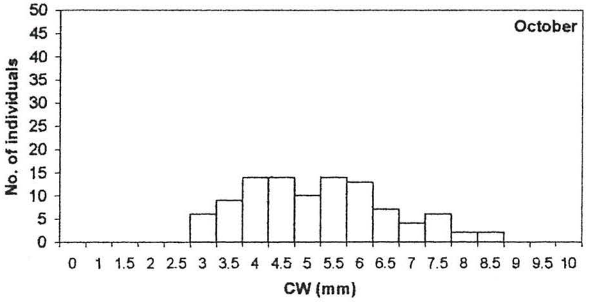
Monthly carapace-width frequency distribution of male *Tylodiplax indica* at TI (Ashish Al-Doha), during each of the 13 sampling periods.

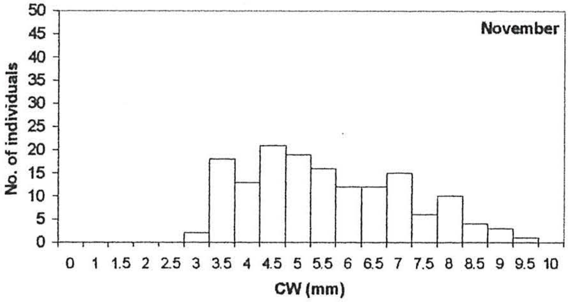

June 98
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

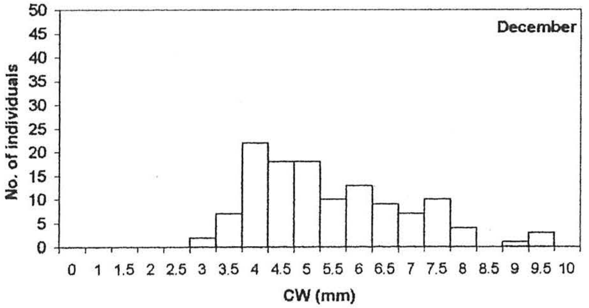

July
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

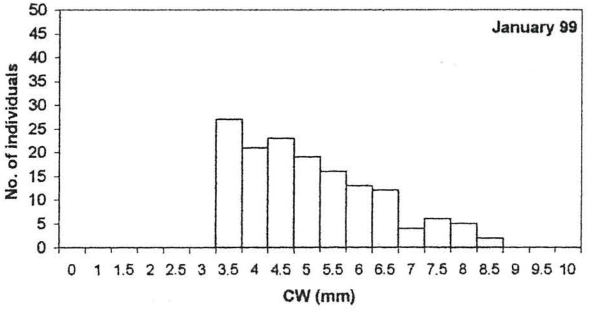

August
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

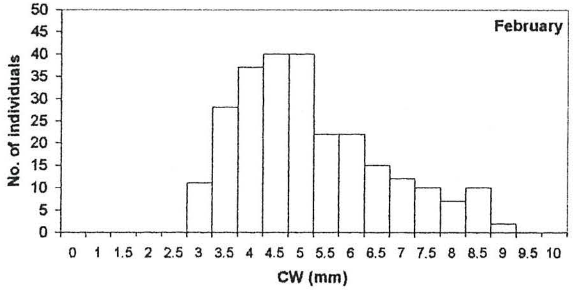

September
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

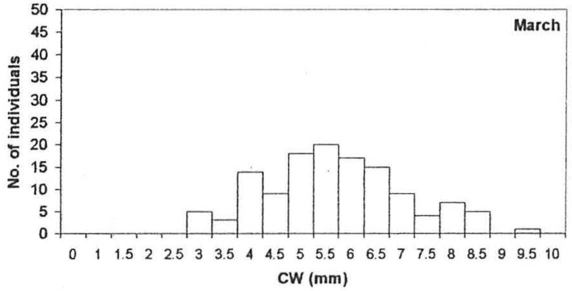

October
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

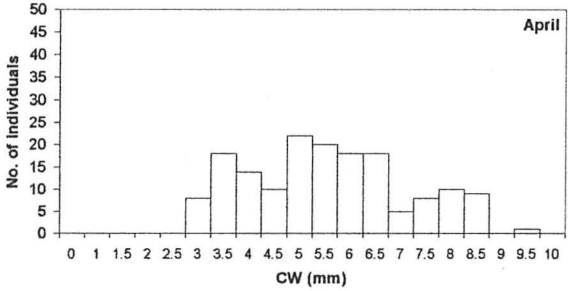

November
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

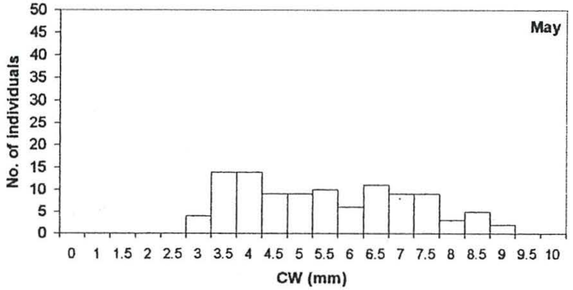

December
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


January 99
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


February
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


March
No. of individuals
0
5
10
15
20
25
30
35
40
45
50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


April
No. of individuals
0
5
10
15
20
25
30
35
40
45
50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


May
No. of individuals
0
5
10
15
20
25
30
35
40
45
50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

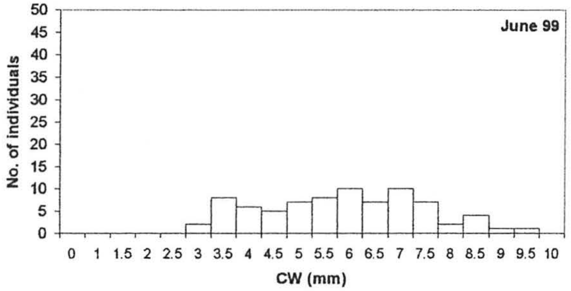
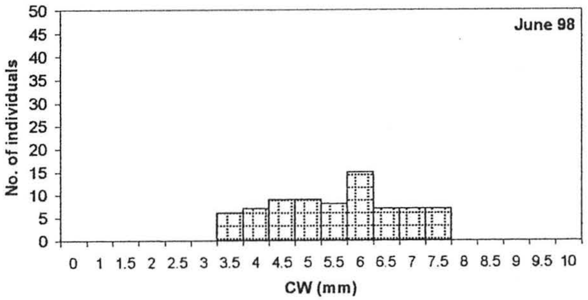
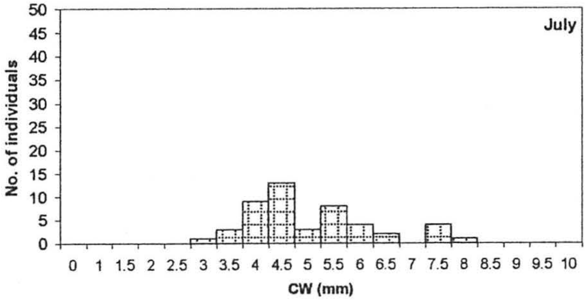
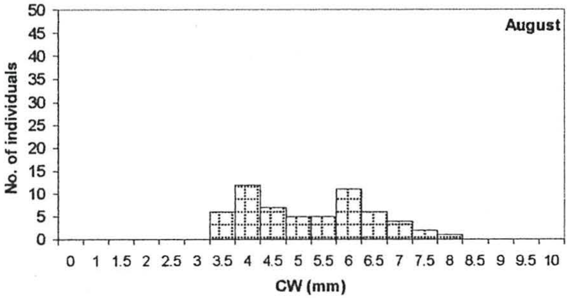

June 99
No. of individuals
0
5
10
15
20
25
30
35
40
45
50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

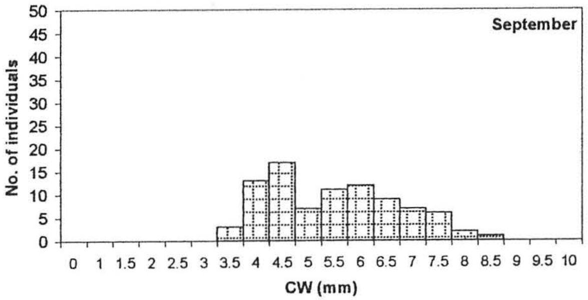
Figure 3.16

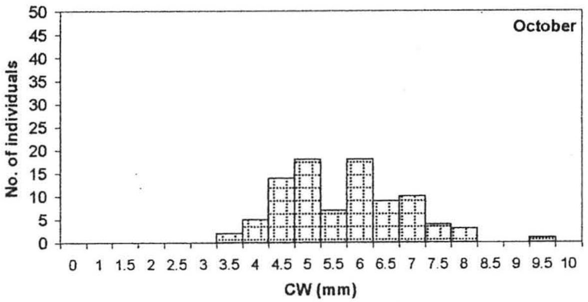
Monthly carapace-width frequency distribution of non-ovigerous female *Tylodiplax indica* at TI (Ashish Al-Doha), during each of the 13 sampling periods.

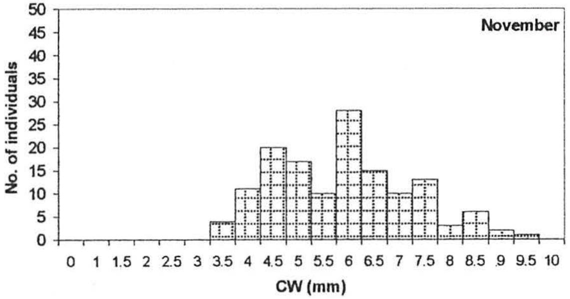

June 98
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

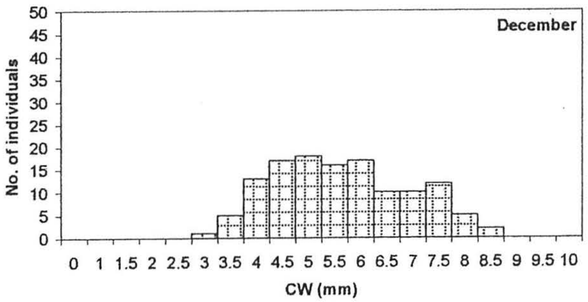

July
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

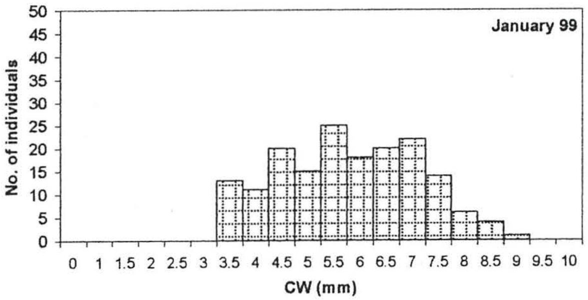

August
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

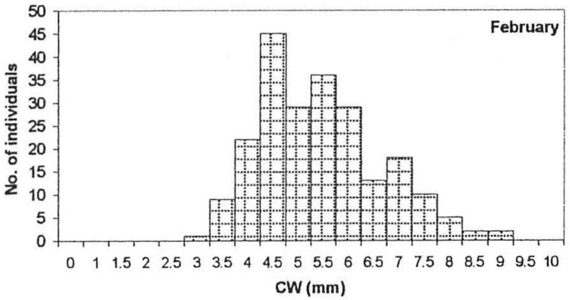

September
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

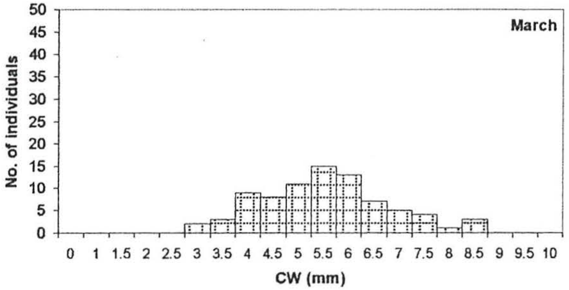

October
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

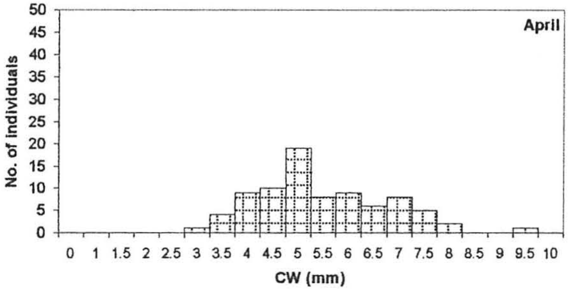

November
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

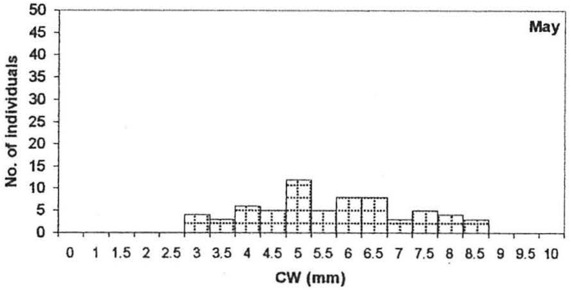

December
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


January 99
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


February
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


March
No. of Individuals
0 5 10 15 20 25 30 35 40 45 50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


April
No. of Individuals
0 5 10 15 20 25 30 35 40 45 50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)


May
No. of Individuals
0 5 10 15 20 25 30 35 40 45 50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

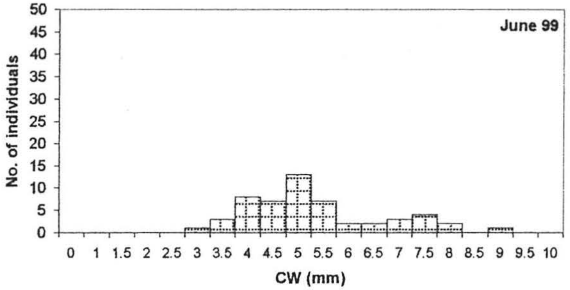
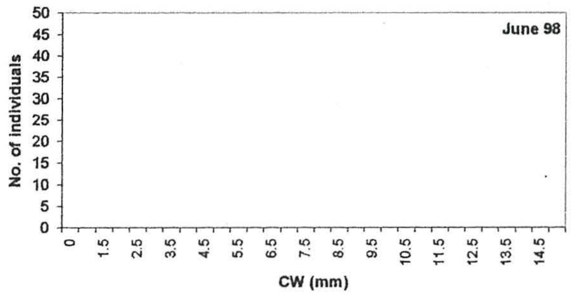
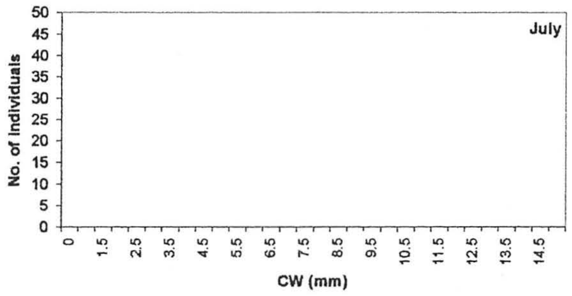
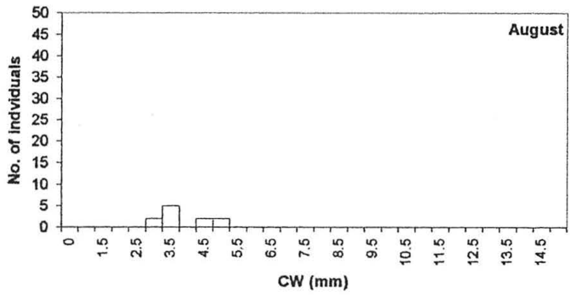

June 99
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
CW (mm)

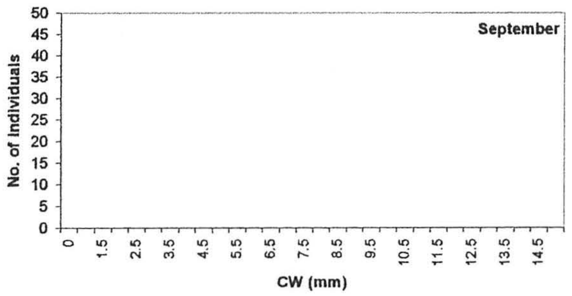
Figure 3.17

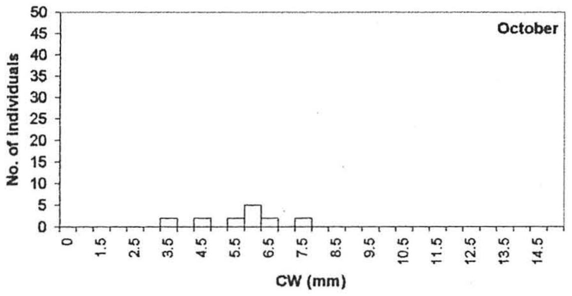
Monthly carapace-width frequency distribution of male *Tylodiplax indica* at TII (Sulaibikhat), during each of the 13 sampling periods.

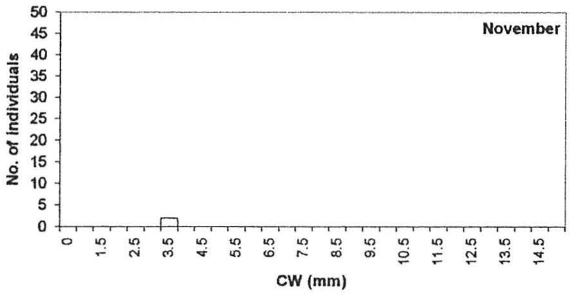

June 98
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5
CW (mm)

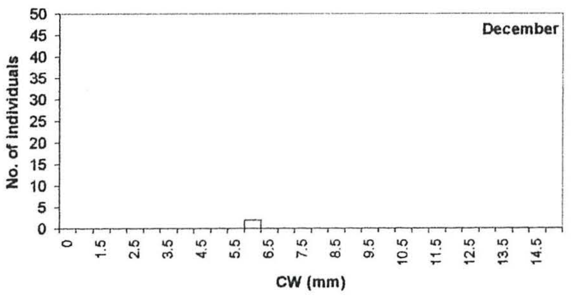

July
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5
CW (mm)

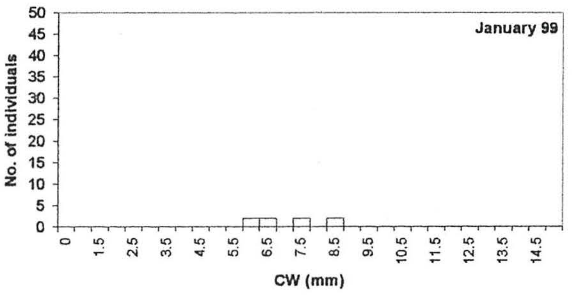

August
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5
CW (mm)

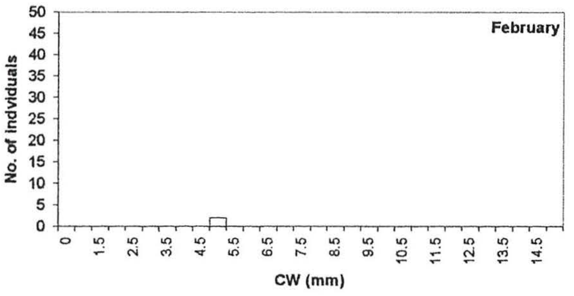

September
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5
CW (mm)

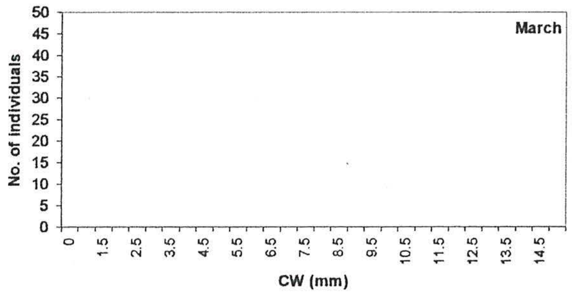

October
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5
CW (mm)

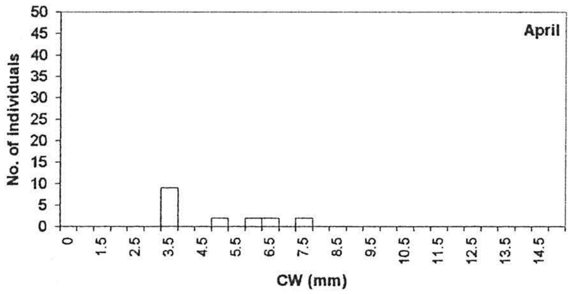

November
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5
CW (mm)

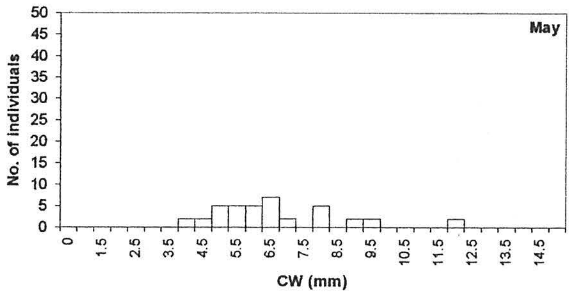

December
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5
CW (mm)


January 99
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5
CW (mm)


February
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5
CW (mm)


March
No. of individuals
50
45
40
35
30
25
20
15
10
5
0
0
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5
14.5
CW (mm)


April
No. of individuals
50
45
40
35
30
25
20
15
10
5
0
0
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5
14.5
CW (mm)


May
No. of individuals
50
45
40
35
30
25
20
15
10
5
0
0
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5
14.5
CW (mm)

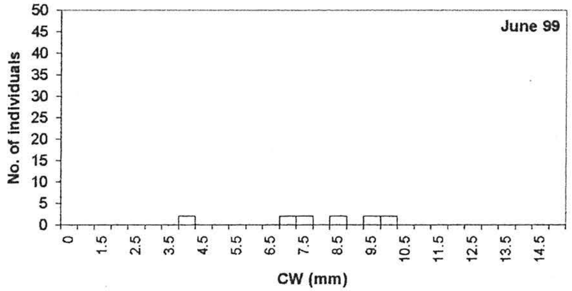
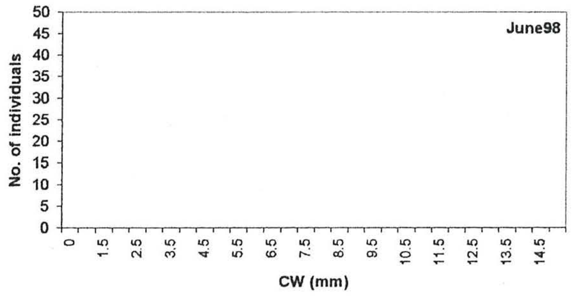
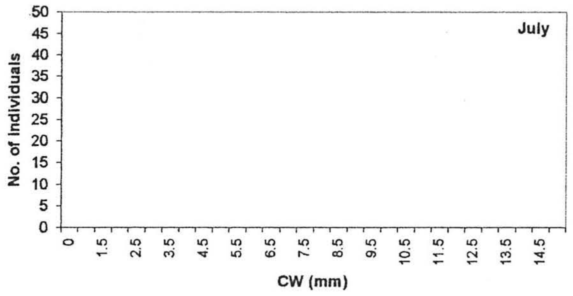
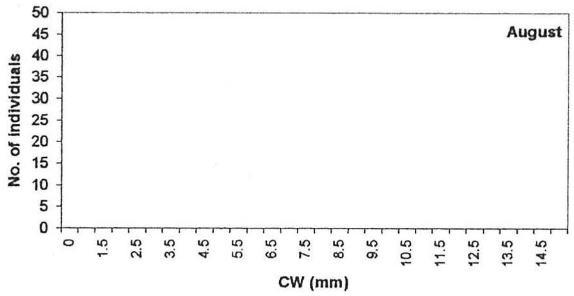

June 99
No. of individuals
50
45
40
35
30
25
20
15
10
5
0
0
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5
14.5
CW (mm)

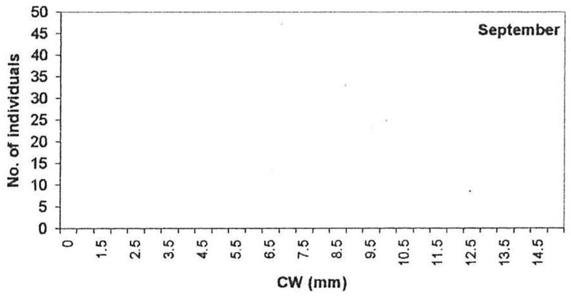
Figure 3.18

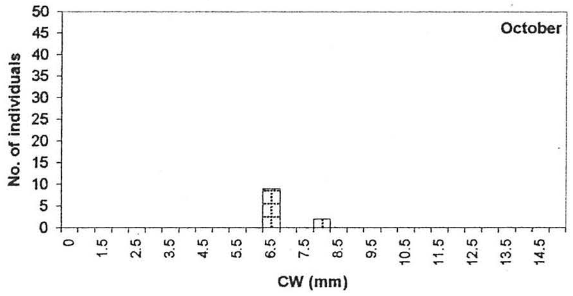
Monthly carapace-width frequency distribution of non-ovigerous female *Tylodiplax indica* at TII (Sulaibikhat), during each of the 13 sampling periods.

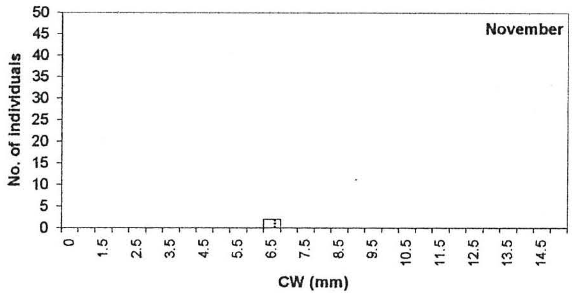

June98
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5
CW (mm)

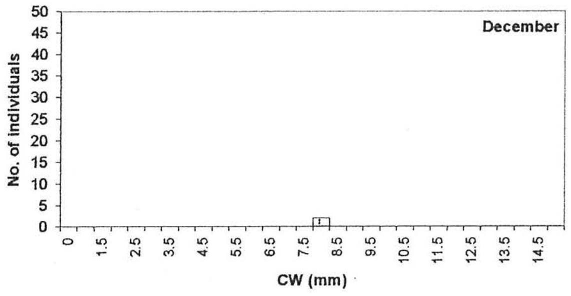

July
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5
CW (mm)

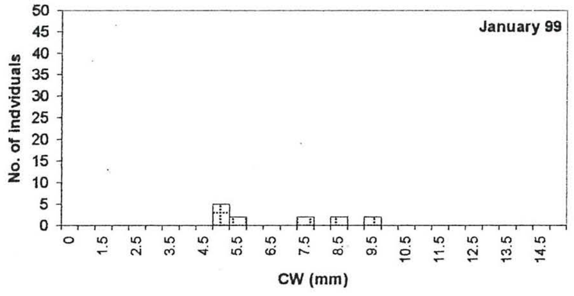

August
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5
CW (mm)

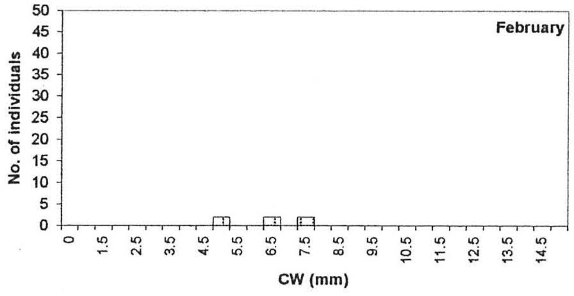

September
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5
CW (mm)

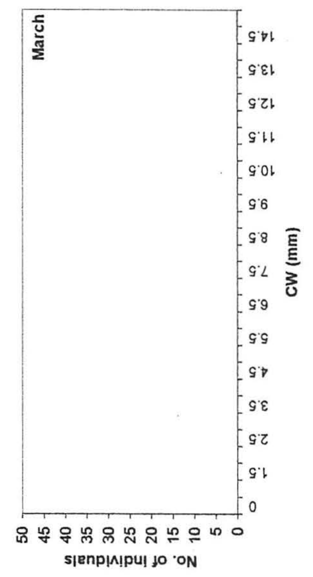

October
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5
CW (mm)

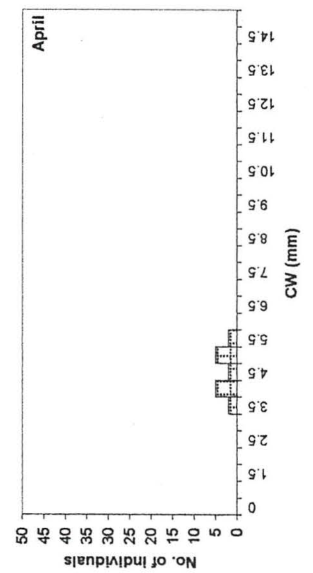

November
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5
CW (mm)

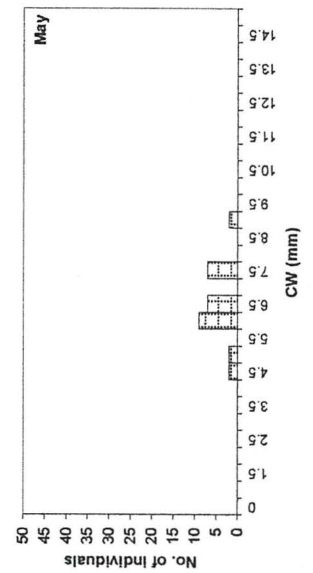

December
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5
CW (mm)

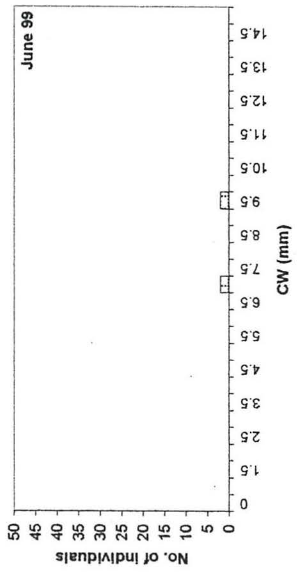

January 99
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5
CW (mm)


February
No. of individuals
0 5 10 15 20 25 30 35 40 45 50
0 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5
CW (mm)


March
No. of Individuals
50 45 40 35 30 25 20 15 10 5 0
CW (mm)
0 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5


April
No. of Individuals
50 45 40 35 30 25 20 15 10 5 0
CW (mm)
0 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5


May
No. of Individuals
50 45 40 35 30 25 20 15 10 5 0
CW (mm)
0 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5


June 99
No. of Individuals
50 45 40 35 30 25 20 15 10 5 0
CW (mm)
0 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5

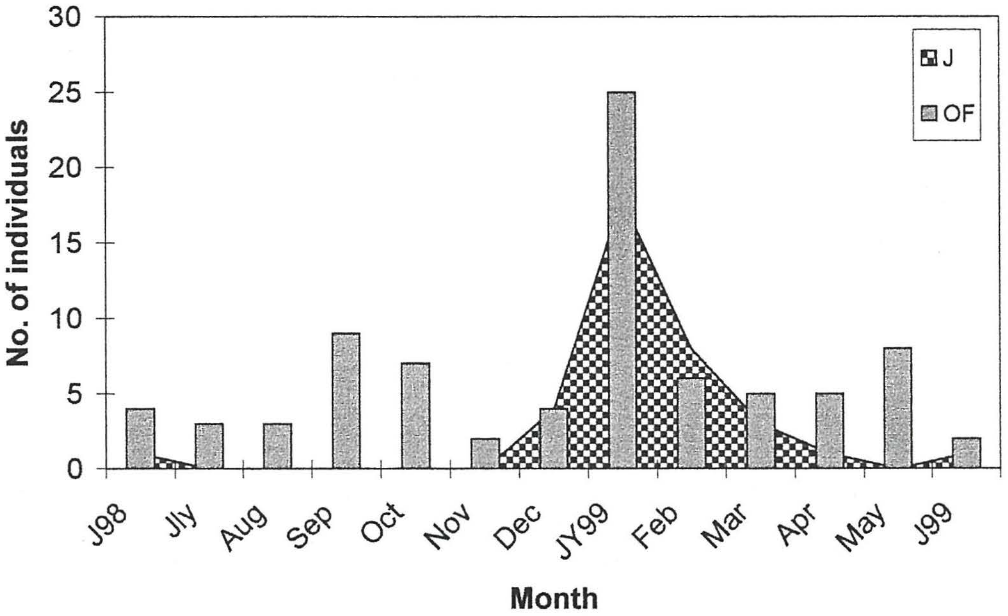


Figure 3.19 Monthly occurrence of ovigerous females (OF) and juvenile (J) *Ilyoplax stevensi* individuals from Ashish Al-Doha (TI).

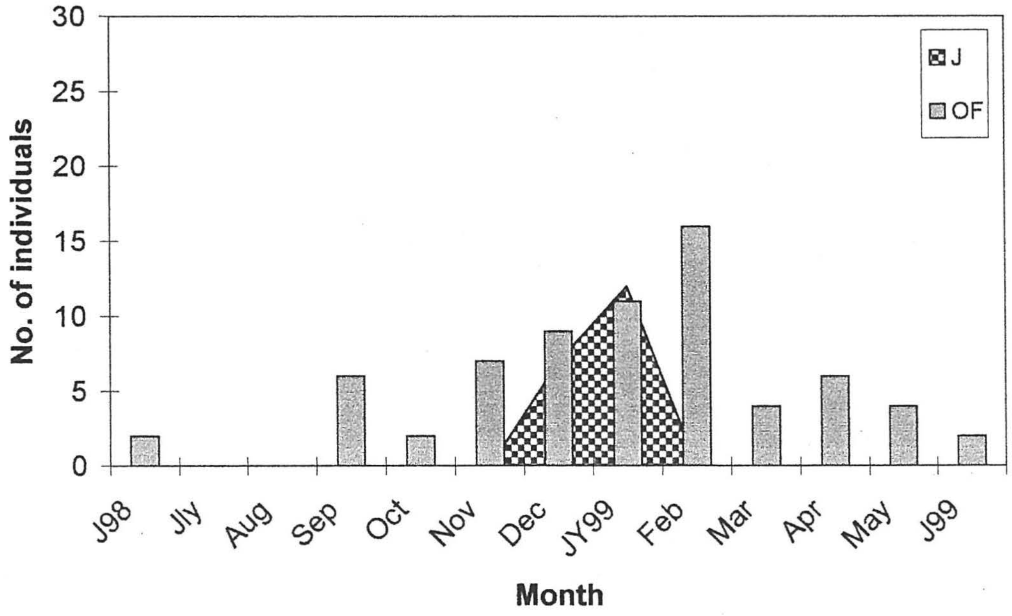
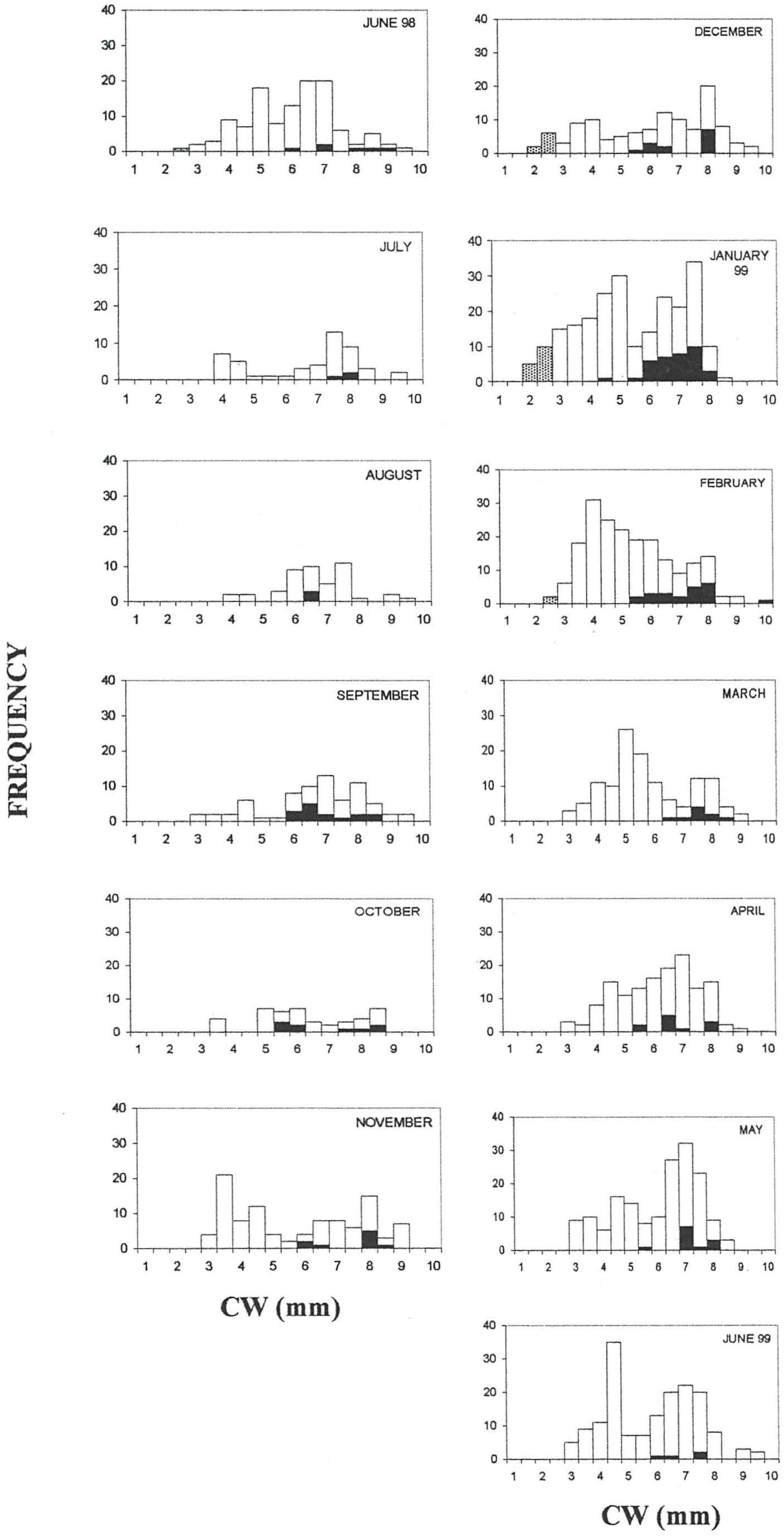


Figure 3.20 Monthly occurrence ovigerous females (OF) and juvenile (J) *Ilyoplax stevensi* individuals from Sulaibikhat (TII).

Figure 3.21

Size-frequency distribution of *Ilyoplax stevensi*, from June 98 to June 99, within Sulaibikhat Bay (TI and TII combined), where open histograms represent males and non-ovigerous females, solid histograms ovigerous females, and dotted histograms unsexable juveniles.


FREQUENCY
JUNE 98
DECEMBER
JULY
JANUARY 99
AUGUST
FEBRUARY
SEPTEMBER
MARCH
OCTOBER
APRIL
NOVEMBER
MAY
JUNE 99
0
10
20
30
40
1
2
3
4
5
6
7
8
9
10
CW (mm)
CW (mm)

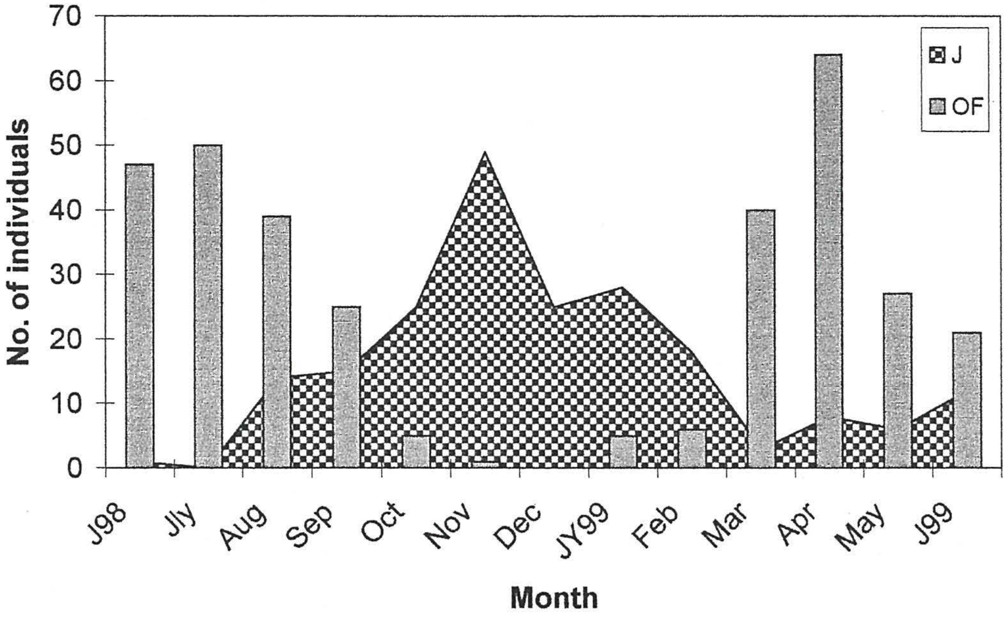


Figure 3.22 Monthly ovigerous females (OF) and juvenile (J) *Tylodiplax indica* individuals from Ashish Al-Doha (TI).

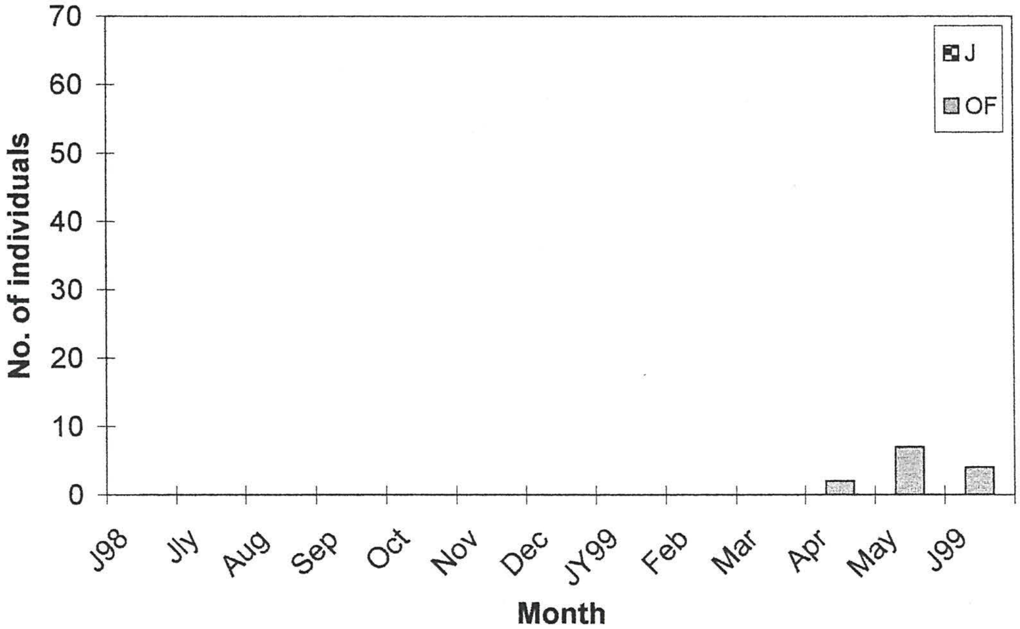
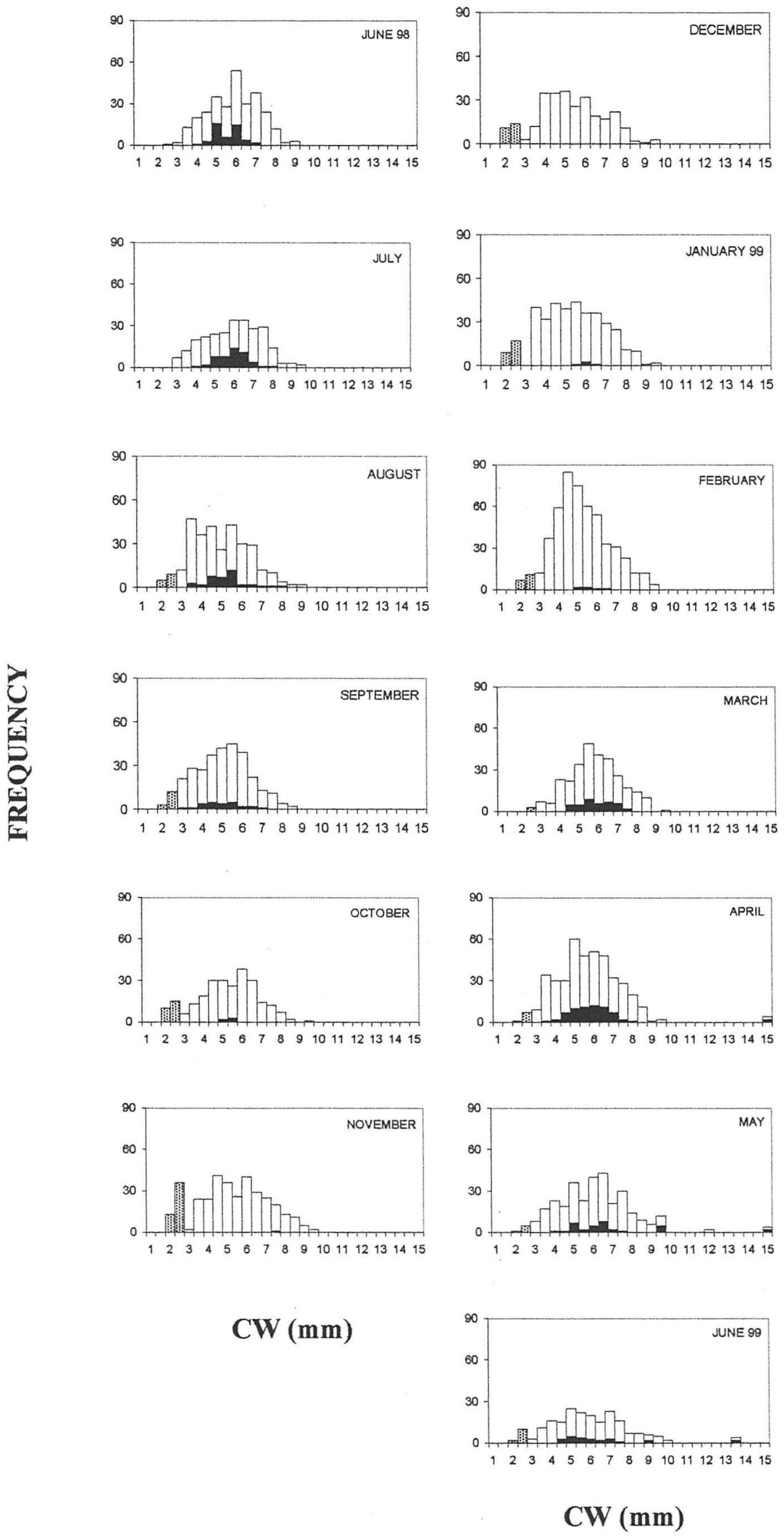


Figure 3.23 Monthly ovigerous females (OF) and juvenile (J) *Tylodiplax indica* individuals from Sulaibikhat (TII).

Figure 3.24

Size-frequency distribution of *Tylodiplax indica*, from June 98 to June 99, within Sulaibikhat Bay (TI and TII combined), where open histograms represent males and non-ovigerous females, solid histograms ovigerous females, and dotted histograms unsexable juveniles.


FREQUENCY
JUNE 98
DECEMBER
JULY
JANUARY 99
AUGUST
FEBRUARY
SEPTEMBER
MARCH
OCTOBER
APRIL
NOVEMBER
MAY
JUNE 99
90
60
30
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
CW (mm)
CW (mm)

DISCUSSION

Schemes for rapid assessment using both biodiversity and abundance indices have been developed successfully for use in aquatic ecosystems, especially in fresh water (Chessman, 1995; Resh, 1995; Reynoldson, 1995). They have proven to be of benefit in determining environmental quality and for the detection of different types of human impacts (e.g. in mangroves; Skilleter, 1996). However, they are less well developed for un-vegetated intertidal mudflats. Generally invertebrates are preferable for ecological risk assessment because they constitute 95% of all animal species (Barnes, 1968), are major components of all ecosystems, and their populations are often numerous, so that samples can be taken for analysis without significantly affecting population dynamics.

The Rapid Shore Assessment (RSA) methodology developed by Price (1990) was modified to include key species biodiversity and used in 1991 in Saudi Arabia to measure the ecological impact of the Gulf War oil spill on the full range of intertidal biotopes (Jones and Richmond, 1992). Later, both biodiversity and abundance of biota were used to monitor recovery (Jones *et al.*, 1996). It was found that during recovery from oil impact there was a sequence in the recovery of biota biodiversity, returning sometime before abundance (Jones *et al.*, 1996).

Results of the current investigation reveal that within Sulaibikhat Bay, *Ilyoplax stevensi* are mostly within the mid-size range (mature: 5.5mm-7.5mm) during summer and autumn (spawning), while small-sized individuals (immature adults: 3-5mm) occur during winter (recruitment). However, for *T. indica,* mid and large-size range individuals (>7.5mm) occur during summer (spawning), and small sizes occur during autumn and winter (recruitment). Hence, both species show highest abundance at both sites during winter and lowest abundance during summer.

The present results confirm and extended those of Snowden *et al.* (1991) who conducted the first study of the population biology of *Ilyoplax stevensi* on Kuwait mudflats. They also found that crab abundance was strongly seasonal and significantly higher during December to March (winter - spring), than from May to November (summer- autumn), and that reproduction occurred throughout the year. However this was of a strong seasonal nature, with the percentage of ovigerous females significantly higher during September to March (66 to 45%), than from May to August (26 to 20%). During studies on crab communities in Saudi Arabia following the 1991 Gulf War oil spill, Apel (1996) also found that a strong seasonality in breeding activity for *Ilyoplax stevensi.* Intense breeding activity occurred from July to October, with maximum activity in October when 90% females were ovigerous. Maximum recruitment accordingly takes place in winter months, following the high reproductive activity in the autumn. In 1994, Snowden and others presented the first ecological study of *Tylodiplax indica* on the mudflats of Kuwait. Results of their investigation are similar to present results showing that species abundance was significantly higher during November – March (winter-spring), but the percentage of ovigerous females was significantly higher during May – September, while highest juvenile abundance occurred in March.

The pristine site Ashish Al-Doha (TI) generally revealed higher abundance values for both ocypodid species compared to the disturbed site- Sulaibikhat (TII). However, both transects showed no significant difference in population abundance and structure for *I. stevensi.* In contrast, *Tylodiplax indica* at TII was approximately eighteen fold less abundant than the population at TI. Difference between population structures of *T. indica* at both sites are also reflected in variation of the non-ovigerous to ovigerous female ratio. At TI, ovigerous females represent 25% of the female population, while they account for only 16% of the female population at TII. At TI, *T. indica* was more abundant in comparison to *I. stevensi.* This may be due to the higher reproductive output of *T. indica* which has two annual spawnings, the higher growth rate associated with a short incubation period and larger sizes attained, as size is the determining parameter for fecundity in brachyurans (Hines, 1982). By comparing the overall magnitude of recruitment events at both sites, it is suggested that the population structure of *Tylodiplax indica* at the modified site (TII) is controlled by differing abiotic and biotic factors.

Physical alterations of habitats are known to have adverse effects on the population structure of infaunal species. Barros (2001) investigated the potential for ghost crabs as a tool for rapid assessment of impacts on sandy shores. Results revealed that urban beaches have significantly lower numbers of burrows of *Ocypode cordimana* than pristine non-urban beaches, due to loss of upper level habitats and intense recreational activities in association with urbanisation. It was concluded that the number of burrows is likely to be a useful indicator for impacts on exposed sandy beaches. One of the anthropogenic impacts affecting transect II is the loss of habitat due to infilling of the supralittoral fringe and the upper littoral zone. This has led to a reduction of niche for fauna inhabiting the upper littoral, producing crowding and competition. Under such circumstances predators are known to exploit prey, thus effecting community structure of other infaunal species (Lovrich & Sainte-Marie, 1997; Palma *et al.*, 1998). Due to infilling, the carnivorous goby *Periophthlamus waltoni*, which feeds on *T. indica* (chapter 4), has become concentrated within a narrow band of approximately 4-5m. By comparison, this species is dispersed across a 200m band on transect I. Furthermore, at this site a relatively higher population of this goby occurs compared to TI. Thus the large population abundance of gobies (biological factor) and their concentration associated with morphological changes of the habitat (physical factor) may enhance predation leading to reduction of the *T. indica* population at this disturbed site (TII).

Chemicals of both organic and inorganic origin are also known to affect the population structure of infaunal species in marine habitats. Most invertebrates maintain discrete populations by depending upon favourable conditions for the development and return of pelagic larvae, and several studies have been conducted to assess the effect of chemical cues on the settlement of crab megalopae (O'Connor, 1993; Wolcott & De Vries, 1994; Forward Jr. *et al.*, 1996; Abello & Guerao, 1999; Paula *et al.*, 2001). Fiddler crab megalopae are known to advance moulting to the first crab instar in the presence of sediments containing chemical stimuli from older con-specifics and delay moulting in their absence (Christy 1989; O'Connor, 1991). O'Connor, (1993) found the distribution of newly-settled and adult fiddler crabs to be correlated, because megalopae settled preferentially in intertidal habitats occupied by con-specific adults. Forward & Rittschof, (1994) suggested that blue crab larvae may become imprinted upon odour from a home estuary during embryological development, and that this induces transport and return of megalopae to the parent habitat. Paula and others (2001) provided further support as they found that a diverse and rich complex mangrove habitat had a higher abundance of brachyuran populations than control flats. They suggested that megalopal settlement does not occur discriminately in near-shore habitats, but in appropriate areas near their respective adult populations.

As the population of *T. indica* at the pristine site (TI) is 18 times greater than that at the impacted site (TII), the concentration and intensity of the chemical cues released by adults must be greater at TI thus attracting larval settlement. Forward *et al.* (1996) suggested that the primary cues accelerating the metamorphosis of the megalopae, once in the parent habitat might be derived from estuarine vegetation. At transect II, the occurrence of the halophyte *Salicornia herbacea* is very scarce in comparison to TI (chapter 2), due to infilling. Hence, the absence of vegetation at the disturbed site (TII) and its chemical odours may also fail to trigger the moult to the first crab stage for *T. indica.* Chemical cues released by predators can also have substantial effect on the behaviour of prey leading to habitat shift (Turner *et al.*, 2000) and reduction of spawning activity (Rawlings, 1994). All of which are further supported by the fact that no juveniles were found during the 13-month sampling period at transect II.

Although a moderate input of organic material may be beneficial in marine habitats leading to an increase in the productivity of the area, higher levels may lead to over-enrichment resulting in de-oxygenation of the water and anoxic sediments eventually causing deterioration of the ecosystem. The most serious problem encountered in bays and estuaries is water disposal associated with industrialisation and urbanisation. Because of the slow water exchange, such ecosystems receiving organic discharges are liable to become anoxic excluding macrofauna. Sewage dumped into a habitat has a direct affect on the benthic fauna. Smothering by particulate matter and reduction of the oxygen concentration due to enhanced bacterial activity excludes the most sensitive species, while more tolerant species flourish because of the input of extra nutrients to the system. The result is a reduction in diversity but increase in the abundance of certain organisms (Clark, 2001). Sewage waste may contain inorganic toxic substances originating from industrial activities as in most cases they both share the same sewerage system. Reductions in fecundity and reproduction have been observed in the laboratory at environmentally relevant metal concentrations for crustacean species (Sundelin, 1984: MacFarlane *et al.*, 2000). MacFarlane *et al.*, (2000) conducted a study to assess the effect of heavy metals on the crab *Heloecious cordiformis* in a mangal system in Australia. Results revealed that heavy metals exhibited a high positive correlation with the percentage of silt and clay in the sediment, and that sites higher in metals tend to have fewer females in the population together with sexual dimorphism.

Within the vicinity of transect II industrial runoff (Shuwaikh port) and sewage discharge may be affecting the population of *Tylodiplax indica* (Birch *et al.*, 1998). Al-Zaidan, (1999) found that transect II had higher organic-loading in the sediment than TI, due to nutrient loading from the sewage discharge approximately 20m from the transect. This coupled with the high proportion of clay in the sediment, capable of trapping high percentages of both organic and inorganic substances (Harbison, 1986), has made the sediment 1cm below the surface extremely anoxic and unfavourable for some infaunal species. Hypoxia in the overlying water is also known to effect population structure (Sagasti *et al.*, 2001; Selberg *et al.*, 2001). Consequently, eutrophication and associated anoxic conditions may also be one of the factors affecting the population of *T. indica*, 2001; Selberg *et al.*, 2001). Consequently, eutrophication and associated anoxic conditions may also be one of the factors affecting the population of *T. indica,* although there does not appear to be any affect on the population dynamics of *Ilyoplax stevensi*. However *T. indica* may be more susceptible to environmental pollution.

The present investigation aims to assess the health of the mudflat ecosystem by using dominant infaunal brachyurans as environmental `indicators' of environmental change over time. The population dynamics of *Ilyoplax stevensi* and *Tylodiplax indica* at both transects within Sulaibikhat Bay were studied during (98-99) to see whether either crab could be used for rapid assessment of impact on mudflats. In summary, it is possible that larval settlement of *T. indica* at TII is probably below optimal levels, thus larval supply is likely a limiting factor during the initial benthic phase rather than predation on early juveniles (Henmi, 1989). As *T. indica* is more affected and susceptible to chemical and environmental changes occurring across the mudflats, it is more sensitive than *I. stevensi.* A biological indicator is defined as a biochemical, cellular, physiological, or behavioural variation measured in tissue/body fluids, or the level of whole organism or population that provides evidence of exposure to and effects of one or more chemical pollutants (Depledge, 1994), and an effective biological indicator must reflect levels of environmental contamination (Depledge and Fossi, 1994). It is likely that the absence of *Tylodiplax indica* will prove useful as an indicator for anthropogenic impacts on mudflats of Sulaibikhat Bay. And since this crab has been reported from Pakistan, Gulf of Oman and elsewhere in the Gulf (Apel and Türkay, 1999) its use as a bio-indicator may be widespread.

CHAPTER IV

PRIMARY PRODUCTIVITY AND STANDING CROP OF MICROBIAL MATS ON MUDFLATS IN SULAIBIKHAT BAY, KUWAIT: A PRELIMINARY STUDY

Part published in:
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INTRODUCTION

Primary Production and Standing Crop

Primary production is the amount of carbon synthesised by chlorophyll-containing organisms from inorganic substances, and is measured as weight of carbon fixed per unit area/volume per unit time. Most estimates suggest that photosynthesis by marine organisms globally produces 30-60x10^9 tonnes of organic carbon annually; around 40% of total global primary production (Jennings *et al.*, 2001). The total amount of organic material fixed in the primary productivity process is termed Gross primary production. Since some of this total production must be used by the plants themselves to operate life processes, a lesser amount is available for transfer or use by other organisms in the sea. This amount left after the loss is termed Net primary production. The Standing Crop is the total amount of the organism biomass present in a given volume of water or area coverage at a given time. Primary productivity and standing crop can vary considerably on a time scale of a few days to a year. Such variation is the result of a large number of factors (light intensity, depth and nutrient availability), that act both directly and indirectly on the photosynthetic process within autotrophs and on the autotrophs themselves.

Productivity and standing crop in inshore and coastal waters

Primary producers are found in shallow waters, specifically in habitats along the coastal margin where light reaches to provide the energy to drive photosynthesis. The majority of carbon in the marine system is fixed by phytoplankton (Figure 4.1, global satellite). However, other autotrophs represented by microphytobenthos, macroalgae, mangroves, reef algae, sea grasses and marsh plants make a smaller contribution to global marine production (~10%), although their production per unit area is higher (Table 4.1). The contribution of such autotrophs to total production is greatest in inshore and coastal systems, which are often abundantly inhabited by primary consumers and provide essential nursery habitats for many commercial fish species.

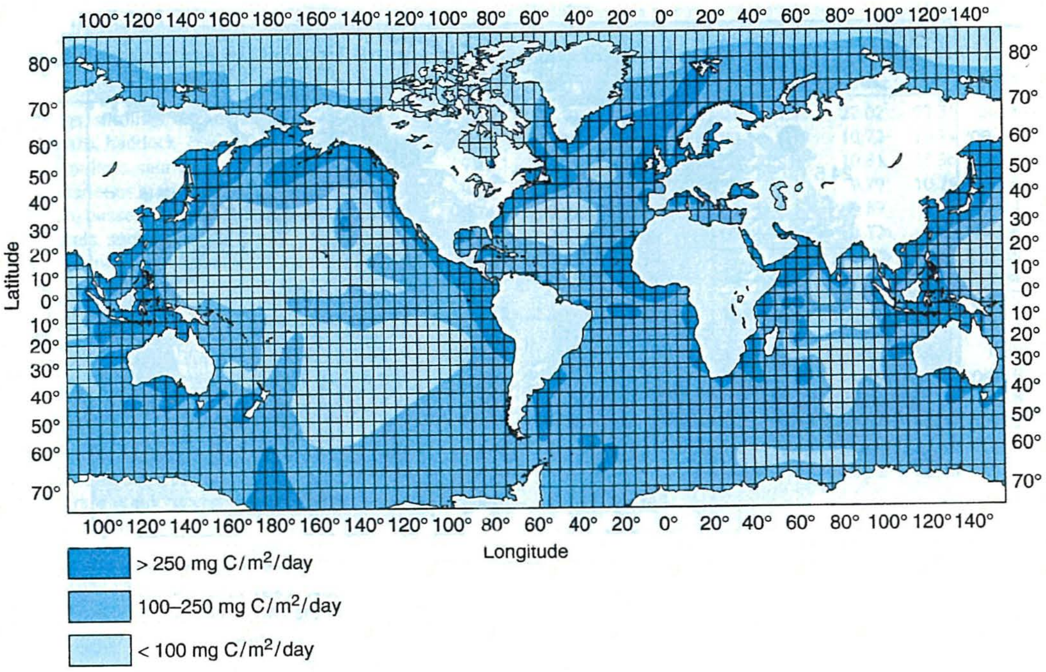


Figure 4.1 Global distribution of phytoplankton production (g $Cm^{-2}y^{-1}$) as estimated from satellite chlorophyll measurements (Source: Nybakken, 2001).

Table 4.1 Production by marine algae. NPP= net primary production (Source: Jennings *et al.*, 2001)

Primary Producer	**Area (10^6 km^2)**	**Area (%total)**	**Total NPP (10^9 t C y^{-1})**	**NPP (%total)**
Oceanic phytoplankton	332.0	88.46	43.0	81.10
Coastal phytoplankton	27.0	7.19	4.5	8.49
Macroalgae	6.8	1.81	2.55	4.81
Mangroves	1.1	0.29	1.1	2.07
Coral reef algae	0.6	0.16	0.6	1.13
Seagrasses	0.6	0.16	0.49	0.92
Marsh plants	0.4	0.11	0.44	0.83
microphytobenthos	6.8	1.81	0.34	0.64

Productivity in Estuarine Systems: Mudflats

The macroflora of estuaries is limited. Most of the permanently submerged portions of estuaries consist of mud substrates unsuitable for macroalgal attachment. In addition, the highly turbid water restricts light penetration to a narrow upper layer. As a result, the deeper layers of the estuary are often barren of macroalgal life. Benthic microalgae (microphytobenthos) form a primary source of fixed carbon in estuarine food webs (Sullivan & Moncreiff, 1990), an important component of inorganic nutrients cycle (Höpner & Wonneberger, 1985), and contribute to sediment stabilisation (Paterson *et al*., 1990; Underwood & Paterson, 1993).

Extensive intertidal mudflats, a prominent geomorphological feature of estuaries and semi-enclosed bays, support abundant populations of such phototrophic organisms. Because they do not harbour a conspicuous vegetation of macroalgae, they are characterised by high levels of benthic microalgal biomass and production (Colijn & de Jonge, 1984; Pinckney & Zingmark, 1991; De Jonge & Colijn, 1994,) which act as primary producers supplying both benthic (Sullivan & Moncrieff, 1990) and planktonic food webs (Baillie & Welsh, 1980; De Jonge & Van Beusekom, 1992).

Such benthic microalgal communities are composed primarily of diatoms, blue-green (cyanophyte) and green (chlorophyte) algae. These communities include those forms motile within the sediments (epilelic) and those attached to individual sand grains (epipsammic). When occurring in dense populations, these autotrophs form microbial bio-films or mats, alternatively known as Microbial mats. Microbial mats are accretionary cohesive microbial communities found growing at solid-aqueous interfaces and stabilise un-consolidated sediments (Bauld *et al*., 1992). They have different morphologies, which depend on environmental factors and species composition (Zhang & Hoffman, 1992). Diatom mats form on the surfaces of many intertidal mudflats, and often occur with seasonal periodicities (Underwood & Paterson, 1993; Underwood, 1994). Such mats consist of dense aggregations of pennate diatom cells and EPS (extracellular polymeric secretions), a component secreted by diatoms during motility which is an important agent in stabilising sediment against re-suspension (Decho, 2000). Diatom numbers can reach sufficient densities to colour the surface of the mud (>10^4 cells cm^{-2}; Paterson, 1989) and significantly contribute to the primary productivity of an estuary (De Jonge & van Beusekom, 1992).

The dominant group of primary producers on most intertidal estuarine mudflats, epipelic diatoms (Admiraal, 1984), respond rapidly to changes in environmental conditions, quickly producing blooms when conditions are favourable. Since light penetrates into the sediment no deeper than 2mm (Colijn, 1982), only the diatoms in this sediment layer play a role in the fixation of inorganic carbon during photosynthesis. At low tide, they can reach high production rates (Colijn & De Jonge, 1984), however during high tide, photosynthesis is strongly reduced due to unfavourable conditions (sediment re-suspension) and the downward migration of microphytobenthos at the end of low tide. Nevertheless, microphytobenthos can potentially enrich coastal waters by means of re-suspension which enhances microalgal biomass in the water column (Baillie & Welsh, 1980; De Jonge & Van Beusekom, 1992).

Intertidal benthic microalgal communities may provide as much as one third of the total benthic primary productivity in some estuarine systems (Sullivan and Moncreiff, 1990). The microphytobenthos of the tidal flats in the Ems Estuary has been found to contribute ~25% to the total annual primary production of the area (Colijn & De Jonge, 1984). Several authors have compared pelagic (phytoplankton) and microphytobenthic primary production. Lackey (1967) noted that benthic diatoms are more abundant in estuaries than their planktonic relatives. In 1978, Joint measured the microbial production of an estuarine mudflat in S.W. England. Results showed that the annual primary production was 143g C m^{-2} for the sediment surface and 81.7g C m^{-2} for the water column. Varela & Penas (1985) found that the total annual benthic microalgae production reached 79g C m^{-2}, while water column production in the same intertidal flat in Spain was only 6g C m^{-2}. Cariou-Le Gall & Blanchard (1995) found that benthic microalgae were the only primary producer on intertidal mudflats at Marennes-Oleron Bay-France- which form about 60% of the total area of the whole bay.

Consumption of mat components, particularly diatoms, is a common feature of sediment-inhabiting microfauna, meiofauna and macrofauna. On the tidal mudflats, the microphytobenthos is grazed by sediment-dwelling nematodes and copepods, as well as by benthic organisms and filter feeders (Incze *et al.*, 1982; Schwinghammer *et al.*, 1983).

Microbial Mats as a source of productivity on mudflats of the Arabian Gulf

Because of the relative shallowness and water clarity, coastal areas of the Gulf support highly productive coastal habitats such as extensive intertidal mudflats. The sediment-based productivity in the Gulf is, therefore, highly significant. According to one estimate the productivity of the benthic system is 1820g C m^{-2} yr^{-1} as opposed to the 200g C m^{-2} yr^{-1} for the water column (McGlade & Price, 1993). In view of the quantitative importance of microphytobenthos as a source of primary productivity world-wide, resulting in high macrofaunal production on mudflats, they have received great attention in temperate areas, but very little is known about the productivity of such assemblages in the Gulf region. The first detailed studies on the microbial mat communities of the Arabian Gulf were carried out by several researchers in Abu Dhabi, U.A.E. (Kendall & Skipwith, 1968; Kinsman & Park, 1976). On the east coast of Saudi Arabia, the occurrence of microbial mats dominated by cyanobacteria was reported by Basson *et al.*, (1977), and in Kuwait by Jones, (1986) and Al-Hassan & Jones, (1989).

The importance of mats has only recently been recognised in association with the catastrophic oil spill during the 1991 Gulf war (Jones *et al.*, 1996; Höpner, 1996; Hoffmann, 1996). In the Jubail Wildlife Sanctuary, Saudi Arabia, extensive microbial mats, dominated by cyanobacteria, covered vast areas of the tar-polluted intertidal zone (Hoffmann, 1996), when most macrofauna were eliminated (Jones *et al.*, 1996). However, two years after the oil spill, the mats reduced in area back to their natural zone at the top of the shore. It was suggested (Jones *et al.*, 1996) that as the macrofauna began re-colonising the shore it used mats as a source of nutrition, rapidly grazing the extensive areas of mat seen immediately after the oil spill. During a 5 year monitoring programme, the area of mat was observed to rapidly reduce to a narrow band on the top of the shore, similar to that found on control un-impacted shores (Jones *et al.*, 1998). These authors suggested that the lower edge of the mats is controlled by grazers consuming this source of primary production as soon as it is produced.

Mudflats of the western Arabian Gulf support a high macrofaunal production (Basson *et al.*, 1977; Al-Sarawi *et al.*, 1985; Vousden, 1985; Jones, 1986a; Jones & Clayton, 1983; Clayton, 1986; chapter 2), and are considered to be among the most productive of natural ecosystems (Basson *et al.*, 1977). Although the mat assemblage of Gulf mudflats may make an important contribution to overall intertidal primary productivity (Jones *et al.*, 2002a; Table 1.2 & 1.3), no attempt has yet been made to assess the importance of this source of primary production to the region. Therefore this preliminary study attempts to (a) determine whether faunal inhabitants of Sulaibikhat Bay mudflats feed on microbial mats, and (b) provide estimation of mat growth rate, standing stock, together with daily and annual productivity rates.

METHODOLOGY

Site Description

The study was conducted at a site situated within the south-eastern part of Sulaibikhat Bay, 47°53.8` E and 29°20.5` N, approximately 6km from transect II (Sulabikhat, see chapter 2), along the seaward boundary of KISR (Kuwait Institute for Scientific Research) (Figure 4.2). The site was chosen due to its restricted access, which ensured that the experimental apparatus was not tampered with. The actual shore in the eastern part of the bay was infilled during the late 70's and early 80's in association with the establishment of Shuwaikh port and the construction of a chain of hospitals as well as KISR. The top end of the shore at the site has been infilled with sand and boulders, parallel to the vertical zonation of the shore. This has made the lower shore accessible, since it would normally only be reached by crossing soft mud. A sewage outfall is sited approximately 60m from the fenced site.

For sampling purposes, a transect perpendicular to the shoreline (KI), almost parallel to the boulder infill, was established (Figure 4.3). It was divided into 3 zones according to visible distinctive characteristics of the sediment surface. Zone I extends approximately 50m from the top of the shore, and is characterised by dry sediment and lack of intertidal macrofaunal activity. Forty metres from zone I lies ZII where the sediment is relatively moist and where gastropods start to appear. Zone III is situated 40m beyond ZII where mud is extremely wet, in a semi-liquid state, and a high density of cerithids occurs. In general, the sediment on this transect is of a clayey nature, and anoxic 0.5cm below the surface, hence the absence of several burrowers in comparison with transect I (TI, chapter 2). Floral assemblage is represented by benthic microalgae (microbial mats), and planted mangrove shrubs, *Avicennia marina*, both occupying the top end of the shore. Under the mangrove plants the brachyurans *Macrophthlamus depressus* and *Uca albimana* occur. Within the sand infill *Uca sindensis* can be seen, while under and in-between boulders, *Metapograpsus messor* was occasionally spotted. The mud snail *Cerithidea cingulata* is the most abundant faunal species on this

Intertidal gobies were seen approximately 300m from the infilled shoreline. Waders also occur in large numbers at this transect throughout the year.

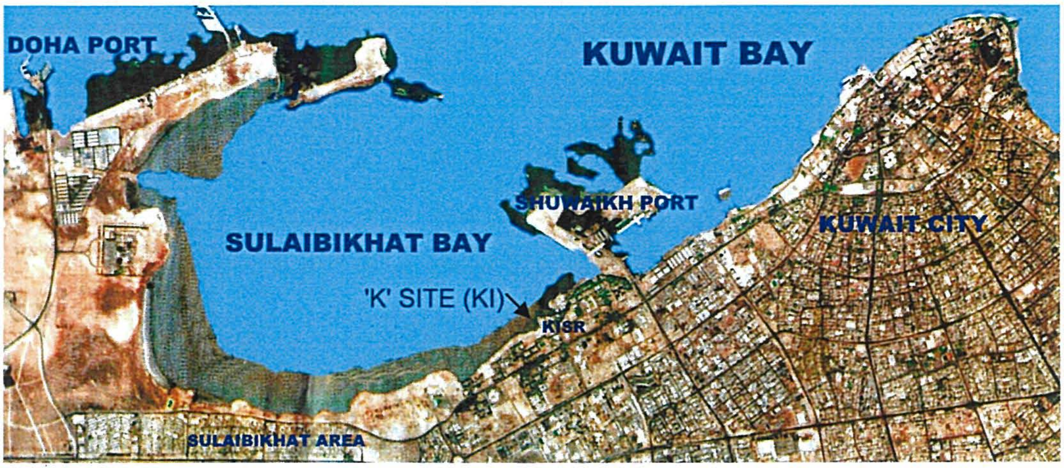


Figure 4.2 Location of KI transect within Sulaibikhat Bay.

Figure 4.3 View of KISR site, showing location of zones along KI transect.

Microbial Mat

Composition

Random samples within an area of 2.25 x 2.25cm, to a depth of 1cm ($\cong 5cm^3$) were taken, using a cube core, from different zones along the KI transect. Samples were taken to the laboratory, where a sub-sample from each of the original samples, with an area of $55mm^2$, and a depth of 1.5mm was remove using a scaled blade. The sub-sample was placed in 100ml of filtered seawater, and carefully mixed using a whirl mixer. A sub-sample of 1ml was taken from the suspension, divided onto 5 glass slides, and covered with a cover slip. The number of cells was counted on each slide, to give the number of cells/1ml. Taxonomical determination to genus was performed using Al-Hasan and Jones (1989).

Correlation between dominating mat component (DMC) and concentration of different types of chlorophyll pigment (CCP)

An attempt was made to relate the abundance of the dominant mat component (DMC) determined above, to the concentration of chlorophyll pigment (CCP). Determination of DMC was conducted following method the described by Sourina, (1978), and the CCP for the same samples was prepared following methods and equations described by Lorenzen, (1967).

A sub-sample was taken from the surface of each of the original samples, with an area of $55mm^2$, and a depth of 1.5mm, [approximate standard weight 0.075g]. Each sub-sample was placed in a 20ml tube and filtered seawater was added to make the contents of the tube up to 5ml. The contents were then homogenised using a whirl mixer for approximately 2min. A drop of the suspension was placed within a counting chamber of an improved Neubauer haemocytometer (depth 0.1mm, $1/400mm^2$; No.BS748, Gallenkamp, Weber Sci. Intl. Ltd., UK), covered with a cover slip, and placed under a light microscope (Olympus CH30). Using an objective of 40x, the number of cells within the central chamber was counted (F), and the actual number present in the 5ml extract was calculated as follows:

Density of DMC = F x Q/ V,

Where (F) number of counted cells

(Q) volume in which the sample was extracted in (5ml)

(V) volume in the central chamber of a Neubauer hemocytometer of 0.1mm depth and area $1/400\text{mm}^2$ (10^{-4}ml).

To determine the concentration of chlorophyll pigments in each sample processed for DMC, the remaining mixture was filtered using 250ml Nalgene disposable filter units (#126-0045; Fisher Sci. Intl, USA), designed to hold 42.5 diameter Whatman glass microfibre filters GF/C with porosity of 1.2µm (#1822-042). Each glassfiber filter was then placed in a stoppered centrifuge tube of 15ml capacity, pigments were extracted from the filter in 5ml of 90% acetone, and stored for 45min in a dark box at room temperature. The contents of each tube were centrifuged (Model: Hermle Z230, #591386) for 15min at 4000rpm. Because the supernatant was highly turbid, due to the nature of the sediment (clay), the supernatant was diluted to 50ml using 90% acetone.

CCP protocol: A digital single cell mode UV/VIS spectrophotometer (BECKMAN DU®520) was used for CCP determination. A 1cm light path cuvette was cleaned appropriately prior to each use. A pasteur pipette was used to transfer the diluted supernatant to the cuvette. Three replicate readings were taken per sub-sample. All readings were made against a 90% acetone blank. The optical density (extinction at certain wavelengths) was recorded at 750, 663, 645 and 630nm. Each extinction was corrected for a small turbidity blank by subtracting the 750nm from the 663, 645 and 630nm absorbencies. The results were then divided by the light path in centimetres of the cells, which in the present case was 1cm light path cuvette (*E*). The amount of pigment was then calculated by using the following equation:

Chlorophyll a (Ca) = $11.64E_{663} - 2.16E_{645} + 0.10E_{630}$

Chlorophyll b (Cb) = $20.97E_{663} - 3.94E_{645} + 3.66E_{630}$

Chlorophyll c (Cc) = $54.22E_{663} - 5.53E_{645} + 14.81E_{630}$

Since the supernatant (chlorophyll extracted in 5ml of acetone) was diluted the actual readings were divided by 10, the calculated concentration of chlorophyll *a* is represented in micrograms per $0.5cm^2(\mu g/0.5cm^2)$, however the final results are presented in mg m^{-2}.

The relationship between DMC and CCP was quantified using simple linear regression analysis. A functional relationship between DMC as the dependant variable and CCP as the independent variable was assumed.

Mat standing crop and growth rate

Field experiment I (EXP I) was conducted to assess the effect of natural grazing on mats, while experiments II - IV (EXP II - IV) attempt to estimate the normal standing crop of microbial mats and to assess the growth rate of the mats. To conduct such experiments, visits were made during low tide, according to predicted low tidal levels shown in Appendix 4.1.

Sample collection

EXP I: six exclusion apparatus (18×10^3 cm^3) were placed within zone 3 at KI on 5 March 2001 during low tide, approximately 120m from the top shore (Figure 4.4). Each apparatus consisted of a polyethylene basket (40 x 30cm, height 15cm) covered by a 2mm pore-sized mesh. Holes were made in the corners of the apparatus in order to insert metal rods, which fixed it down into the sediment. Three of the apparatus contained 32 cerithids with a shell length of 21mm (C= with *Cerithidea*), while the remaining 3 were devoid of cerithids (WC= without *Cerithidea*). The first sample was randomly collected from the excluded area on 6 March 2001, using a cube core within an area of 2.25 x 2.25cm, inserted to a depth of 1cm ($\cong 5cm^3$), with the aid of a spatula., placed in labelled and divided plastic containers. Further samples were collected on a daily basis after that for a total of 5 days (120hr). Previously sampled-points within the exclusion area were not re-sampled during the experiment period. Figures 4.5 and 4.6 show the sampled areas before and after sample collection at both WC and C exclusions respectively. Samples were transferred to the laboratory, and freeze-dried at -80°C until analysed for CCP.

EXP II: to conduct this experiment, KI was visited on 3 October 2001. Upon arrival, and at each of the 3 zones, an area (35 x 35cm) was randomly selected. Each sampling area (SA) was marked at the corners using metal rods but fauna occupying the intertidal zone or migrating with the rising tide was not excluded. The sampling area was visually divided into 7 vertical columns each 5cm wide, one for each visit (day) made during the sampling period. At each sampling area (SA-I, SA-II, SA-III), and within each column, 6 replicate sediment samples (22.5 x 22.5 mm, depth 1cm) were obtained in the same manner as in EXP I. At 0hr, an initial sample was obtained and placed in a distinct compartment in a pre-labelled plastic container (0hr*), after which the top 1cm of the sediment surface in each SA was scraped and another sample at 0h obtained (0hr). Figures 4.7, 4.8 and 4.9 show the sampled area in each zone and the visual daily recovery of the mats. Samples were taken and freeze-dried at –80°C until analysed for CCP. Daily visits were then made during the following 5 days.

Experiment III (EXP III) aimed to measure the mat recovery rate during the 6h submersion period when mats were covered with the flood tide (1 tidal cycle) in March 2002. However, EXP IV was conducted during the first 3hr-exposure period, as soon as the tide dropped (following the ebb tide), in May 2002. Similar sampling techniques used during experiment II were used for these experiments; however surface mat was not scraped before initiating these experiments.

Sample preparation for CCP

A sub-sample was sliced off the surface of each of the original sample, with an area of 55mm^2, to an approximate depth of 1.5mm using a scaled blade [approximate standard weight of 0.075g]. The sub-sample was placed in a 15ml Pyrex glass, pestle-type manual homogeniser, 3ml of 90% acetone solution was added using a high precision micro-pipetter (#1111-G; Volac, UK), and the sample was homogenised for approximately 1min. The mixture was then transferred to a 15ml centrifuge tube, and the pestle and homogeniser were rinsed 2-3 times with 90% acetone. The washes were added to the centrifuge tube, making sure that the final volume in the centrifuge tube was about 5ml. The centrifuge tubes were allowed to stand for 45min in a dark box at room temperature, centrifuged (Model: Hermle Z230, #591386) at 4,000rpm for 15min, after which the supernatant was carefully decanted. The supernatant was diluted to 50ml using 90% acetone.

CCP determination

Concentration of chlorophyll pigments was determined following the procedure previously mentioned using a digital single cell mode UV/VIS spectrophotometer (BECKMAN DU®520).

Mat gross primary production (GPP)

Primary production contributed by microbial mats to the mudflats of Sualibikhat and Kuwait Bay, was estimated following the method described by Bot and Colijn, (1996). They described a standard algorithm for calculating primary production (PP) based on chlorophyll (CCP) measurements performed according to Lorenzen, (1967). They estimated the effect of changes in chlorophyll on primary production by linear regression of chlorophyll *a* (X= intercept = mg m^{-3}) and primary production (Y= slope = mg C m^{-3}) derived from coastal and open-sea measurements. This resulted in the following regression equation with a squared correlation co-efficient (r^2) of 0.91:

$$\mathbf{GPP = 1.04 + 1.27CCP}$$

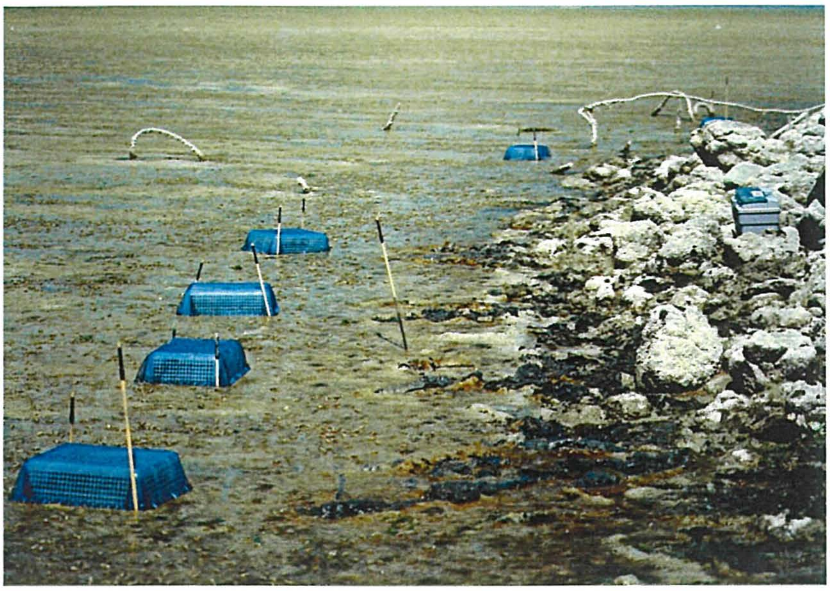
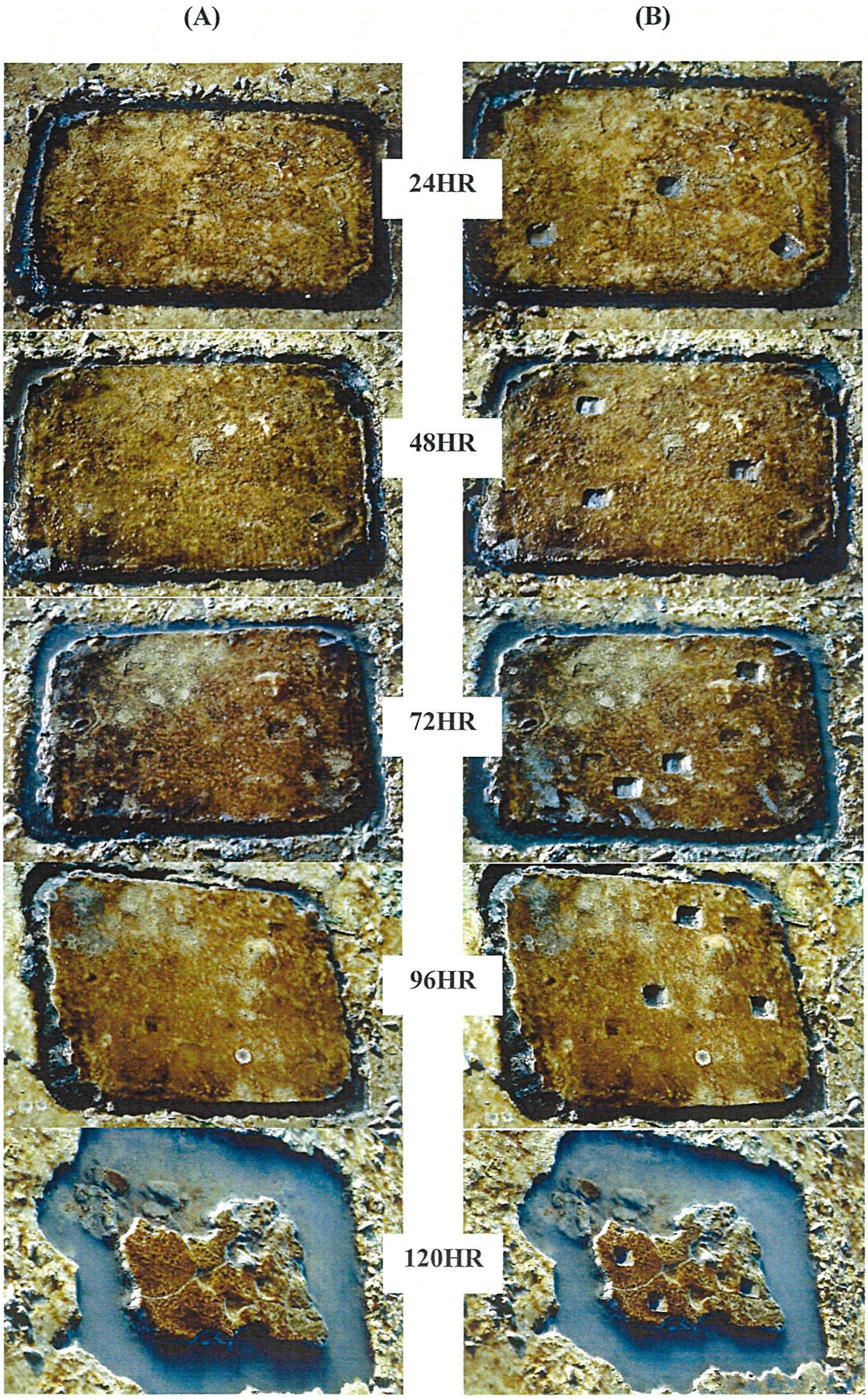


Figure 4.4 Location of exclusion cages for experiment I, at zone III, along 'KI' transect- Sulaibikhat Bay.

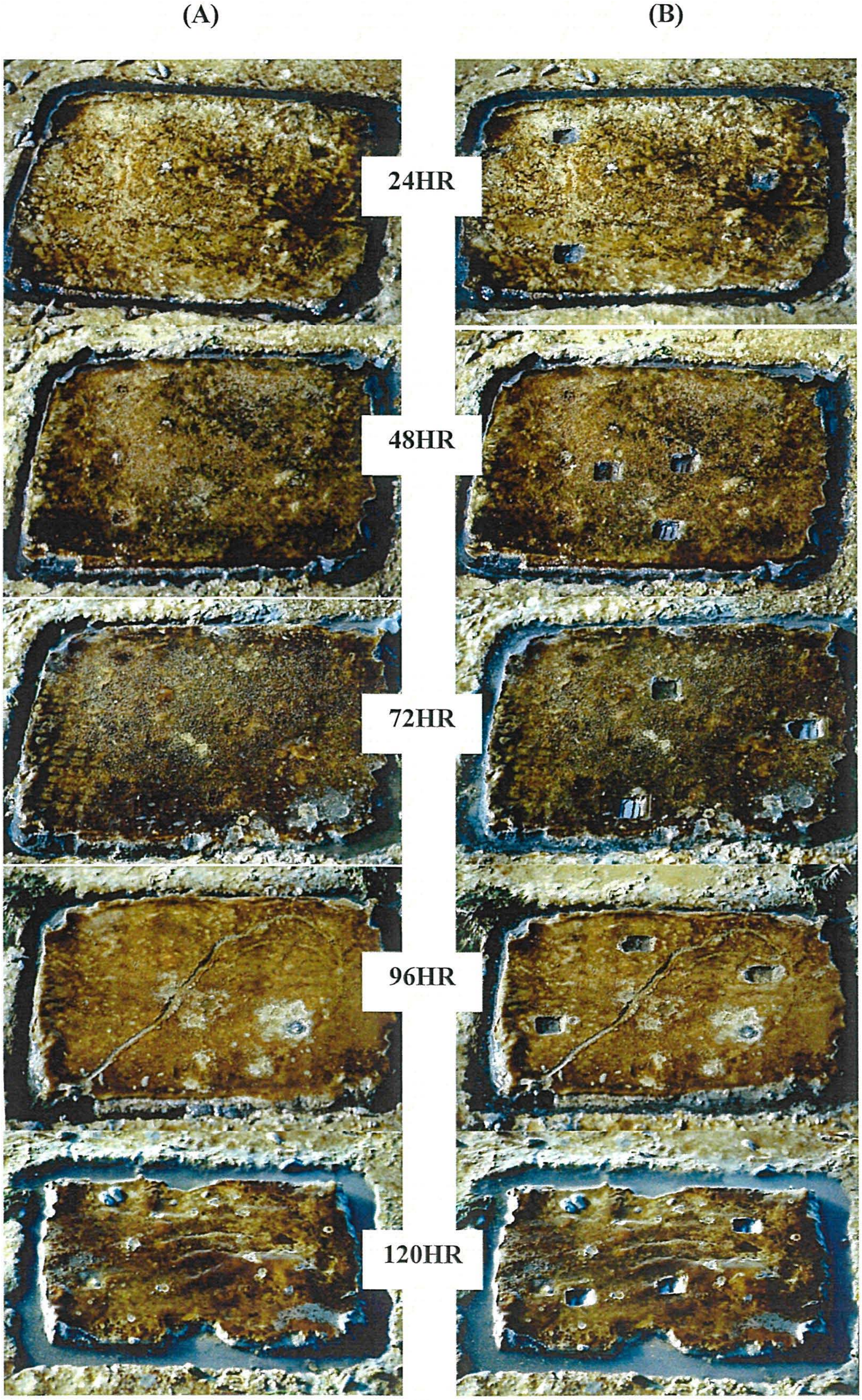
Figure 4.5

Excluded areas under cages (EXP I) for the 3 replicate exclusions (I, II, III) without *Cerithidea cingulata* (WC), before (A) and after (B) sample collection during the 5-day sampling period.

WC-I



WC-II



WC-III

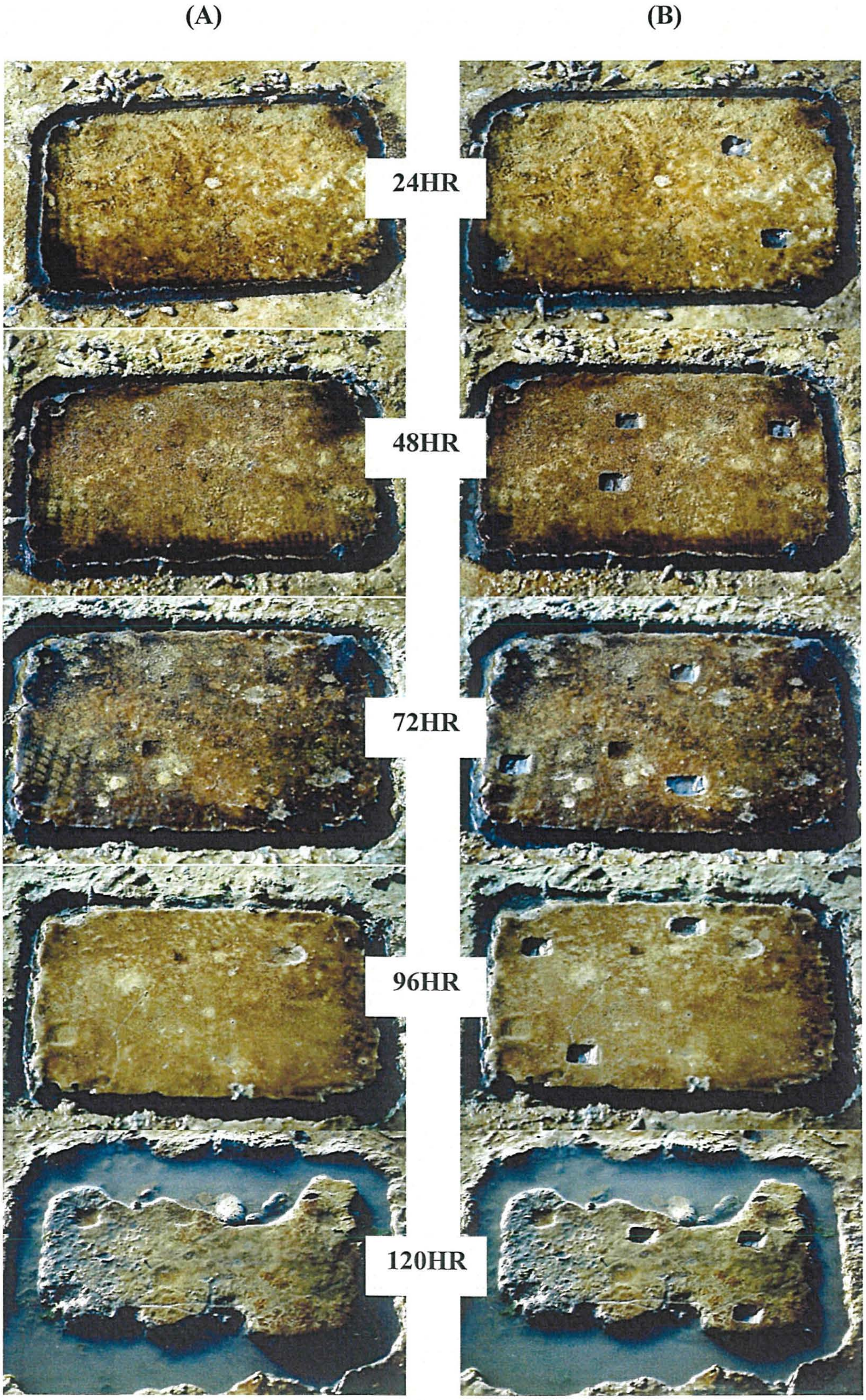
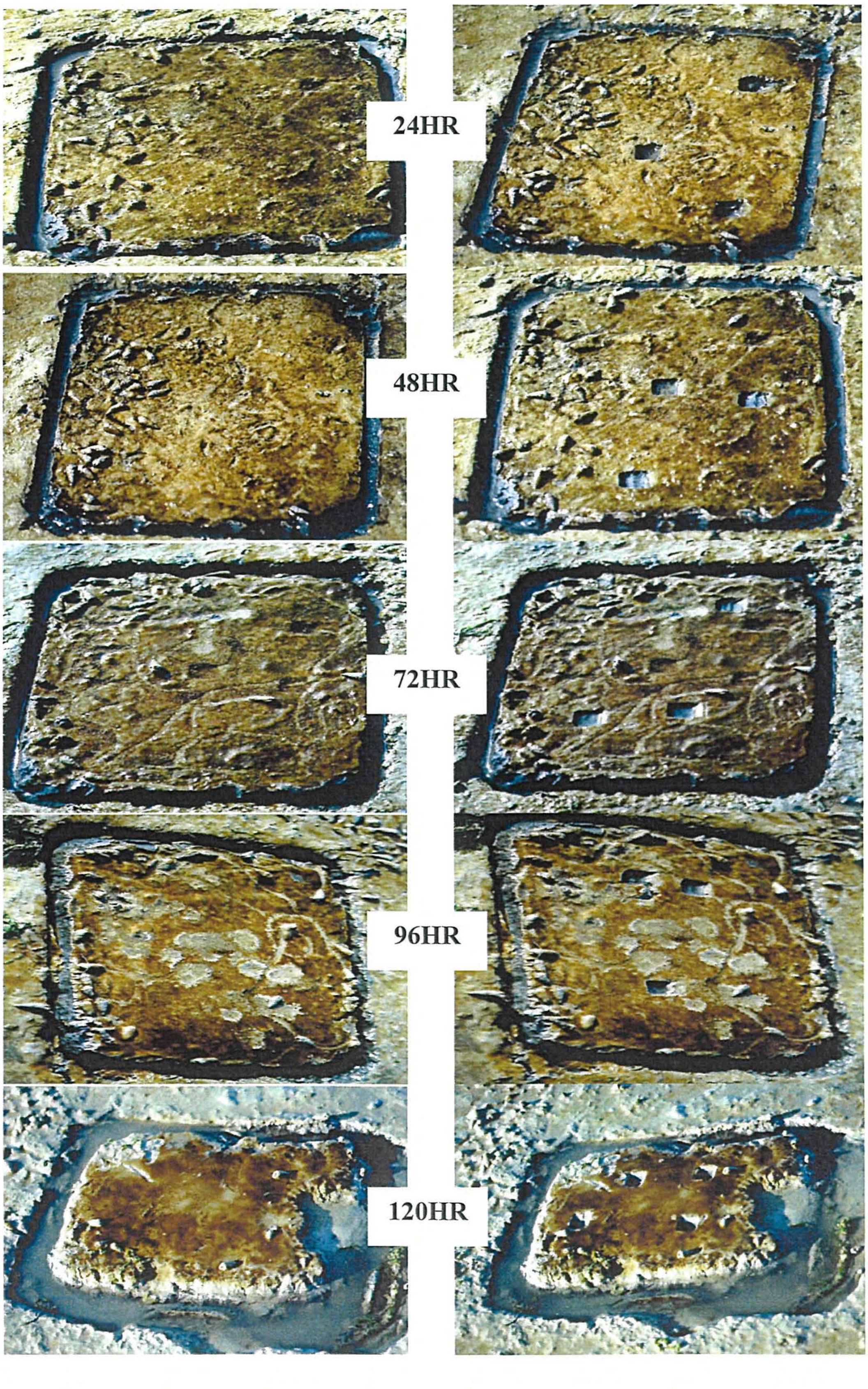


Figure 4.6

Excluded areas under cages (EXP I) for the 3 replicate exclusions (I, II, III) with *Cerithidea cingulata* (C), before (A) and after (B) sample collection during the 5-day sampling period.

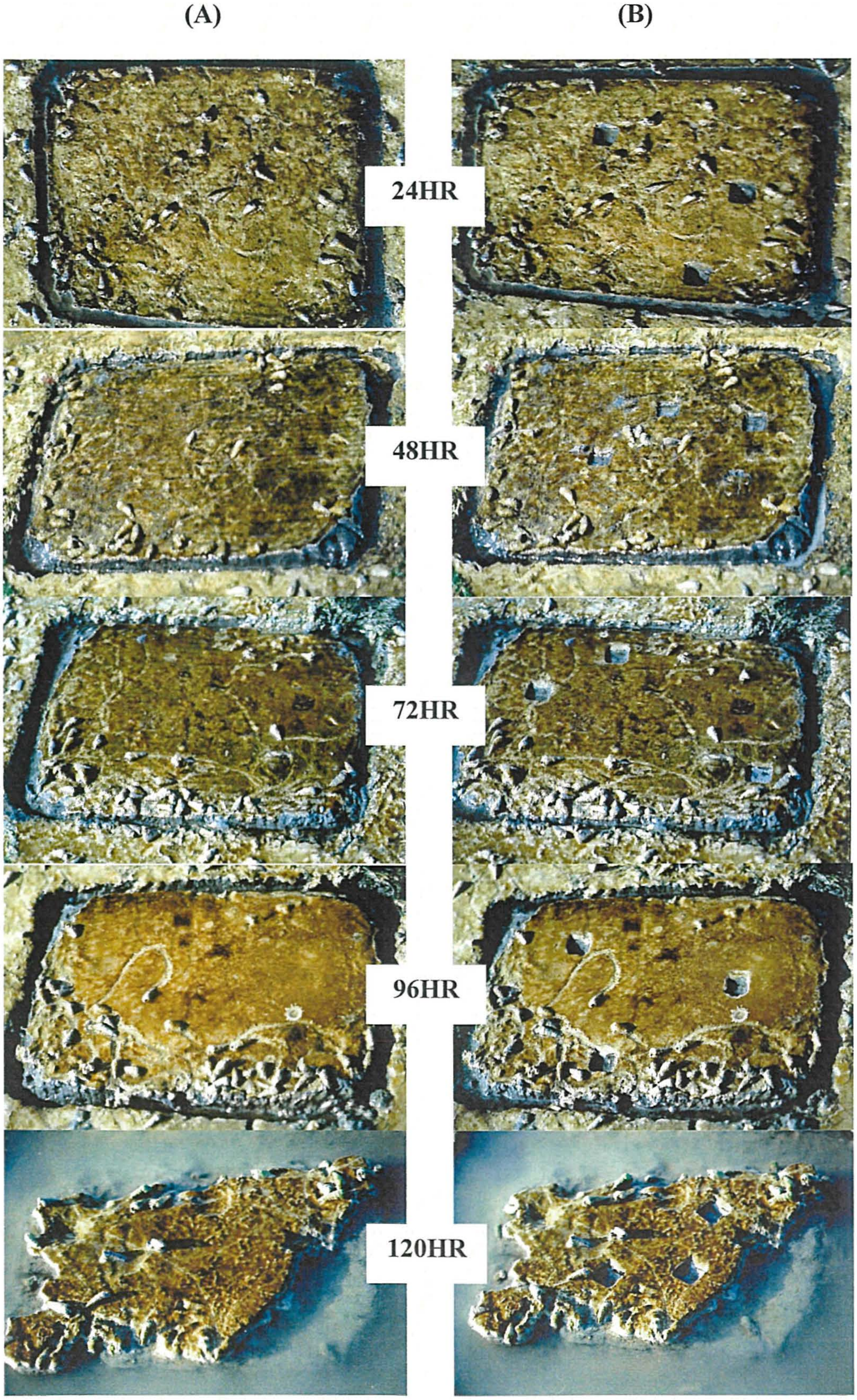
C-I



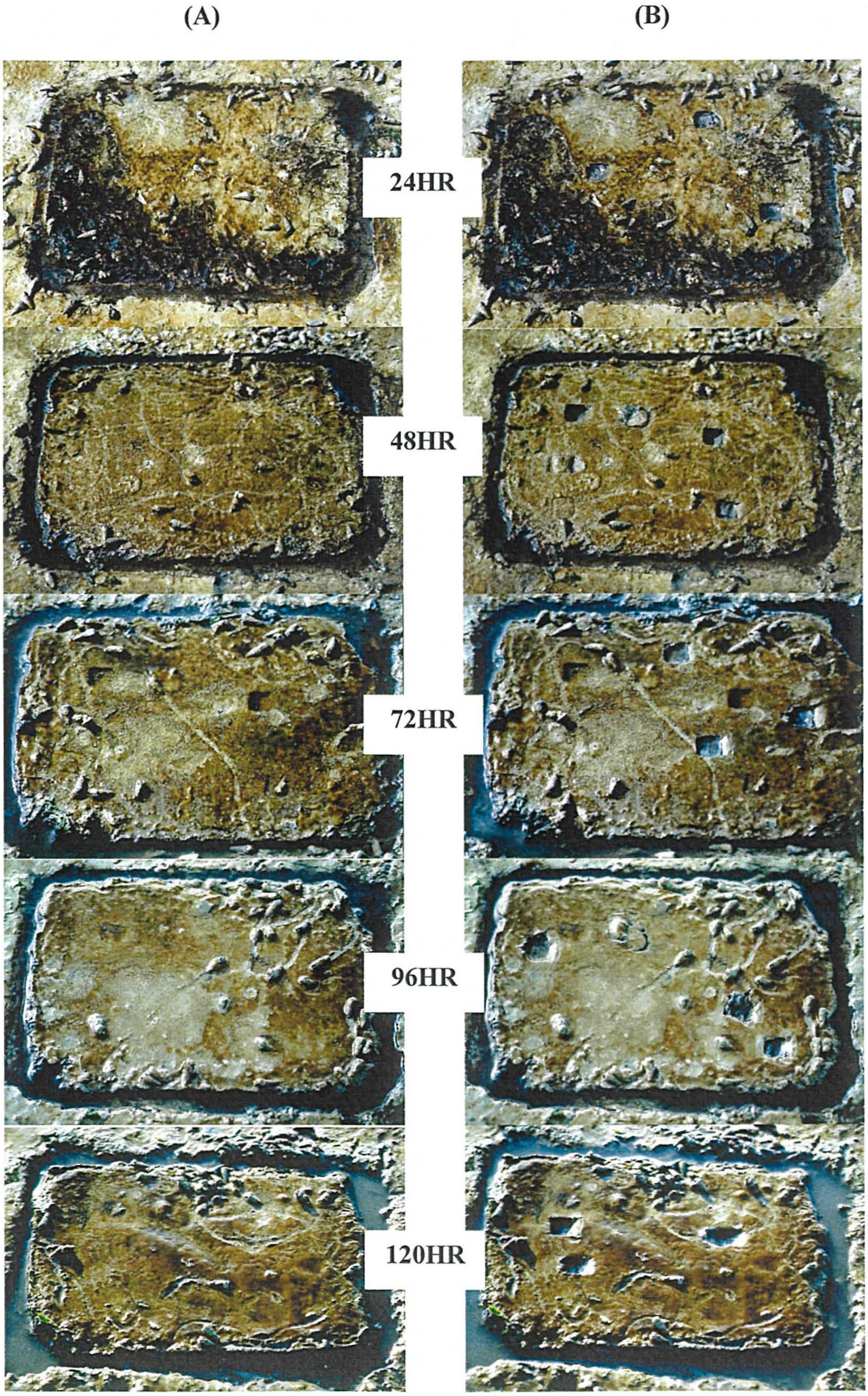
(A)

(B)

C-II



C-III



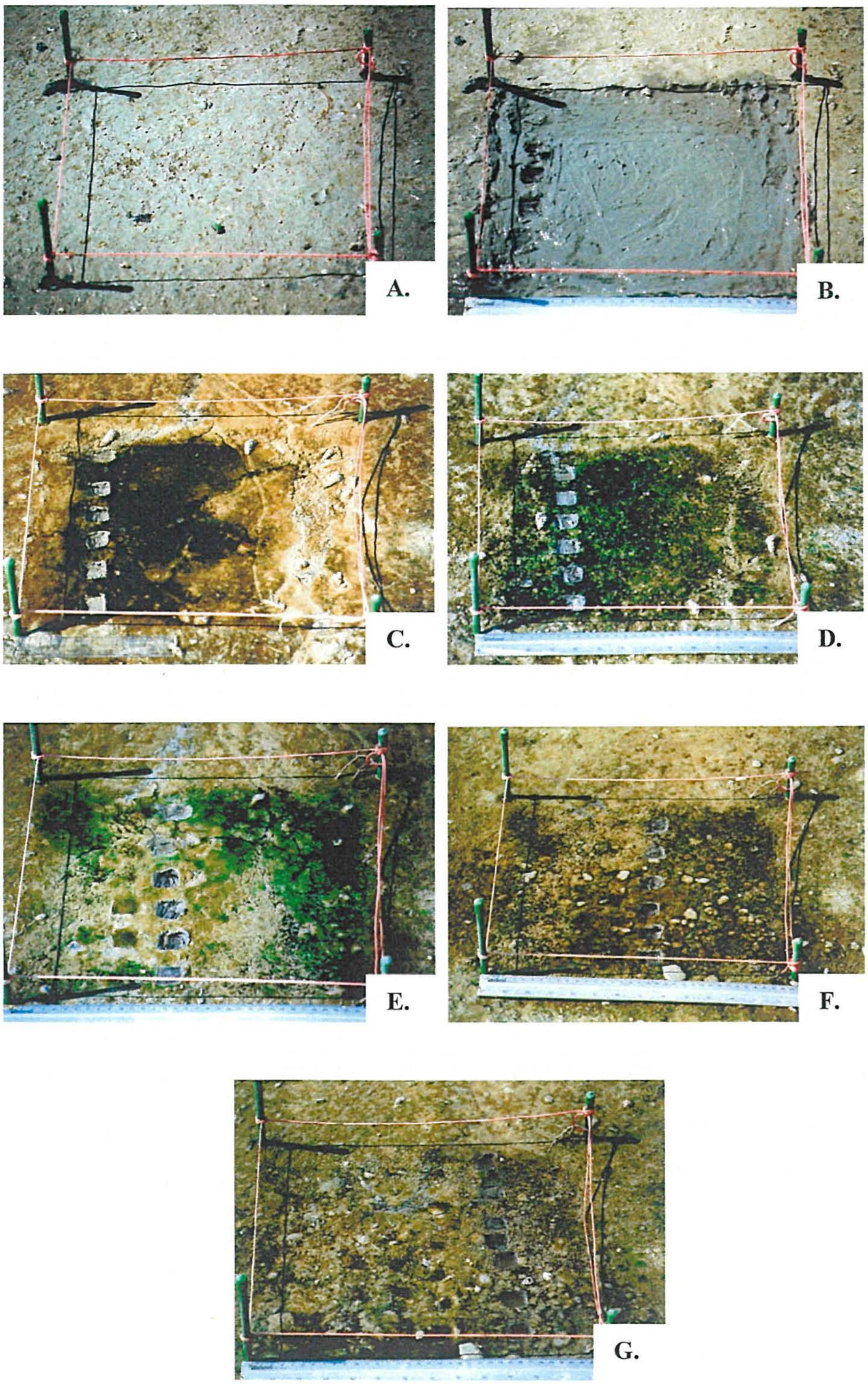


Figure 4.7 Experiment II (Exp II) re-growth and standing crop at zone I along KI.

A. Before scraping (0h*)
B. After scraping (0h)
C. After 24h
D. After 48h
E. After 72h
F. After 96h
G. After 120h

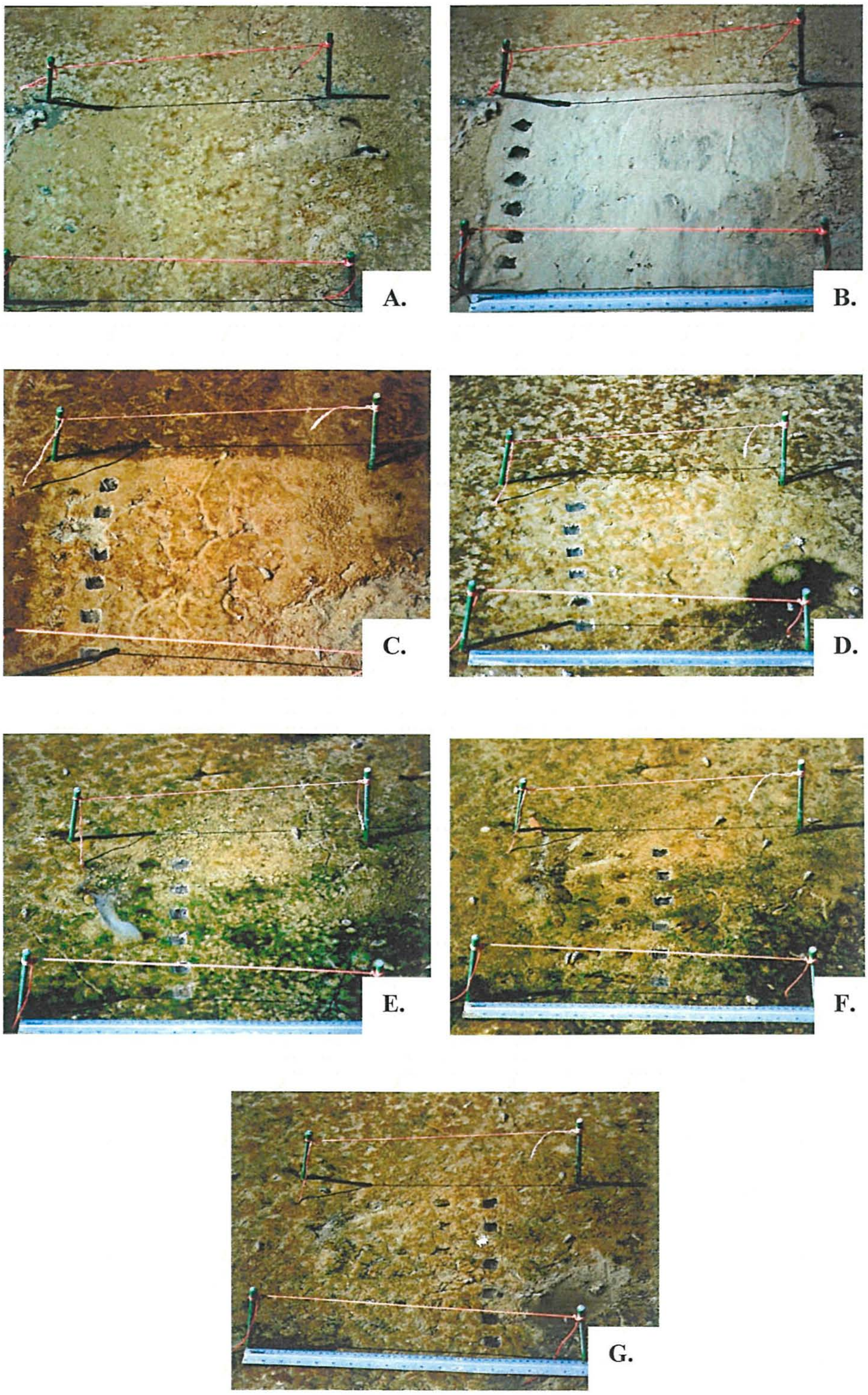


Figure 4.8 Experiment II (Exp II) re-growth and standing crop at zone II along KI.

- **A.** Before scraping (0h*)
- **B.** After scraping (0h)
- **C.** After 24h
- **D.** After 48h
- **E.** After 72h
- **F.** After 96h
- **G.** After 120h

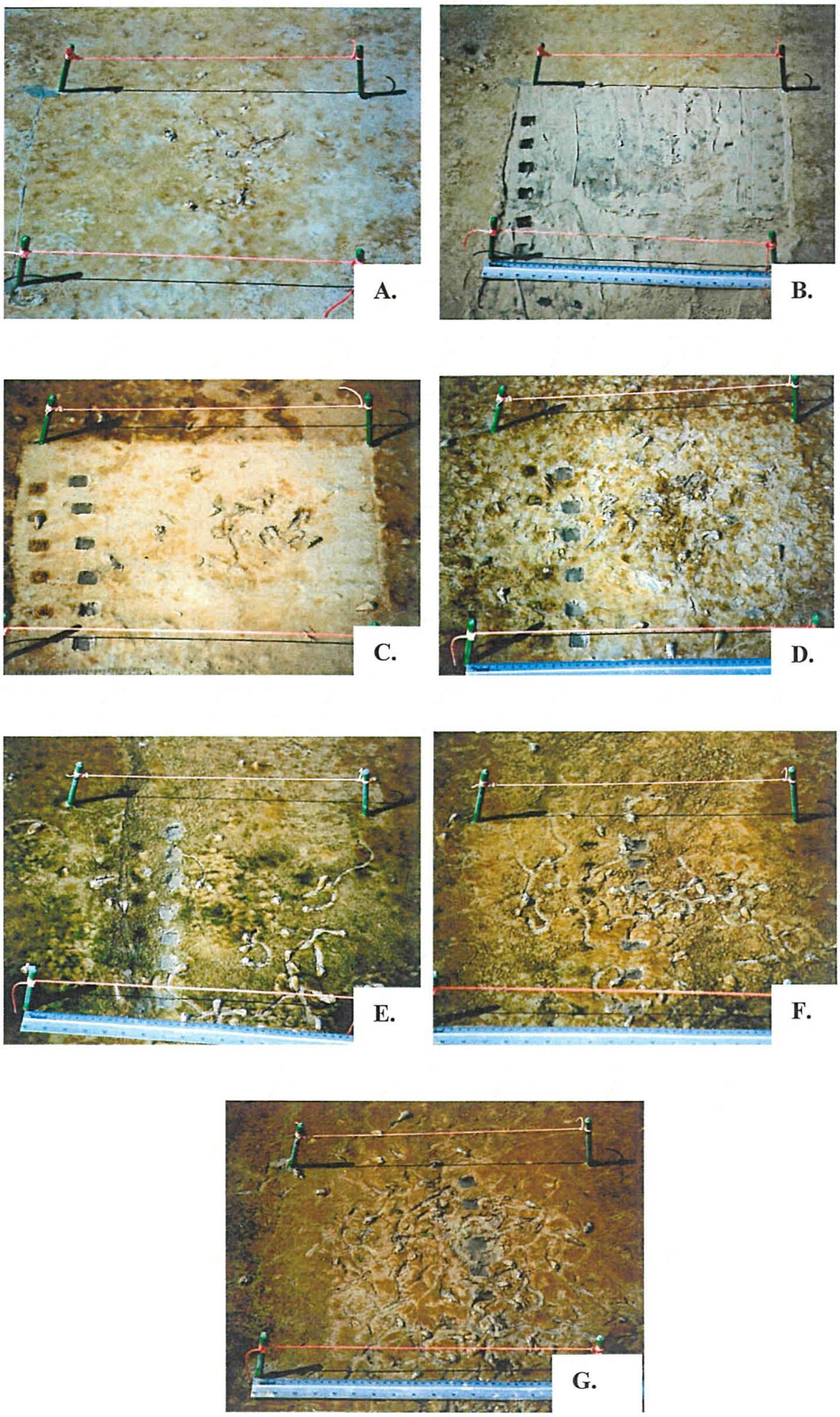


Figure 4.9 Experiment II (Exp II) re-growth and standing crop at zone III along KI.

A. Before scraping (0h*)
B. After scraping (0h)
C. After 24h
D. After 48h
E. After 72h
F. After 96h
G. After 120h

Microbial Mat Grazing

Initially, it was essential to determine whether faunal inhabitants of Sulaibikhat mudflats actually feed on the microbial mats. This was accomplished in several ways: examination of contents of the gut, contents of the faeces, and monitoring grazing activity of certain species in the laboratory.

Gut and faecal analysis

Random visits were made throughout the study to Ashish Al-Doha and Sulaibikhat (TI and TII respectively, see chapter 2), and the KISR site (KI). Macrofaunal species were obtained by hand and/or by net, or by placing fish traps along the transects (see chapter 2). Species collected using fish traps were placed in an icebox, and transferred to the laboratory where they were dissected for gut content analysis. Those collected by hand/net were placed in plastic containers filled with filtered seawater, transferred to the laboratory and each species was placed in an aquarium where its natural habitat was simulated in order to facilitate defecation. Burrowing brachyurans were placed in aquaria containing sterilised sediment from the mudflats, laid at a 45° angle and covered half way with filtered seawater. This produced an ebbing tide effect, keeping the top end of the sediment exposed but moist, and allowed the organism the choice of staying in or out of the water. For the gastropod *Cerithidea cingulata* and shrimp *Metapenaeus affinis*, no sediment was added. An aerator was placed in each aquarium. During a 24h period, faeces were collected, using a pipette, and placed in pre-labelled plastic jars with some seawater and stored in the freezer until examination. Both contents of the gut and faeces were examined under a dissecting and compound light microscope.

Feeding experiments

Experiment I: Approximately 155 cerithids were placed in an aquarium (75cm x 35cm; natural occurrence of cerithids within this site ranges between 450 – 700m^{-2}) similar in setting to that above for the burrowing crabs. Pieces of microbial mats taken from the top end of the shore were placed at the top end of the sloping sediment in the aquarium, the feeding activity was then monitored.

Experiment II: This experiment attempts to estimate the consumption rate of mat by *C. cingulata*, however, initially the total defecation period for cerithids had to be ascertained. This was achieved by collected several individuals from KI, placing them in a bucket with seawater, and transferring them to the laboratory. Upon arrival, the green algal filaments attached to their shell were removed and scrubbed off using a rough brush. Six cerithids were then placed in an aquarium, with separate compartments, and were monitored. As soon as 2 cerithids defecated (approx. 30min), they were removed from the aquarium, and their digestive tract removed. The gut was placed in a 15ml Pyrex glass, pestle-type manual homogeniser, 3ml of 90% acetone solution was added using a high precision micro-pipetter (#1111-G; Volac, UK), and homogenisation of the sample was conducted for approximately 1min. The mixture was then transferred to a 15ml centrifuge tube, and the pestle and homogeniser were rinsed 2-3 times with 90% acetone. The washes were added to the centrifuge tube, making sure that the final volume in the centrifuge tube was about 5ml. The centrifuge tubes were allowed to stand for 45min in a dark box at room temperature, centrifuged (Model: Hermle Z230, #591386) at 4,000rpm for 15min, after which the supernatant was carefully decanted, and concentration of chlorophyll pigment was determined as given in the CCP protocol. The same procedure was conducted for cerithids obtained after 24h and 96h. After determining the rate of gut evacuation, 3 groups, each comprising 3 cerithids were formed. Cerithids group 'A' had a shell length of 26mm, those in group 'B' were 21mm in length, while cerithids group 'C' had shells approximately 18mm long. Each cerithid was placed in a petri-dish with seawater. Because the faeces of *C. cingulata* can not be distinguished from the sediment surface, no sediment was placed in the compartments. A piece of mat of approximately similar size and weight (0.55cm^2, approx. 0.05g) was placed as feed for each cerithid, and feeding activity was then monitored.

RESULTS

Microbial Mat

Composition

The mat samples collected at KI, contained 20 genera belonging to 4 algal groups which contributed to the mat assemblage obtained during the 6-month sampling period (Table 4.2). Bacillariophyceae (diatoms) showed a high mean contribution of 61%, followed by Cyanophyceae (blue-green algae) with 30.6%. Chlorophyceae (green algae) represented 6.9% of the mats sampled, while Rhodophyceae (red algae) had the lowest contribution (0.3%).

Since the abundance of both chlorophyte and rhodophytes within the mat were low (i.e. less significant) in comparison to those of benthic diatoms (Bacillariophyceae) and blue-green algae (Cyanophyceae), it was decided to describe the mat composition from its dominating constituents only. Accordingly, diatoms makeup 69.4% of the mat, forming the dominating mat component (DMC) while blue-green algae form 30.6%.

Figure 4.10 shows the abundance of benthic diatoms in the mat samples collected from KI (KISR site) within Sulaibikhat Bay, during the 6 month sampling period (April 01- October 01). The Bacillariophyceae class consisted of 7 genera with the pennate diatoms *Bascillaria*, *Nitzchia* and *Navicula* dominating (41.3%, 25.2% and 11.9% respectively), and *Gyrosigma* the rarest (3.65%). The abundance of *Bascillaria* was lowest in June (85.45 x 10^6 cells/m^2) and highest in July (316.36 x 10^6 m^{-2}). It was almost always commonest during the sampled period except in June 01 when *Nitzchia* dominated. The cell numbers of *Nitzchia* showed gradual increase from April 01 reaching highest cell numbers during July 01 (167.27 x 10^6 m^{-2}), after which this diatom gradually decreased to reach a lowest count during September 01 (9.09 x 10^6 m^{-2}). The number of *Navicula* cells appear to increase from April to reach a peak of 103.64 x 10^6 m^{-2} in July, and a drop to 1.82 x 10^6 m^{-2} in August. *Navicula* was usually lower in numbers than both *Bacillaria* and *Nitzchia*, however during September cell number were approximately 2% higher than those of *Nitzchia*. During September 01, the cell count of *Rhizosolenia* out-numbered both *Nitzchia* and *Navicula* by 5.4% and 3.4% respectively. However during October 01 it was only approximately 0.5% higher in numbers than *Navicula.* The 3 dominating pennate benthic diatoms all showed highest abundance during July 2001.

Figure 4.11 shows the abundance of blue-green algae in the mat samples collected from KI (KISR site) within Sualibikhat Bay, during the 6 month sampling period (April 01- October 01). Six genera of Cyanophyta were found in the microbial mats. *Microcoleus* with a percentage of 42.2 was the most dominant followed by *Oscillatoria* (31.52%), and *Spirulina* was rarest (1.21%). *Microcoleus* showed a gradual decrease from April 01 and was absent in July 01, but increased in August to reach a peak of 149.1 x 10^6 m^{-2}. *Oscillatoria* was most abundant during April (174.6 x 10^6 m^{-2}) and decreased to lowest counts in October (3.64 x 10^6 m^{-2}). The unicellular blue-green algae *Chroccocus*, was the next commonest species in this class. It was absent during April 01- July 01, however during October a peak of 32.73 x 10^6 m^{-2} was recorded.

In general, the pennate diatom *Bascillaria* formed 28.6% of the mean total mat composition, followed by *Nitzchia* (17.5%). The filamentous cyanophyte *Microcoleus* contributed 12.9% to the mat, followed by another filamentous blue green *Oscillatoria* (9.7%). The pennate diatom *Navicula* contributed 8.3% to the mat composition.

Table 4.2 Genera list of flora contributing to the composition of microbial mats within KISR site (KI) - Sulaibikhat Bay, collected within a 6-month sampling period (April 01- October 01).

Components	**Mean %**
BACILLARIOPHYCEAE	
Bascillaria spp. (Pennate diatom)	25.0
Nitzchia spp. (Pennate)	15.0
Navicula spp. (Pennate)	8.1
Rhizosolenia spp (Centrale)	5.2
Coscinodiscus spp (Centrales)	2.6
Pleurosigma spp. (Centrale)	2.6
Gyrosigma spp. (Pennate)	2.5
	61.0
CHLOROPHYCEAE	
Cladophora spp	2.2
Enteromorpha spp.	2.2
Chaetomorpha spp.	1.6
Chalamidomonas spp.	0.6
Urospora spp.	0.3
Acrosiphonia spp	0.1
	6.9
CYANOPHYCEAE	
Microcoleus spp.	14.2
Oscillatoria spp.	8.5
Chroccocus spp	3.7
Lyngbya spp.	3.0
Calothrix	0.8
Spirulina spp.	0.3
	30.6
RHODOPHYCEAE	
Porphyra spp.	**0.3**

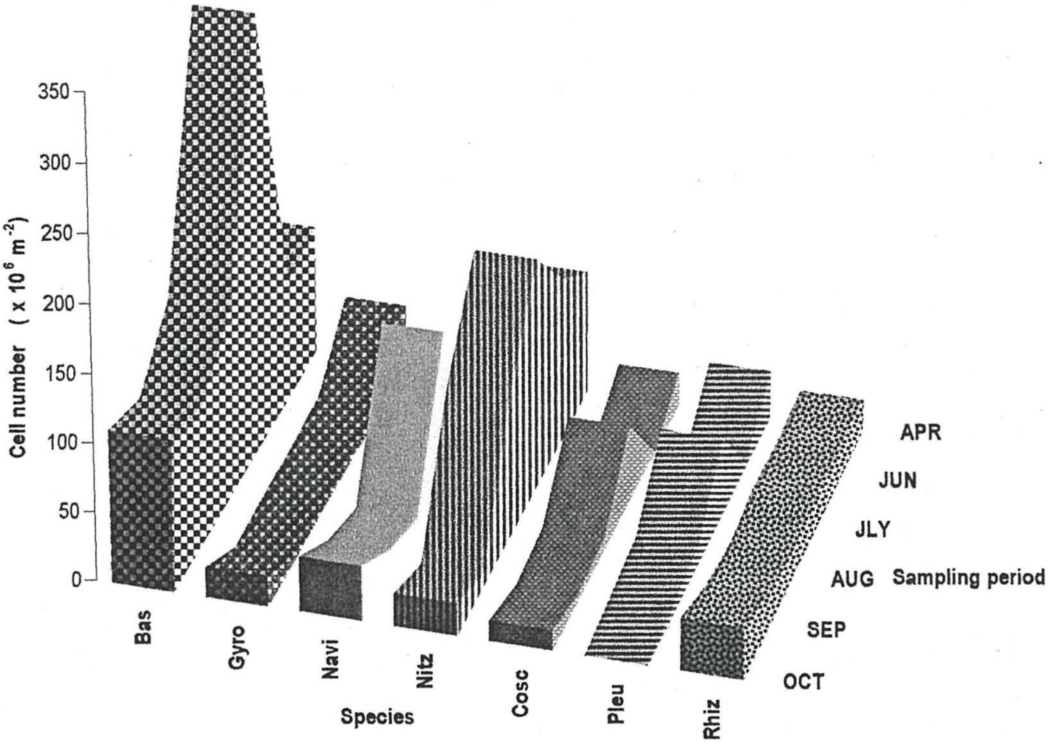


Figure 4.10 Contribution by Bacillariophyceae (diatom) genera to the microbial mat assemblage [Bas: *Bascillaria*, Gyro: *Gyrosigma*, Navi: *Navicula*, Nitz: *Nitzchia*, Cosc: *Coscinodiscus*, Pleu: *Pleurosigma*, Rhiz: *Rhizosolenia*].

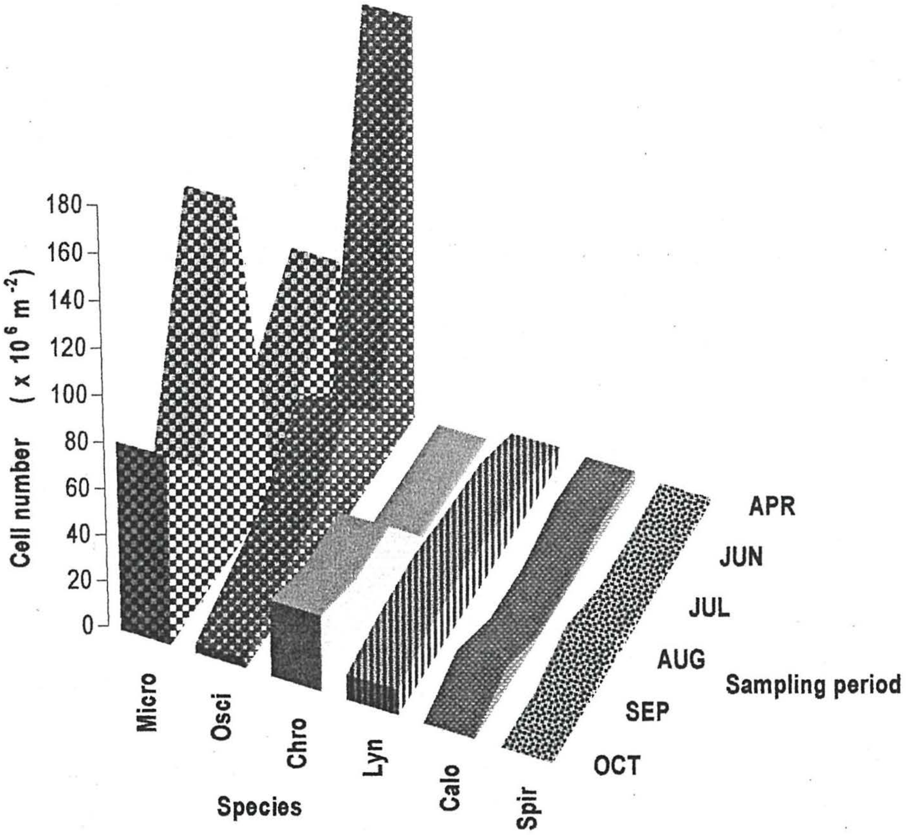


Figure 4.11 Contribution by Cyanophyceae (blue-green algae) genera to the microbial mat assemblage [Micro: *Microcoleus*, Osci: *Oscillatoria*, Lyn: *Lyngbya*, Calo: *Calothrix*, Spir: *Spirulina*].

Qualitative change in mat zonation along the transect

At KI, *Microcoleus* dominates on the top shore where sediment is almost dry, particularly occurring at the rock infill, and in the area containing sand infill (figure 4.12). Where sand infill has leached mixing with mud, mats are formed from a combination of *Microcoleus* and *Oscillatoria.* At the fine mud interface, where the actual mudflats start and sediment is relatively moist, the abundance of *Microcoleus* in the mat decreases until it is virtually absent and bundles of *Oscillatoria* filaments dominate, appearing as a dark band at the mud interface (figure 4.13). Below this level, and lower across the mudflats extending towards the horizon, mats have a golden brown appearance and are dominated by benthic diatoms (figure 4.14). At both TI and TII (chapter 2), *Microcoleus* dominates at the top of the shore, but *Oscillatoria* is absent. Diatom-dominated mats occur across the whole mudflat surface and within any water-retaining depressions in the sediment at both TI and TII, particularly abundant in pools at TII and between clay crevices at TII.

DMC versus CCP

Appendix 4.2 shows the diatom count and the concentration of different chlorophyll pigments (*a, b & c*) from the same 0.55cm^2 sample. Table 4.3 shows statistical results of the simple regression between cell count (Y) and chlorophyll concentration (X).

Pearson's correlation coefficient showed highest significance for cell number versus chlorophyll *a*, and lowest significance comparing cell number with chlorophyll *b*. The relation between cell count and chlorophyll *c* concentration is less significant than that for chlorophyll *a*. Accordingly, it was decided to assess growth rate and primary production using the chlorophyll *a* concentration.

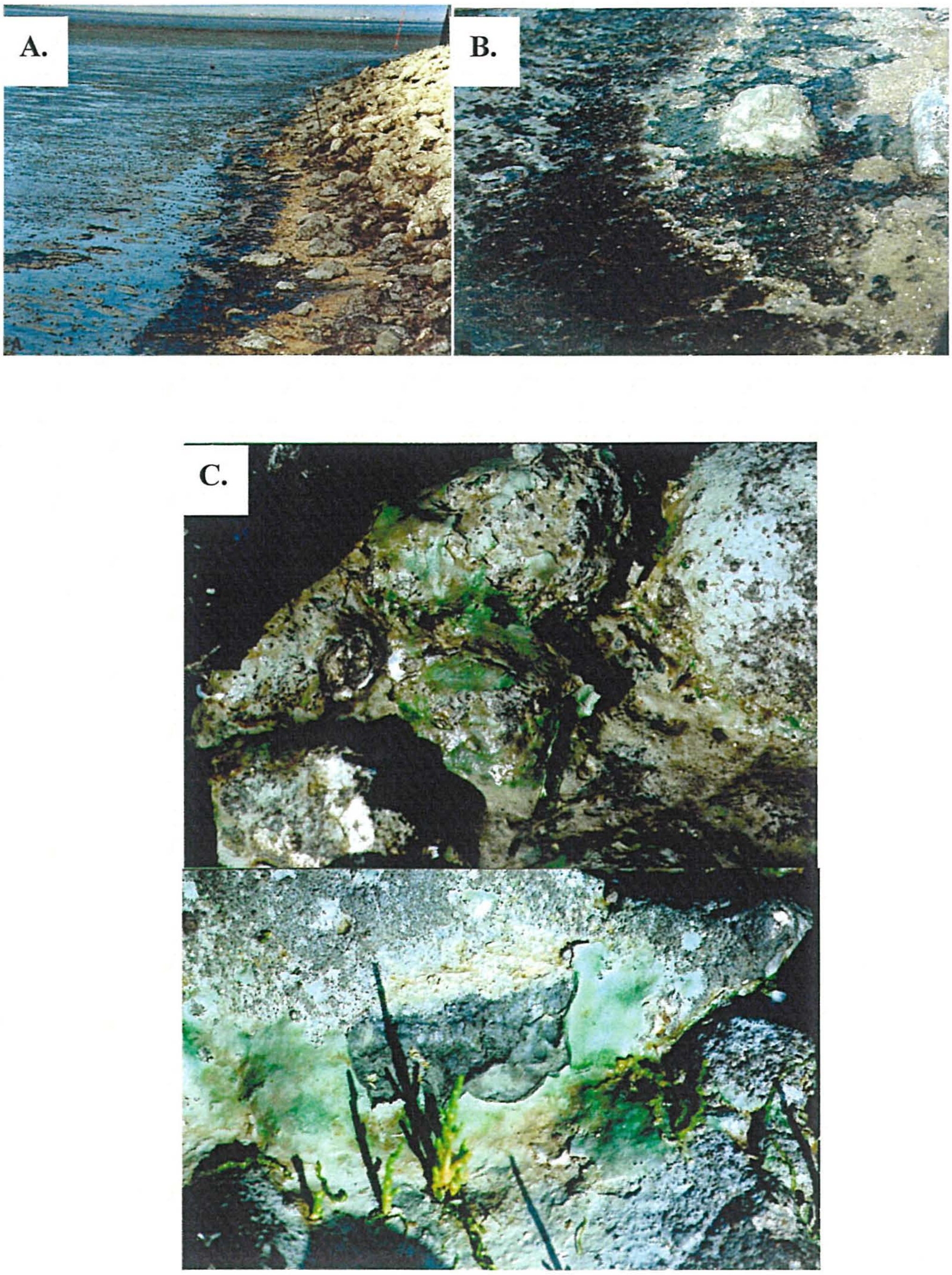


Figure 4.12 Distribution of the different microphytobenthos along 'K' site:

A. Infill at upper shore

B. microbial mat on sand, and

C. rock interface- made up of the cyanobacterium *Microcoleus* sp.

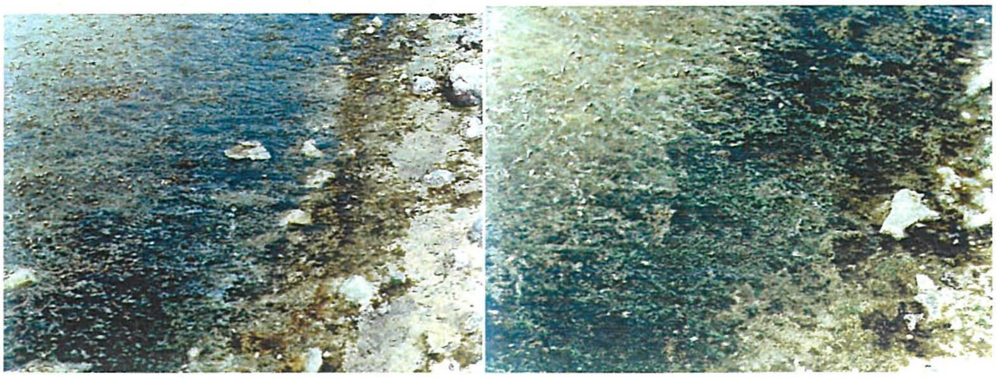


Figure 4.13 The Dark band, occurring where sand and mud mix, dominated by the blue-green algae *Lyngbya* sp.

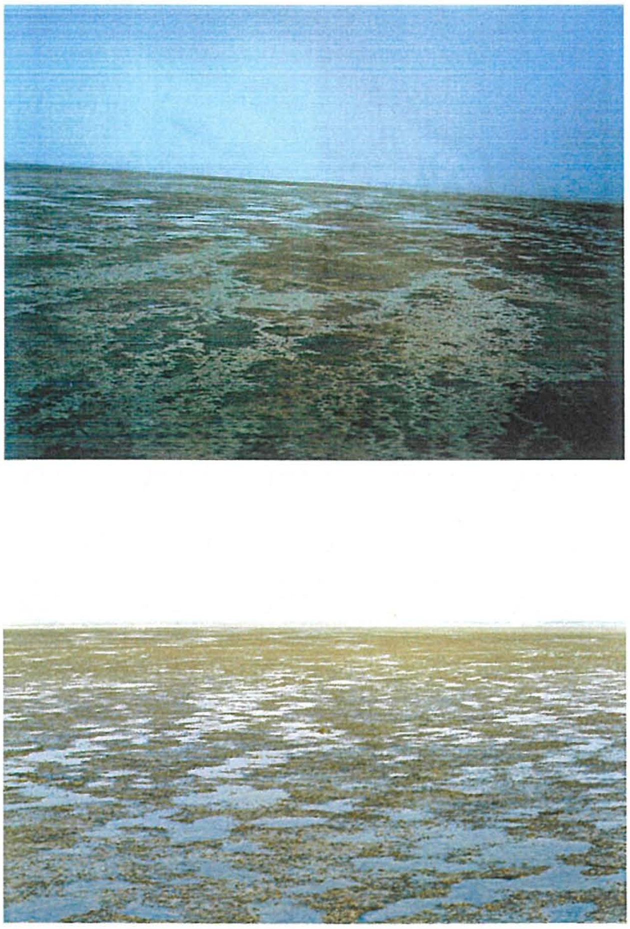


Figure 4.14 Patchy distribution of the diatom-dominated mats, below the dark band of *Lyngbya*, seaward along the mudflats at 'K' site.

Table 4.3 Statistical results of the regression lines comparing abundance of dominating mat component (Y) and the concentration of 3 types (a, b & c) of chlorophyll pigments (X) (μg cm^{-2}).

Type of relationship	**Pearson's correlation**		**Regression equation**	**Intercept**	**Slope**
	r^2 (%)	***P***			
Cell # vs Chl *a*	87.3	< 0.001	Y=-2.78 + 4.62 X	P≥0.05	P< 0.001
Cell # vs Chl *b*	31.0	< 0.05	Y= 5.34 + 43.1 X	P<0.05	P< 0.05
Cell # vs Chl *c*	78.3	< 0.001	Y= 0.47 + 21.1 X	P>0.05	P< 0.001

Mat standing crop and growth rate

Figure 4.15 shows the mean concentrations of chlorophyll 'a' for both WC (without cerithids) and C (with cerithids) exclusions during the 5-day sampling period (EXP I)(data in appendix 4.3).

Effect of grazing

"WC" exclusions: on day 1, chlorophyll concentration was 56.84 ± 2.27 mg Chl*a* m^{-2}, reaching the highest concentration of 66.23 ± 2.69 mg Chl*a* m^{-2} on the 2nd day. Chlorophyll values gradually decreased to reach the lowest concentration 96h after initial exclusion (52.63 ± 4.11 mg Chl*a* m^{-2}). Since mean Chl*a* concentrations during the sampling periods did not show normality in distribution, nor homogeneity in variance (Levene's test statistics = 4.17, $p< 0.05$), a Moods Median non-parametric test was conducted. It revealed that the medians differed significantly from each other ($Chi^2 = 15.19$, DF= 4, $p< 0.05$, overall median = 57.60).

"C" exclusions: Concentration of chlorophyll *a*, 24h after initial exclusion (51.85 ± 1.55 mg Chl*a* m^{-2}), was almost similar to that recorded during day 2 (51.28 ± 1.49 mg Chl*a* m^{-2}). On the third day, a significant increase was noticed and a peak of 58.81 ± 2.47 mg Chl*a* m^{-2} was recorded, which then gradually decreased to reach the lowest concentration of 42.08 ± 1.61 mg Chl*a* m^{-2} 120hr after initial exclusion. Although mean Chl*a* measurements (n= 27) during each day showed normality in distribution, variances were not homogenous (Bartlett's test statistics = 9.83, $p<0.05$). Therefore, a Moods median test was performed and showed that there is significant difference between the Chl*a* measurements ($Chi^2 = 27.44$, DF= 4, $p< 0.001$, overall median = 50.30).

Figure 4.15 also allows estimation of the mean standing crop for the 5 days sampled. Areas devoid of cerithids had a mean standing crop of 57.30 ± 1.11mg Chl*a* m^{-2} ($A^2= 0.321$, $p>0.05$), while those containing cerithids had a mean of 50.81 ± 0.92 mg Chl*a* m^{-2} ($A^2= 0.574$, $p>0.05$). A two-sample t-test reveals that there is a significant difference between both means (T= 4.53, DF= 259, $p<0.001$).

The difference between chlorophyll *a* concentrations (CCP) measured over the 5-day sampling period reveals a 70% decrease in CCP in the 'C' excluded areas in comparison to the 'WC' areas (Table 4.4).

It is evident that chlorophyll *a* values recorded during the sampling period fluctuated, with mats lacking *C. cingulata* having higher Chl *a* than those measured for mats where cerithids were allowed to graze.

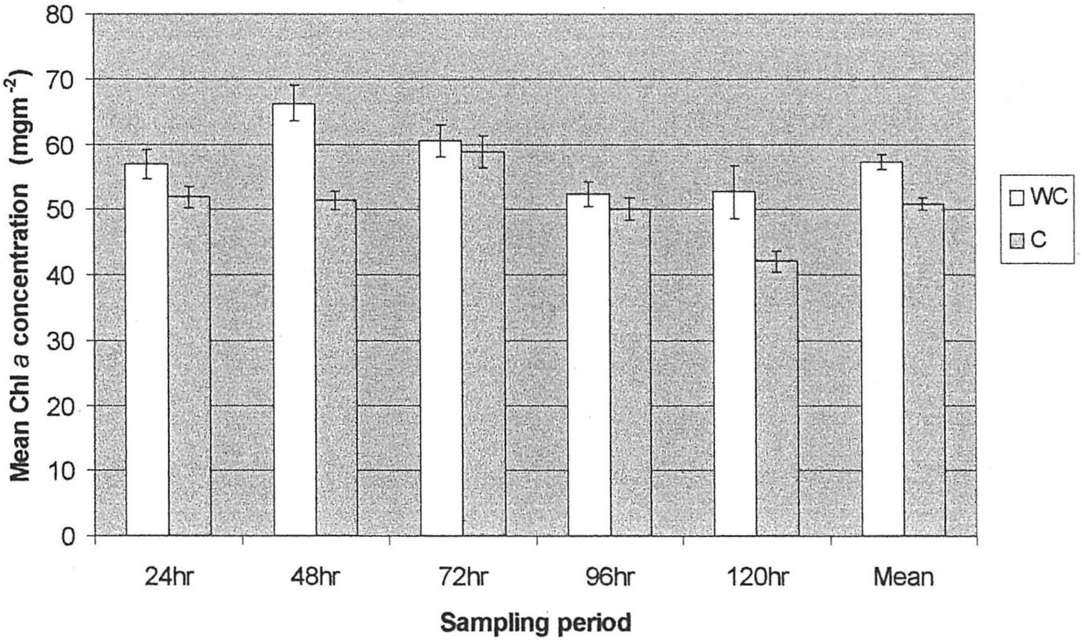


Figure 4.15 Daily Chlorophyll *a* concentrations (mg m^{-2}) in exclusions without (WC) and exclusion with (C) the dominating mud snail *C. cingulata* (EXP I), during March 2001 at KISR site- Sulaibikhat Bay [error bars represent S.E. of mean].

Table 4.4 Daily and total difference in chlorophyll *a* concentrations (CCP) measured over the 5-day sampling period for the cerithid grazed 'C' excluded areas and areas lacking grazers 'WC'.

	Δ Chlorophyll a concentration (mg Chl*a* m^{-2})	
Period	**'WC'**	**'C'**
48hr – 24hr	+ 9.39	- 0.57
72hr – 48hr	- 5.84	+ 7.53
96hr – 72hr	- 8.07	- 8.79
120hr – 96hr	- 0.31	- 7.94
Total	**- 4.21**	**- 9.77**

+ denotes increase, - denotes decrease

Daily standing crop and daily growth rates

Figure 4.16 shows the chlorophyll *a* concentrations at each of the 3 zones measured each day, and pooled mean of the 3 zones, along KI, during October 2001 during 5 day experimental period (EXP II)(data in appendix 4.4). This experiment aimed to assess the daily growth rate of mats under natural grazing activity and environmental changes.

The standing stock at zone I, before the start of the experiment (at 0hr before scraping = 0hr*) was 26.05 ± 1.39 mg Chl*a* m^{-2}. At zone II a standing crop of 17.01 ± 1.03 mg Chl*a* m^{-2} was recorded, however at ZIII it was approximately half the value of that measured at ZI (13.77 ± 1.19 mg Chl*a* m^{-2}). A mean standing stock of 18.94 ± 1.20 mg Chl*a* m^{-2} was recorded for the 3 intertidal zones.

Upon initiating the experiment to determine the recovery of the mat the top 5-10mm of the sediment was scraped. The samples obtained at 0h from zones I, II and III represent the traces of mat after clearing, exhibited traces of chlorophyll 'a' pigment (8.43 ± 1.22 mg Chl*a* m^{-2}, 8.87 ± 0.55 mg Chl*a* m^{-2} and 5.46 ± 0.43 mg Chl*a* m^{-2} respectively). Thus giving a mean initial concentration of 6.37 ± 0.73 mg Chl*a* m^{-2}.

At zone I, approximately 24hr after initiating the experiment, the concentration of chlorophyll increased 8 fold above that of the initial concentration (at 0hr), reaching a value of 61.14 ± 6.42 mg Chl*a* m^{-2}. A slight increase occurred after 48h giving the highest recorded concentration of 61.76 ± 7.22 mg Chl*a* m^{-2}. The Chl*a* concentration then dropped to 53.81± 9.40 mg Chl*a* m^{-2} on the 3rd day, reaching the lowest value of 47.99 ± 2.77 mg Chl*a* m^{-2} after 96h. On the 5th and last day of the experiment Chl*a* concentration increased by 16.38 mg Chl*a* m^{-2} above that of the previous day. Over the 5-day experimental period there was a total increase of 55.94 mg Chl*a* m^{-2} from the initial Chl*a* concentration, revealing a mean daily increase of 11.19 mg Chl*a* m^{-2} at zone I.

The chlorophyll *a* concentration at zone II after 24hr had a value of 14.13 ± 0.93 mg Chl*a* m^{-2}, increasing by 5.26mg m^{-2} over the initial concentration at 0h. On the 2nd day a 3.17 mg Chl*a* m^{-2} increase occurred, reaching the highest concentration of 46.13 ± 2.59 mg Chl*a* m^{-2} on the 3rd day. At 96hr, the Chl*a* concentration decreased (33.32 ± 2.19 mg Chl*a* m^{-2}), to a value of 32.24 ± 2.99 mg Chl*a* m^{-2} at 120h. At this zone, a 23.37 mg Chl*a*m^{-2} increase occurred during the 5-day experimental period, giving a mean daily increase of 4.67 mg Chl*a* m^{-2}.

At ZIII, a 2.02 mg Chl*a* m^{-2} increase occurred 24hr after initiating the experiment (7.48 ± 0.49 mg Chl*a* m^{-2}). On the 2nd day, a concentration of 11.87 ± 0.90mg Chl*a* m^{-2} was recorded. Highest increase of 22.51mg Chl*a* m^{-2} occurred 72hr after initial experimentation giving a value of 34.38 ± 2.50 mg Chl*a* m^{-2}. This value then decreased to 21.68 ± 1.14 mg Chl*a* m^{-2} on day 4, showing a slight increase (23.06 ± 1.47 mg Chl*a* m^{-2}) on day 5. A total increase of 17.6 mg Chl*a* m^{-2} occurred during the experimentation period, giving a mean daily growth rate of 3.52mg Chl*a* m^{-2} d^{-1} at zone III.

The pooled mean of the 3 zones reveals a total increase of 33.52 mg Chl*a* m^{-2} during the 5-day experimental period, giving a daily increase rate of 6.70 mg Chl*a* m^{-2}.

Chlorophyll *a* concentration at each of the 3 zones, as well as the pooled mean of the 3 zones, showed a significant decrease in concentration in samples collected 96h after the start of the experiment.

A one-way ANOVA statistical test, conducted on the data from 3 zones, revealed that at least one zone significantly differs in its mean chlorophyll concentration from at least one other (Table 4.5). To specifically determine which zone differed significantly from the other, a 2-sample t-test was conducted, statistically compares each zone with the other. Results reveal that both ZII and ZIII differed significantly from ZI ($T= 4.45$, associated $p<0.05$; and $T= 6.83$, associated $p< 0.001$ respectively). However, statistical analyses showed no significant difference between zone II and III ($T= 1.19$, associated $p>0.05$). Figure 4.16

shows that Chl*a* at ZI was significantly higher than concentrations at both ZII & ZIII.

Visual observation of the sampling areas at each zone showed a gradient in pigment level towards the lower intertidal (decrease in coloration).

The mean chlorophyll *a* concentration measured over a 6hr (EXP III: growth rate during emersion & submersion) and 3hr (EXP IV: growth rate during emersion) period are shown in table 4.6 (data in Appendix 4.5 and 4.6 respectively).

From experiment III (growth rate during 6hr: emersion and submersion) a 10.02 mg Chl*a* m^{-2} increase in Chl*a* occurred after 6hr at ZI. At ZII there was a 6.29 mg Chl*a* m^{-2} increase, while at ZIII the increase was slightly more (8.43mg m^{-2}). Thus giving an average increase of 8.25mg Chl*a* m^{-2} $6h^{-1}$ (1.37 mg Chl*a* m^{-2} h^{-1}) along the transect.

The level of Chl*a* during the 4th experiment (growth rate during emersion) at ZI increased by 14.66 mg Chl*a* m^{-2}, while an increase of 14.87 mg Chl*a* m^{-2} occurred at ZII. Samples for zone III could not be obtained because the sampling area at the lower end of the shore was already covered by incoming tide upon arrival at the site. However the average increase along the transect was 14.77 mg Chl*a* m^{-2} $3h^{-1}$ (4.92 mg Chl*a* m^{-2} h^{-1}).

Since experiments II (daily growth rate), III (growth rate during 6hr; emersion and submersion) and IV (growth rate during 3hr; emersion) were conducted during autumn/winter, spring and summer respectively, and the CCP of samples collected at 0hr* (before scraping of the sediment) represents the daily standing crop of the mat assemblage, it was decided to assess seasonal variation. In autumn/winter the diatom biomass (measured by Chl*a* concentration) was 18.94 mg Chl*a* m^{-2}. There was a slight increase during spring (22.08 mg Chl*a* m^{-2}) and a drastic increase during summer to a value of 81.70 mg Chl*a* m^{-2}. This gave a mean daily standing stock of 40.91 mg Chl*a* m^{-2} (14.93×10^3 mg Chl*a* m^{-2} y^{-1}). A one-way ANOVA compares the standing stock of each season, and revealed that at least one season one season significantly differs in its standing stock from at least one other (Table 4.7). The graphical plot associated with the ANOVA test shows that the standing stock measured during autumn/winter and spring is significantly different from that of summer (Figure 4.17).

Primary Production

The annual gross primary production (GPP) estimated by inserting the calculated standing crop (14.93×10^3mg Chl*a* m^{-2} y^{-1}) in the equation suggested by Bot and Colijn, (1996) produces a value of 190.97g C $m^{-2}y^{-1}$.

To determine the total area of production, the approximate areas of mudflat habitats in Sulaibikhat Bay, and along the coast of Kuwait are required. Re-calculation of shoreline distance and intertidal zone width from maps (Al-Sarawi *et al.* 1985), indicates that Sulaibikhat Bay and the whole muddy coast of Kuwait cover an area of approximately 70km^2 and 1840 km^2 respectively. This estimated area was then multiplied by the estimated GPP to produce an estimated annual GPP of 35.1×10^{10}g C y^{-1} for the mudflats occurring along the whole of the coast of Kuwait. The benthic microphytes in Sulaibikhat Bay contribute 3.5% to the GPP of the mudflats of Kuwait with a GPP of 1.3×10^{10}g C y^{-1}.

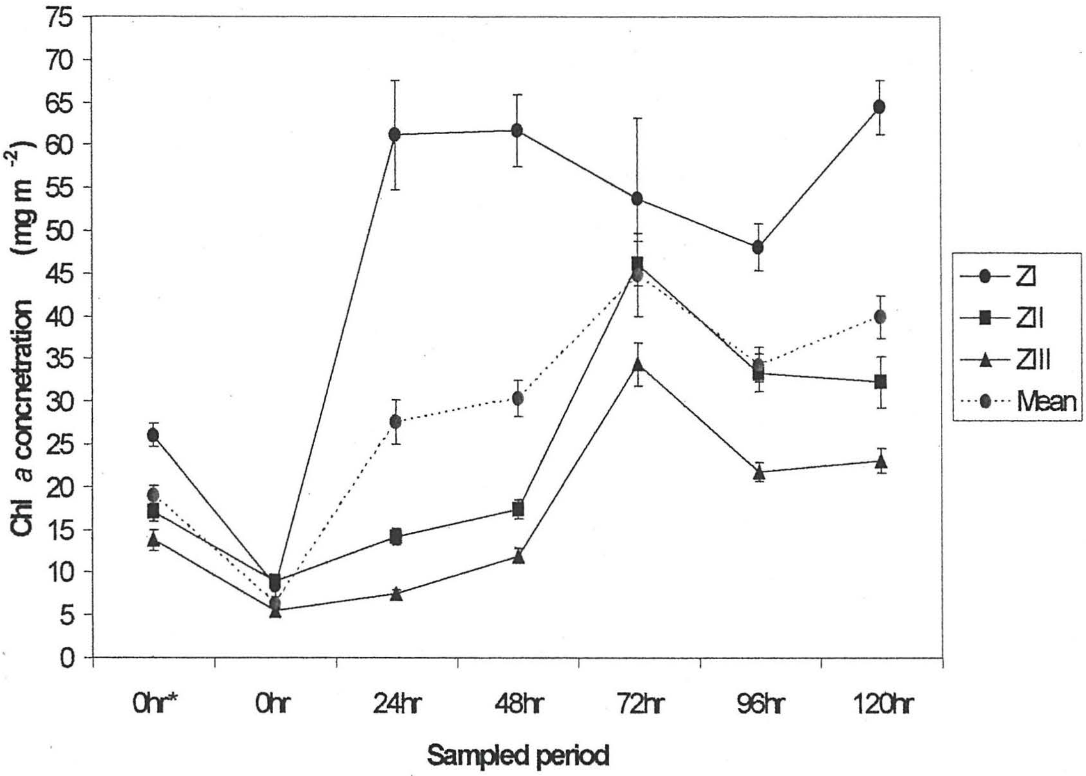


Figure 4.16 Daily concentration of chlorophyll 'a' pigment (CCP) at the 3 zones, and pooled mean of the 3 zones, along KI, during October 2001 over a 5-day experimental period (mg Chl*a* m^{-2})[chlorophyll *a* concentration: 0hr*= before scraping; 0hr= after scraping; 24hr= 1st day after 0hr; 48hr= 2nd day after 0hr; 72hr= 3rd day after 0hr; 96hr= 4th day after 0hr; 120hr= 5th day after 0hr; error bars represent S.E. of mean].

Table 4.5 Results of One-way ANOVA statistical analysis for the effect of location on the shore (zonation) on Chl*a* concentration.

Source	**DF**	**SS**	**MS**	**F**	**P**
ZONES	2	3975	1987	18.30	0.00
Error	12	1303	109		
Total	14	5278			

DF= degrees of freedom; SS= sum of squares; MS = mean square

Table 4.6 Concentration of chlorophyll *a* pigment (CCP) in samples collected during experiment III & IV.

		CCP (mg m^{-2}) ± S.E.			
		ZI (n=18)	**ZII (n=18)**	**ZIII (n=18)**	**Pooled Mean**
EXP III (03/02)	0hr (STD)	20.71±1.53	28.39±1.61	17.14±1.96	22.08±3.32
	6hr	30.73±2.90	34.68±2.03	25.57±1.23	30.33±2.64
	Δ	10.02	6.29	8.43	8.25
EXP IV (05/02)	0hr (STD)	73.41±3.26	89.99±2.20	NA	81.70±8.29
	3hr	88.07±4.25	104.86±3.91	NA	96.47±8.40
	Δ	14.66	14.87	NA	14.77

ZI= zone I, ZII= zone II, ZIII= zone III; STD= standing crop

Table 4.7 Results of One-way ANOVA statistical analysis for the effect of season on Chl*a* concentration.

Source	DF	SS	MS	F	P
ZONES	2	8194	4097	74.41	0.00
Error	6	330	55		
Total	8	8525			

DF= degrees of freedom; SS= sum of squares; MS = mean square

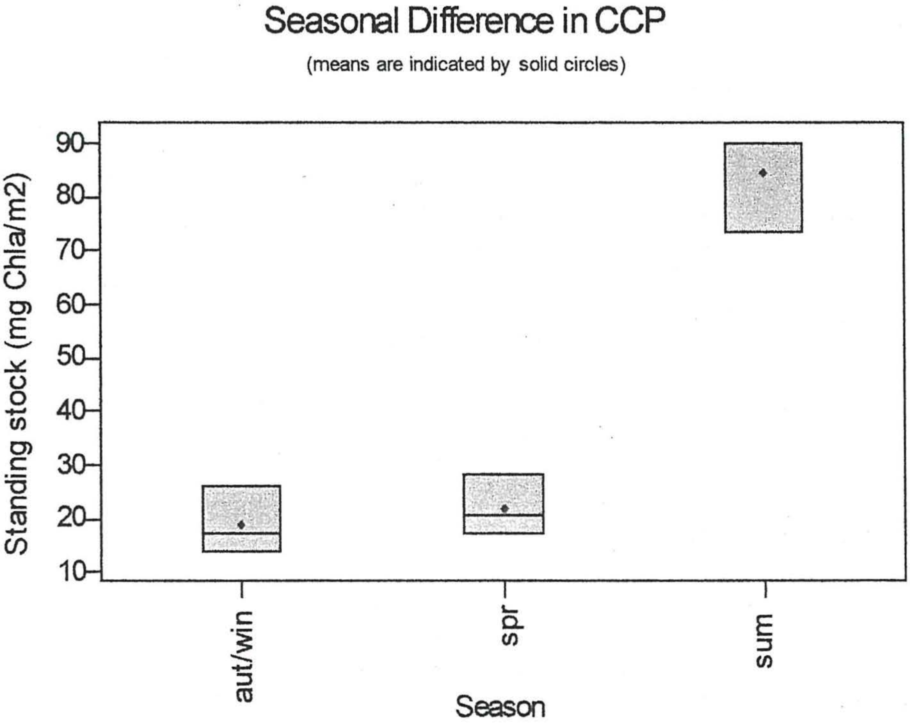


Figure 4.17 Boxplot associated with ANOVA statistical analysis showing the Difference in standing stock in relation to season [aut/win= autumn and winter, spr= spring, sum= summer].

Microbial Mat Grazing

Gut and faecal analysis

Nine macrofaunal species were analysed for gut contents: 3 intertidal and 6 subtidal.

The intertidal faunal species included the common mud snail *Cerithidea cingulata*, the carnivorous mudskipper *Periophthlamus waltoni*, and the herbivorous goby *Boleophthlamus boddarti*. In the gut of *C. cingulata* benthic algae consisting of diatoms and blue green algal filaments plus inorganic debris were found. Fully intact crabs of the species *Tylodiplax indica* and some other flesh were found in the gut of *P. waltoni*. In the gut of *B. boddarti* diatoms and sediment particles were present.

Of the 6 subtidal species, there were 2 shellfish and 4 fish species all of commercial importance. The edible blue crab *Portunus pelagicus* had flesh and skeleton remains of the small brachyuran *T. indica* in its gut. A green coloured organic residue occurred in the gut of the shrimp *Metapeneaus affinis*. In the gut of the mullet *Lisa subviridis* algal material, foraminifera and organic residues were seen, while the highly commercial mullet *Lisa macrolepis* appeared to feed on phytoplankton and a variety of microalgae represented mainly by benthic diatoms (*Pleurosigma, Bascillaria, Navicula, Nitzchia*). Brachyurans and bivalves were found in the gut of *Sillago sihama*. In the gut of another commonly edible fish, *Acanthopagrus* sp., algae, gastropods and other organic residues were found.

The faeces of six macrofaunal species were investigated for mat components (Table 4.8), all of which were intertidal except the shrimp *Metapenaeus affinis*. It was evident that the xanthid crab *Eurycarcinus orientalis* does not feed on mats, however the remaining species all contained mat residues in their faeces. The endemic crab *L. kuwaitense* and the fiddler *U. sindensis*, both inhabitants of the upper intertidal also contained a significant amount of diatoms in their faeces. Intact blue-green algal filaments out-numbered diatoms in the faeces of *C. cingulata* and the largest mud crab *M. dentipes* which inhabits the mid to lower intertidal mudflats. A large amount of intact blue-green algal filaments occurred in the faeces of the subtidal commercial shrimp *M. affinis*.

Feeding experiments

Figure 4.18 shows the results of experiment I. Thirty minutes after inoculating an aquarium with mat pieces, cerithids began to ascend up the sloping sediment towards the mat pieces placed at the highest point of the sediment. After 24h, the cerithids were aggregated at the top of the sediment slope, around the areas where the mats occurred. The mat pieces appeared to have lost most of their greenish colour. After 48hr, there was no sign of the mats, and the sediment was extremely bioturbated.

The initial task in experiment II was to determine the gut evacuation rate for *C. cingulata*. Concentration of chlorophyll *a* pigment (CCP) in the digestive tract of the gastropods is presented in table 4.9. Results show that CCP in the gut of this gastropod decreased with time. Although the CCP in the gut after 92hr was low, the snails were left for an extra 24hr before use in this experiment. Unfortunately, during experiment II, none of the snails fed on the mat pieces placed within each of the compartments, although they were left to feed for a 17-day period.

Table 4.8 Presence and absence of microbial mat components (diatoms, blue green algal filaments "BGAF") in the faecal product of some faunal species found along the intertidal mudflats of Sulaibikhat Bay.

			Mat component	
No.	**Species list**	**Location**	**Diatoms**	**BGAF**
1	*Leptochryseus kuwaitense*	High intertidal	**	+
2	*Uca sindensis*	High	***	+
3	*Eurycarcinus orientalis*	Low	-	-
4	*Macrophthlamus dentipes*	Low	*	++
5	*Cerithidea cingulata*	Low	*	++
6	*Metapeneaus affinis*	Subtidal	*	+++

(*)shell only, (**)empty and full shells, (***)full diatoms; (+)sheath only, (++)empty and full sheaths, (+++)full sheaths

Figure 4.18

Grazing activity of *Cerithidea cingulata* during feeding experiment (EXPI)

(A) At 0hr.

(B) After 30 min.

(C) After 24 hr.

(D) After 48hr.

A.

B.

C.

D.

Table 4.9 Changes in chlorophyll *a* concentration in relation to time in the gut of the mud snail *Cerithidea cingulata*.

	Statistical Description			
Evacuation Time	**Chl*a* conc. (µg ml^{-1})**	**Mean Chl*a* conc. (µg ml^{-1}) ± S.E.**	**Normality (A^2)**	**P value**
0hr	0.625	1.047 ± 0.137	0.459	>0.05
	0.747			
	0.880			
	1.302			
	1.347			
	1.380			
24hr	0.414	0.4562 ± 0.034	0.195	>0.05
	0.459			
	0.503			
	0.346			
	0.424			
	0.592			
96hr	0.035	0.04678 ± 0.004	0.570	>0.05
	0.056			
	0.056			
	0.033			
	0.045			
	0.056			

DISCUSSION

In comparison to European estuarine systems and associated mudflats, there is a paucity of quantitative and qualitative information regarding microphytobenthic communities as a source of nutrition for macrofaunal populations on mudflats of the western Arabian Gulf. Although these mudflats are highly productive, the associated microphytobenthos has not been subjected to the attention given to other sources of primary production such as phytoplankton (Huq *et al.*, 1978; Al-Yamani *et al.*, 1997b; Rao *et al.*, 1999).

Microbial Mat Speciation and Zonation

Jones (1986a, b) and Clayton (1986) first observed the occurrence of microbial mats on shores of Kuwait. They both stated that the littoral fringe on muddy shores is marked by a band of laminated algal mats characterised by layers of intertwined filamentous and unicellular blue-green algae binding the sand particles. Apart from this information, there does not appear to be any literature on the microphytobenthos community (mat assemblage) occurring on the mud surface of intertidal flats in Sulaibikhat Bay- Kuwait. During the present investigation, the filamentous cyanobacterium *Microcoleus* was found to dominate the higher intertidal region attached to rocks and grains of sand infill. Lower on the shore, at the transitional point where sand and mud mix, diatoms appear and *Oscillatoria* replaces *Microcoleus*. Diatoms dominate the mat composition where silt/clay predominate in the sediment. This agrees with findings by Watermann *et al.* (1999) who found that cyanobacteria favour high temperatures (*Microcoleus* dominated biofilms cultured at 25°C) and coarser sediments, while diatoms dominate at low temperatures (*Nitzchia* dominated biofilm at 15°C) on mud with small grains. Diatoms preferred finer grain sizes as for large grains interstitial space in sediments may be too large, preventing raphe-based gliding which occurs during diatom migration. In the Ouse estuary, Hopkins (1963) found that *Navicula* and *Nitzchia* occurred abundantly near MLWL (mean lowest water level), where sediment temperatures are low and grain size is small. In present work, diatoms represented 92% of the mat components at the site during July 2001, when sediment temperatures were relatively low in comparison to the remaining sampling months (Al-Mohanna, pers. Com.). However during August 2001, high sediment temperature was recorded during the sample collection (Al-Mohanna, pers. Com.), with blue-green algae represented almost 50% of the mat components.

Epipelic (motile) diatoms are found to dominate the mat assemblage on temperate European mudflats. Colijn and Dijkema (1981) found that pennate diatom species dominated the mat assemblage of mudflats in the Dutch Wadden Sea. Madsen *et al.* (1993) studied the influence of benthic algae on the stability of subtidal sediments in a Swedish bay. They found that diatoms, specifically *Navicula*, made up approximately 75% of the algal biomass, while the remaining 25% consisted of the blue-green *Oscillatoria*, and to a lesser extent other colonial cyanobacteria and flagellates. In 1993, Underwood and Paterson found that *Nitzchia* and *Navicula* were characteristic of upper intertidal mudflats in the Severn Estuary in summer. Investigations on the photosynthetic characteristics of microphytobenthos on mudflats at Marennes-Oleron Bay, France, revealed that pennate diatoms represent 95% of the microbenthic community, dominated by *Navicula, Nitzchia, Gyrosigma* and *Pleurosigma* (Blanchard & Cariou-Le Gall, 1994). Similarly Yallop *et al.* (1994) found that diatoms dominated the microphytobenthic community on a sandy beach in the Wadden Sea, with *Navicula* being the most abundant specie. Blue-green algal filaments also contributed to the micro-community with *Microcoleus* and *Oscillatoria* forming the dominating species in their class. A recent investigation on the pigment diversity on mudflats of the Westerschelde Estuary, Netherlands (Lucas & Holligan, 1999) revealed that *Nitzchia* and *Navicula* dominated the diatom assemblage. In the present investigation of the mudflats of Sulaibikhat Bay, the mat assemblage was also dominated by diatoms, however the pennate *Bacillaria*, was the most abundant diatom species followed by *Nitzchia*, while the filamentous cyanobacteria *Microcoleus* was the 3rd most important component of the mat assemblage.

DMC and CCP

As in phytoplankton studies, Chl *a* concentration in surface sediments provides the best overall information about the distribution of microalgal biomass. The different types of chlorophyll pigments are taken as diagnostic markers for algal groups. For example, chlorophyll *a* is a cosmopolitan pigment present in all photosynthetic plants, however Chl *b* is known to be present only in Chlorophyta and Euglenophyta, while Chl *c* is a characteristic pigment of Bacillariophyta (South & Whittick, 1987; Brotas & Plante-Cuny, 1998; Lucas & Holligan, 1999). Detailed taxonomic composition of microphytobenthic communities contributing to the mat biomass has been analysed qualitatively, as microscopic cells are difficult to count on a large scale. Brotas & Plant-Cury (1998) found a 77% correlation between Chl *a* and Chl *c* in relation to cell count, stating that both pigment results and microscopic observations testified that diatoms were the major taxonomic group present on the tidal flats of Tagus Bay, Portugal. Lucas & Holligan (1999) found that the major changes in algal biomass (Chl *a*) were due to changes in diatom abundance, and that low levels of Chl *b* suggest that Chlorophyta and Euglenophyta were not an important component of microalgal biomass during their study. Part of the present investigation was aimed at relating the cell number of the dominating mat component (DMC), pennate diatoms, to the concentration of chlorophyll pigment (CCP) in the mats, and results agree with previous literature. Results show a significant correlation between diatom cell number and Chl *a* and Chl *c*, however, no correlation was established between diatom abundance and Chl *b*.

Chlorophyll *a* concentration can not be regarded as a completely accurate measure of diatom biomass, as it has been shown that the ratio of cellular carbon to Chl *a* may vary seasonally for benthic diatoms (De Jonge, 1980). However, such changes are relatively small in comparison with the Chl *a* accumulation that rapidly occurs with biofilm development (Underwood and Paterson, 1993). More reliable estimates of biomass can be produced by cell counts paired with chlorophyll *a* data. Such methods are extremely effort-intensive, however regression analysis reveals a significant correlation between cell counts and Chl *a*, providing a good indication that diatoms constituted the major contributing group to the Chl *a* concentration in mats during the study period. Accordingly, chlorophyll *a* was considered to provide a sufficiently accurate estimate of biomass for the purpose of this study. In addition, sediment analysis using light microscopy confirmed that epipelic pennate diatoms were the dominant components of the mats at the site. Therefore it is assumed that Chl *a* concentrations reflects the biomass of diatoms rather than that of other photosynthetic groups.

Microbial Mat Standing crop and Primary Productivity

The microphytobenthos community, made up of diatoms, cyanobacteria, and euglenoids plays a key role in tidal flat dynamics in estuaries. The cycling of microalgae both within tidal flats and between the tidal flats and overlying water column has considerable importance both for benthic and pelagic herbivores, and in modifying sediment dynamics. Primary production of benthic microalgae living in the upper few millimetres of the sediment may account for ~30% of the annual carbon budget of an estuary (De Jonge & Colijn, 1994). Because of their close association with sediments, benthic microalgae are subjected to the same physical forces of currents and wave action.

Results of experiment I (EXP I) show that a comparison of grazed exclusions with non-grazed exclusions indicate that *Cerithidea cingulata* does, to some extent, reduce the biomass of microphytobenthos on the mudflats of Sulaibikhat Bay. This agrees with findings by Hargrave (1970) who studied the influence of herbivore grazing on the primary production of benthic microflora, and found that snail density significantly changes microphytobenthic production. Results also showed that the daily growth rate, within replicate exclusions (EXP I: with or without *Cerithidea cingulata*), fluctuated throughout the sampling period. Lopez and Levington (1978) found that snails ingest a specific volume of sediment and attached microphytobenthos at any given time, suggesting that higher standing stock would respectively signify higher microbial productivity rather than decrease in the ingestion rate. In 1998, Niu and others stated that older (=larger) limpets have a higher energy consumption than younger (=smaller) ones (positive correlation), while Blanchard *et al.* (2000) discovered that algal ingestion rates decreased with density. During experiment I (EXP I), exclusions inoculated with grazers 'C' contained equal densities of cerithids of similar size, assuming relatively constant daily ingestion rate. Hence, it is unlikely that the ingestion rate plays a role in the temporal variation of the standing stock of 'C' exclusion areas occurring within such a micro-scale (within 24hr). Such variation most probably reflects spatial heterogeneity of mats (patchiness) generated by interspecific interactions between naturally occurring physical and biological disturbances.

Analysis of the spatial structure of the mat at micro-scale (within $1m^2$) has shown that mat patchiness may be due to the sediment structure, faunal patchiness and associated grazing, and tidal action. Diatoms prefer fine sediment grains to coarser ones (Hopkins, 1963; Watermann, *et al.* 1999), and since sediment sorting shows spatial heterogeneity even on a small scale (Eltringham, 1973; Gray, 1981), sedimentary characteristics of the surface can be a strong component in the control of microbial standing stock (Levington and Bianchi, 1981). Van Duyl *et al.* (2000) found that distinct differences in mat colour appeared to be due to chlorophyll *a* concentration (colour intensity α Chl*a*), with Chl*a* concentration in dense mat patches (dark) 8-10 times higher than in eroded mat patches (light) (Table 4.10). Similar distinctions between dark areas rich in diatoms and lighter patches were observed during the present study (Figure 4.7 & 4.8). This patchiness will contribute to the variability seen in standing stock measurements over the short sampling period.

Consumer spatial heterogeneity also plays a role in microbial standing stock in association with mat patchiness. Irregularity in grazing by snails is known to affect microbial availability causing variability even on a small spatial scale (Levington and Bianchi, 1981). Admiraal (1984) stated that in order to avoid limiting food concentrations nematodes occurring on mudflats tend to accumulate on diatom patches. During the daily visits made while conducting experiment I, *Cerithidea cingulata* were occasionally confined to a certain section within the excluded area (Figure 4.6), thus possibly contributing to mat patchiness causing temporal heterogeneity in standing stock.

Experiments II (120hr), III (6hr) and IV (3hr) were conducted with no alteration to the naturally occurring physical and biological variables. Therefore, in addition to patchiness in the mat, both spatial distribution of grazers, their density and ingestion rate associated with size, and variability in physical disturbances (wave action, climatic conditions) might have attributed to the heterogeneity in standing stock of the mats. Experiment IV (3hr) was conducted to assess growth during emersion. Therefore it was exposed to normal grazing activity by intertidal consumers, mainly cerithids. However, because EXP II & III involved submersion, grazing might have involved both intertidal consumers and subtidal grazers migrating with the rising tide. The extensive occurrence of faecal pellets on mat surface during low tide (Figure 4.19) supports the likelihood of grazing during submersion. In tidal pools along the transect, and at the edge of the rising tide, mats were noticed floating on the water surface (Figure 4.20). This phenomenon results from the settlement of dense populations of diatoms on the sediment accompanied by the formation of slimy mats in which oxygen bubbles are trapped, resulting in suspension of mat pieces that might be carried away by the incoming tide (Admiraal, 1984). In addition to resuspension during tidal rhythm, the degree of wave action is known to induce mat scouring causing erosion (Van Duyl *et al.*, 2000; Table 4.10) contributing to standing stock variability.

Because the photosynthetic activity of mat components relies greatly on availability of solar energy, irradiance is an important factor that might cause variability in standing stock even on a small temporal scale (within 1hr), effected by resuspension, sky-cover and/or length of day. In 1973, Anderson found that the difference in temperature between the water and sediment causes convection currents, which, in combination with tidal currents in shallow water, results in the resuspension of sediments. Since benthic microflora are bound to sediment particles, they also are subjected to resuspension, releasing a pulse of chlorophyll into the water column which forms a valuable component of the plankton community. The presence of microphytobenthos as temporary members of the phytoplankton is well-documented (Baillie & Welsh, 1980; De Jonge & van Beusekom, 1995). Baillie & Welsh (1980) found that tidal resuspension can affect the spatial distribution of epipelagic algae in two ways. The diatom cells are either distributed horizontally causing a shoreward transport of cells further up the shore, or are suspended vertically into the water column becoming available for filter feeders. Visual observations made during this investigation clearly reveal suspension of epipelic diatoms in the water (Figure 4.21). If the increase in growth (Δ: 14.77 mg Chl *a* m^{-2}) during the emersion experiment (Exp III, ebb tide "3hr") is used to calculate increase in growth rate found during the submersion experiment (Exp IV, ebb+flood tide "6hr"), a growth equivalent to 29.54 mg Chl *a* m^{-2} is predicted. However, the actual increase in growth during the submersion experiment was 8.25 mg Chl *a* m^{-2}. As the Bay is characterised by fine sediments, inflowing tidal water is turbid reducing light intensity during high tide. Since EXP III included both emersion and submersion periods (6hr), low irradiance in addition to sediment and mat resuspension during submersion might explain lower standing stock in comparison to EXP IV. Experiment IV (EXP IV) measured mat growth during emersion, higher standing stock may be related to higher irradiance levels. Visual observations during EXP III (submersion effect on mat standing stock), also revealed that scraped areas were covered by diatoms after the tide receded. This indicates that epipelic diatoms are resuspended during submersion, and may also lead to variability in standing stock (Figure 4.22).

Sky cover (cloud) in arid areas such as Kuwait occurs infrequently and only on a seasonal level (winter/ spring) in comparison to temperate regions (daily). However during summer, sand storms and suspension of dust may play a role in sky cover rather than clouds. Because all experiments were conducted during days of clear skies, it is unlikely that this potential variable affected the results. Chlorophyll *a* concentrations varied seasonally during this investigation, and were generally higher during the warmer months. This is likely to be correlated with high temperature and light intensity during the summer season. Underwood and Paterson (1993) conducted a Spearmans rank correlation coefficients between Chl *a* and temperature, and found a strong relationship with temperature ($r_s = 0.40$ & associated $p<0.001$). However, patterns are highly variable and high concentrations of chlorophyll *a* have been measured during the colder months of the year (Cadee & Hegeman, 1974). Leach (1970) found that production of diatom mats is positively correlated to day length with higher production during June when longest days of the year occur (Table 4.11). Montagna (1984) and Morrisey (1988) observed that both desiccation and grazing by invertebrates and fish was a possible cause for summer declines in algal standing stock. Because lowest macrofaunal biomass occurs during summer within Sulaibikhat Bay (chapter 2), when length of day and associated radiation period are highest, the interaction between such factors perhaps explains the high algal biomass observed during that season.

Standing stock of mats in relation to location along the intertidal gradient was determined based on the concentration of chlorophyll *a* pigment (CCP) of microalgae living on the tidal mudflats of Sulaibikhat Bay during experiments II, III and IV. In general, chlorophyll *a* concentrations were greater at upper (ZI) and middle (ZII) shore stations than at the lower shore station (ZIII) at KI throughout the study. These results are similar to those found from studies of spatial distribution in the Ems Estuary, Netherlands (Colijn & Dijkema, 1981), and the Severn Estuary, United Kingdom (Paterson *et al.*, 1990; Underwood & Paterson, 1993). In the Severn Estuary, the sediment at the lower stations was wetter and less stable than the sediment at the middle and upper station. This was partly due to the strong tidal flow (exposure) and regular suspension of sediments at the lower stations. Such factors would cause the removal of mat by turbulent scouring leading to floating of the mats (Van Duyl *et al.*, 2000), and the sediment erosion and re-suspension of fine sediment particles associated with frequent tidal-cover which may restrict light penetration required for photosynthesis (Cadee & Hegeman, 1974; Pinckney & Zingmark, 1991). In addition, grazing activity might have also contributed to such spatial difference. Zone I, lacks burrowers and grazers as the sediment is dry they are excluded due to desiccation, while lower down the shore towards ZIII, the gastropod grazers appear in increasing numbers as the moisture content of the sediment rises.

Gross Primary Production

In laboratory experiments all variables are kept constant except the one under consideration. However, in field experiments all naturally occurring environmental variables are left the same, or only a single variable is altered. Assessing pressure of previously mentioned environmental variables (biological, physiochemical, and climatic) on mat standing stock and productivity at the scale of the ecosystem is difficult because of the heterogeneity of the mudflats at different temporal and spatial scales. Hence, even if the same experiments were extensively replicated, at same date and time of day during consecutive years, heterogeneity in standing stock and primary productivity would unquestionably occur because such factors can not be controlled. Hence, the estimate of primary productivity of mats within Sulaibikhat Bay can only be preliminary and is based on the assumption that production rate is related to standing stock of total chlorophyll *a* in the mats, using the equation represented by Bot and Colijn, (1996).

Data on gross primary production from intertidal mudflats and shallow coastal areas around the world has been compiled in Table 4.12. Two important results are obvious from this table. Firstly, the mean annual GPP in temperate regions is 50% less than that for semi-tropical and tropical areas. Secondly, the annual GPP quantified during the present study is similar to the mean annual GPP values for other semi-tropical/tropical areas. This provides confidence in present calculations which suggest that the high productivity in Kuwait bay is associated with microbial mats.

Based on GPP values from the literature for the major producers found in the Gulf or in similar regions (Table 1.2), and the area coverage of marine habitats of Kuwait (Table 1.3), Jones *et al.* (2002a) estimated the GPP for biotopes in Kuwait coastal waters (Table 1.4). These crude calculations suggested that mudflats may supply some 3.5% of the overall primary productivity in Kuwaiti waters contributing more than reefs, seagrass and rock macroalgae, although pelagic phytoplankton dominates forming 70% of total GPP. Using the actual quantified annual GPP for microbial mat production measured in present work, in conjunction with the area cover in table 1.2, calculations reveal a GPP of 3.5 x 10^{11}g C y^{-1} for mudflats of Sulaibikhat Bay. This value is 2.5 fold greater than the estimation made by Jones *et al.* (2002a) based on GPP values obtained from the literature. If the GPP values for all soft sediments (intertidal sand/mud and subtidal sand/mud; Table 4.13) found in Kuwait are combined, it appears that the microphytobenthos associated with these sediments would have a GPP value of 12.72 x 10^{11}g C y^{-1}. This is approximately 50% of the GPP contributed by the phytoplankton in the water column, and 30% of the total gross primary production of the coastal waters of Kuwait. De Jonge & Van Beusekom (1992) and Guarini *et al.* (2000) suggest that tidal currents causing resuspension of microphytobenthos in the water above mudflats make up 30-90% of the food available for secondary producers in both pelagic and benthic ecosystems. Similarly, it could be assumed that as a result of resuspension, benthic microalgae are available to the local water column and benthic suspension feeders, and that they may be exported (re-distributed) several kilometres away, contributing to food web in adjacent habitats in coastal waters of Kuwait. Nevertheless, caution must be taken when using the current GPP estimation, since it is difficult to scale-up to a broader geographical scale from a single site in a limited area.

Table 4.10 Chlorophyll a concentration just as water receded from the sediment (emersion), and just before the sediment was flooded (Van Duyl *et al.*, 2000).

		Chla (μg cm^{-3} wt sediment)		
	Date	**At emersion**	**At submersion**	**Δ**
Diatom mat	**4 July**	**98.2 (±10)**	**103.8 (±4.0)**	**+ 5.6**
	8 July	**84.9 (±2.5)**	**87.2 (±9.9)**	**+ 2.3**
Eroded mat	**4 July**	**7.4 (±1.7)**	**10.8 (±4.4)**	**+ 3.4**
	8 July	**6.7 (±2.6)**	**11.6 (±6.8)**	**+ 4.9**

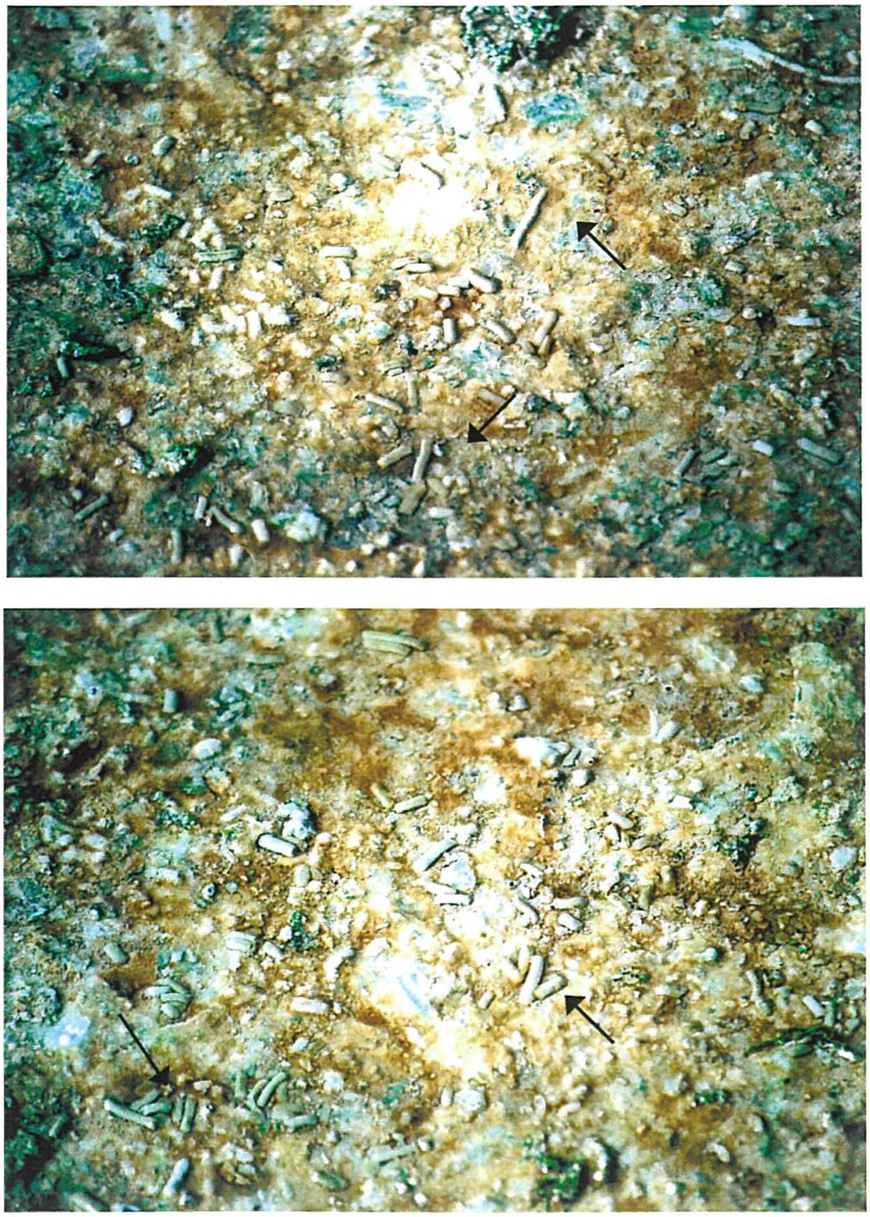


Figure 4.19 Faecal pellets of subtidal species on the top shore of K site during low tide.

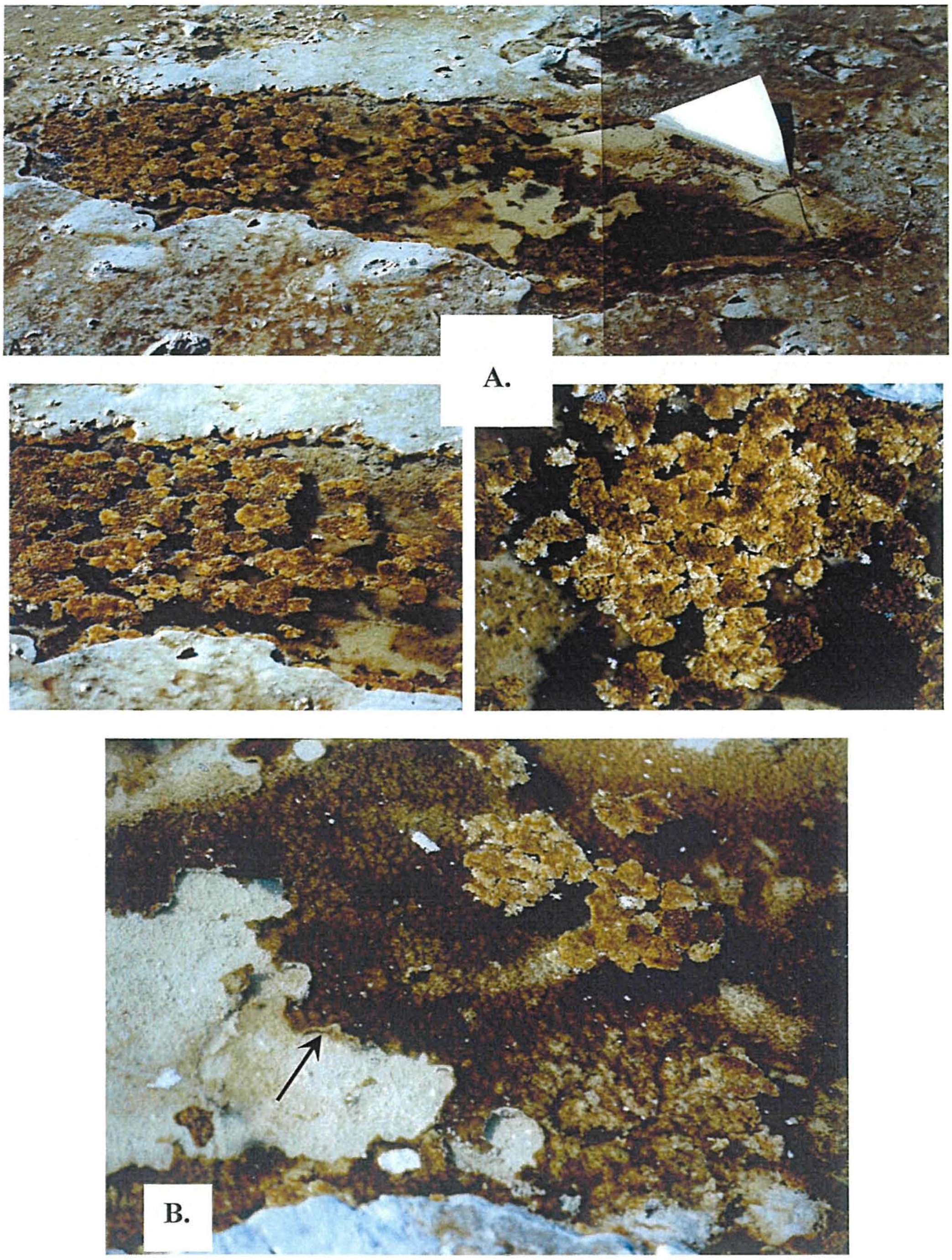


Figure 4.20 Suspensions of densely populated mat pieces within the overlying water:

a. mats peeling within water pools during low tide

b. mat scouring induced by tidal rhythm during submersion.

Figure 4.21 Suspension of epipelic diatoms in the water edge during Flood tide at KI transect.

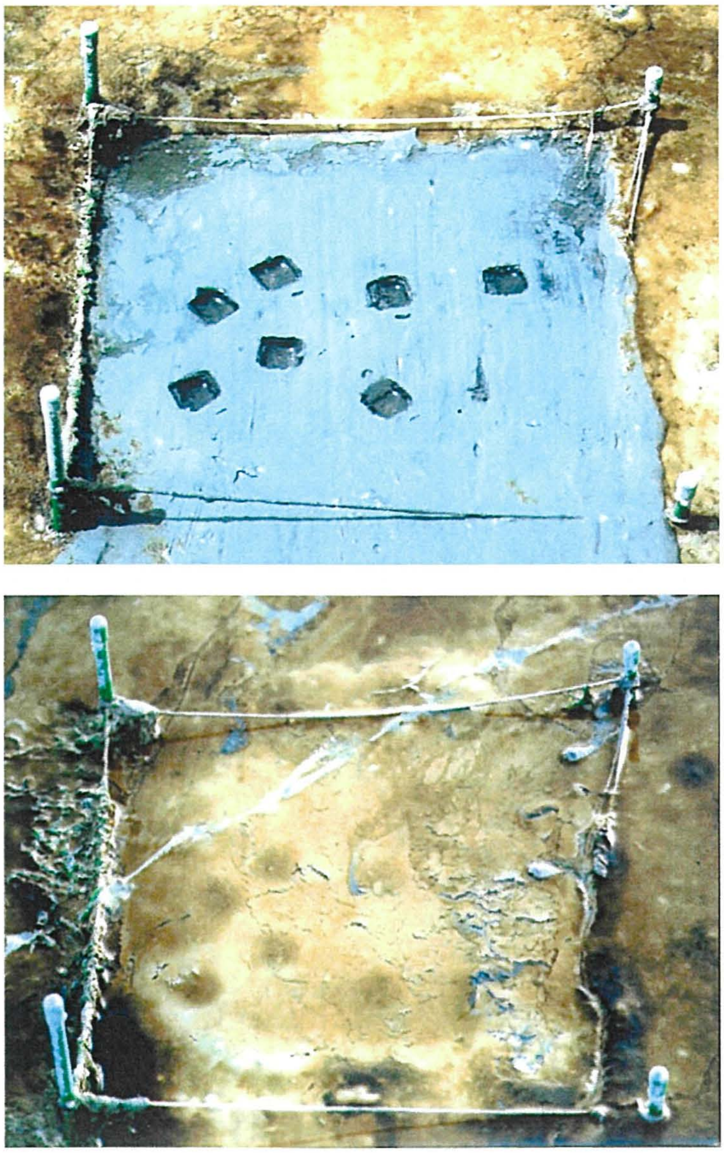


Figure 4.22 Positive effect of resuspension during submersion on the standing stock of mats within KI transect:

a. Scraped area before submersion

b. After submersion.

Table 4.11 Conversion of 5h experiments conducted on epibenthic algal production, in the Ythan Estuary - Scotland, to daily production rates from January 1968 to December 1969 (Leach, 1970).

Month	**Mean measured production ($mg\ C\ m^{-2}\ period^{-1}$)**	**Day-length factor**	**Mean calculated production ($mg\ C\ m^{-2}\ day^{-1}$)**
Jan	**20.5**	**1.12**	**23**
Feb	**41.0**	**1.24**	**51**
Mar	**59.0**	**1.54**	**91**
Apr	**76.5**	**1.84**	**141**
May	**54.5**	**1.89**	**103**
Jun	**114.5**	**1.97**	**226**
Jul	**53.0**	**1.87**	**100**
Aug	**73.5**	**1.85**	**136**
Sep	**44.0**	**1.59**	**70**
Oct	**28.5**	**1.40**	**40**
Nov	**28.0**	**1.14**	**32**
Dec	**8.5**	**1.06**	**9**

Table 4.12 Summary of annual gross benthic microalgal production (GPP) estimates from different geographical areas (values between brackets represent mean of range).

Region	**Location**	**GPP** **($g\ Cm^{-2}y^{-1}$)**	**Reference**
Temperate	Ythan Estuary, Scotland	31	Leach (1970)
	Dutch Wadden Sea	101	Cadee & Hegeman (1974)
	SW England	143	Joint (1978)
	Ems Estuary, Netherland	62-276 (169)	Colijn & De Jonge (1984)
	Baltic Sea	60	Meyercordt & Meyer-Reil (1999)
	MEAN ± S.E.	**100.8 ± 25.5**	
Semi-tropical / tropical	Bolsa Bay, USA	115-246 (181)	Riznyk *et al.* (1978)
	South Carolina, USA	56-234 (145)	Pinckney & Zingmark (1993)
	Santos Estuary, Brazil	225	De Sousa *et al.* (1998)
	MEAN ± S.E.	**183.7 ± 23.1**	
	Sulaibikhat Bay, Kuwait	**191**	**Current study**

Table 4.14 Contribution of microphytobenthos, associated with soft sediments to GPP in relation to other autotrophs associated with biotopes in Kuwaiti waters (modified from Jones *et al.*, 2002a).

Biotope	**GPP x 10^{11} (g $Cm^{-2}y^{-1}$)**	**%GPP**
Benthic Microalgae (soft sediment*)	12.72	32
Phytoplankton	26.20	66
Macroalgae (rock)	0.30	0.77
Microalgae (reefs)	0.06	0.20
Seagrass	0.30	0.77

*includes microbial mats on intertidal mudflats, biofilms on shallow and deep sand/mud from table 5.9.

Microbial Mat Grazing

Grazing on benthic microalgae occurring on depositing shores has recently been studied in temperate areas, using many methods including straightforward techniques such as direct observation, mouthpart structure, gut structure and content, and food-choice experiments in the laboratory (Niu *et al.*, 1998; Iken, 1999; Raffaelli, 2000; Blanchard *et al.*, 2000). Unfortunately, there are no similar resources for the sub-tropical Gulf region. To support the importance of microbial mat production to the mudflats of Sulaibikhat Bay, it is essential to determine whether intertidal species feed upon these mats. Gut content analysis reveals that the mat assemblage contributes to the food of at least some of the intertidal and subtidal commercial species of Sulaibikhat Bay mudflats. The results of the faecal analyses show that species located at highest level of the mudflats had more diatoms in their faecal pellets than blue-green algae, while faecal pellets of species located on the lower intertidal contained a higher number of cyanobacteria than diatoms.

This is in contrast to the distribution of these food items on the shore, and the following explanations are suggested. Firstly, the presence of specific mat components in faeces may indicate that some macrofaunal species have differential utilisation/assimilation rates for the different forms of microphytobenthos that make up the mat assemblage. Kofoed (1975) found uniformly high assimilation efficiencies of 60-71% for diatoms by the gastropod *Hydrobia ventrosa*, and suggested that diatoms form the main energy source for these snails, at least during periods of the year when diatoms are abundant. However, assimilation efficiencies for two species of blue green algae were lower than that for diatoms, namely, 49-51% for *Oscillatoria* sp. and only 8% for *Chroococcus* sp. This large difference is probably due to the very thick mucous sheath surrounding the *Chroococcus* cells which appear to pass through the gut undigested (judged by microscopic examination). In 1976, Fenchel & Kofoed found that *Hydrobia* sp. did poorly on sediment dominated by *Oscillatoria,* perhaps due to the indigestibility of this alga. In contrast Kofoed (1975) found that the *Hydrobia* sp. grew well on sediments poor in diatoms and rich in *Oscillatoria.*

They came to the conclusion that microbial availability is strongly dependent upon grazing pressures and floral species availability. This may also explain observed gut contents on Kuwait mudflat. Cyanobacteria prefer coarser sediments for colonisation (Watermann *et al.*, 1999), and this grain size occurs on the upper intertidal zone of mudflats in Sulaibikhat Bay (Chapter 2) where *L. kuwaitense* and *U. sindensis* are found. However, benthic diatoms prefer, and are more abundant in muddier sediments (Colijn & Van Buurt, 1975; Admiraal, 1977), occurring at mid to lower intertidal levels in the Bay, where macrofauna with higher levels of cyanobacteria in their faeces occur. It is possible that the fauna in each zone assimilate the dominant mat component with higher efficiency than the less dominant component, and this would leave the less dominant form to be discharged with the faeces.

Because gastropods are dominant inhabitants of intertidal mudflats (Reise 1985), and are frequently known to function, directly or indirectly, as a trophic link in food webs, they have been used worldwide to investigate grazer/algal interaction (Kofoed, 1975; Fenchel & Kofoed, 1976; Levinton & Bianchi, 1981; Niu *et al.*, 1998; Iken, 1999; Blanchard *et al.*, 2000). They recycle the nutrients assimilated by the algae to make them available to higher trophic levels either as faeces for detritivores (Austen *et al.*, 1999) or as prey.

During this investigation the deposit-feeding mud snail *Cerithidea cingulata* provided clear evidence of mat consumption in the laboratory under simulation of habitat conditions, which was further supported by gut analysis. When attempting to determine the assimilation-consumption-egestion (ACE) rates, pilot evacuation tests showed that the concentration of chlorophyll pigment (CCP) in the gut decreased with time and that although cerithids were left to starve for 4days their guts still contained traces of chlorophyll. It was evident that within the first 24h the Chl *a* concentration decreased by 50%, however it took 3 further days for a similar decrease (0.409mg/ml), indicating less evacuation and retention of food. This agrees with findings by Kofoed (1975) who found that faecal production by *Hydrobia* is at a significant rate for at least 48h after feeding but then is reduced, with some ingested food still remained in the alimentary canal of the animals.

During the preliminary ACE experiment, the snails did not feed although they were left to graze for 17 days. Davies *et al.* (1990) also found that the gastropod *Patella vulgata* was less active under laboratory conditions than in the field. Gastropods are general browsers, swallowing small sedimentary particles and lightly brushing the radulae across sediment grains scraping off microalgae (McQuaid, 1996). Animals in present experiments had limited space in the compartments, which lacked sediment particles, in contrast to the field where they would move freely scraping the sediment surface for microalgae as they browsed. Further experimental design is required to more closely replicate field conditions in the laboratory.

This investigation represents the first attempt at determining mat production within the Gulf region. Such pilot estimations reveal that within Sulabikhat Bay, microphytobenthos may act as a main supplier of primary productivity in addition to phytoplankton. The microphytobenthos, occurring as mat assemblages, consists mainly of diatoms supporting both intertidal and subtidal faunal species. Altogether, it is calculated that intertidal and subtidal microphytobenthic primary production may account for 32% of the total production within the coastal waters of Kuwait, equivalent to 50% of that contributed by phytoplankton. However the amount transferred to the water column by resuspended microphytobenthos is not yet not known. Because biological, physical and climatic conditions affect the productivity of mats, interspecific interactions between such factors may be extremely complex and variable. Therefore it is recommended that detailed studies on mat standing stock and primary production are conducted using sophisticated techniques. More emphasis should be given to the contribution by microphytobenthos to suspended microalgal biomass suspended in the water column, since this source of primary productivity may provide the base of food webs in the Bay.

CHAPTER V

INTERTIDAL MARINE FOOD WEB ON MUDFLATS IN SULAIBIKHAT BAY, KUWAIT: DERIVED FROM STABLE CARBON ISOTOPE ANALYSIS

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INTRODUCTION

Studies of stable isotope composition can provide indications of the origins and transformations of organic matter (Fry & Sherr, 1984), acting as an alternative, and in some cases as a better tool for investigating trophic relationships within food webs (Peterson *et al.*, 1985; Peterson & Fry, 1987; Fry, 1988), than standard approaches (gut content analysis, direct field and laboratory observations). Insights into sources of nutrition for consumers and trophic relationships among marine organisms have been gained by using ratios of naturally occurring isotopes of carbon and nitrogen (Rau *et al.*, 1992; Newell *et al.*, 1995; Bull *et al.*, 1999; Bouillon *et al.*, 2000; Kaehler *et al.*, 2000; Lesage *et al.*, 200; Moncreiff & Sullivan, 2001).

Biological materials (i.e. food source) contain carbon and nitrogen with various proportions of their naturally occurring stable isotopes ($^{13}C/^{12}C$ and $^{15}N/^{14}N$). Animal tissues are built with atoms of the food they assimilate, thus retaining the stable isotope signal of the food. In other words, carbon and nitrogen isotopic ratios in animals are largely determined by those of their diet: "they are what they eat" (DeNiro & Epstein, 1978, 1981; Fry and Sherr, 1984; Gearing *et al.*, 1984; Minagawa & Wada, 1984). However, as a consequence of isotopically selective excretion or respiration of the lighter isotopes, heavy isotope enrichment can occur over a trophic gradient.

Trophic fractionation of ^{13}C is typically small compared to that of ^{15}N, resulting in relatively smaller enrichment (0 to 1‰ increase of $\delta^{13}C$ per trophic level; Fry & Sherr, 1984) along the food chain than the latter (2.6 to 3.4‰ increase in $\delta^{15}N$ per trophic level; Minagawa & Wada, 1984; Owens, 1987). Thus, $\delta^{13}C$ measurements primarily act as a tracer of sources of primary productivity (main sources of carbon to consumers), while enrichment of ^{15}N informs on trophic distance of consumers from the food base (Minagawa & Wada, 1984).

Primary producers vary in their isotopic carbon signatures according to their origins (terrestrial or aquatic), carbon pool used, and concentration (CO_2 in air, dissolved CO_2 or HCO_3 in water), prevailing carbon pathways (C_3 'Calvin cycle photosynthetic pathway' versus C_4 plants' Hatch-slack cycle') and the condition of the surrounding environment (well mixed or stagnant) (Smith & Epstein, 1971; Fry, 1996). Such factors which distinguish the food resources isotopically have governed the success of stable carbon isotope analysis.

There have been several excellent studies of marine food webs, in different systems, using $\delta^{13}C$ measurements. These studies were characterised by primary food sources that were isotopically distinct, and direct relationships were seen between the organisms and their diet. Much of the application of stable carbon isotope analysis to food web studies in the marine environment has been conducted on estuaries (Haines & Montague, 1979; McConnaughey & McRoy, 1979; Simenstad & Wissmar, 1985; Deegan & Garritt, 1997; Bouillon *et al.*, 2000), Salt marshes (Smith & Epstein, 1970; Haines, 1976a.b; Bull *et al.*, 1999; Dittel *et al.*, 2000), Gulfs (Achituv *et al.*, 1997), bays and open seas (Parker, 1964; Fry & Sherr, 1984; Fry *et al.*, 1984), mangroves (Rodelli *et al.*, 1986; Chandra Mohan *et al.*, 1997; Marguiller *et al.*, 1997), kelps and eelgrass beds (Stephenson *et al.*, 1984; Moncreiff & Sullivan, 2001).

Intertidal mudflats, which fringe estuaries, semi-estuaries and coastlines world-wide, have been relatively poorly researched in all aspects of marine sciences, including tracing food webs isotopically, in comparison with other intertidal habitats mentioned above. Such mudflats provide an important habitat as their flora and resident infauna act as a food resource for larger, inshore, offshore and visiting biotic communities, acting as feeding and nursery areas which inevitably contribute a large part of their biological productivity to humans (Dyers, 2000). Although intertidal mudflats are of great importance in providing, directly or indirectly, other habitats with major sources of primary productivity, scarce amount of literature has dealt with such habitats. Schwinghamer *et al.* (1983) suggests that *Spartina*, from nearby systems, and benthic diatoms may form a major carbon source in an intertidal mudflat ecosystem in the Bay of Fundy, Canada. Most scientific studies deal with energy flow within vegetated mudflats associated with salt marsh meadows or mangrove habitats; however it seems that no study as yet has aimed to solely investigate the sources of energy providing inhabitants of non-vegetated mudflat habitats.

Tidal flats, in particular mudflats, are known to be among the most productive of all natural ecosystems (Odum, 1971), and those of the north-western Arabian Gulf, Kuwait, are no exception to the rule. Intertidal mudflats cover about 50.5% of the total length of Kuwait's coastline (calculated from Al-Sarawi *et al.*, 1985). Despite their un-interesting appearance and apparent lack of vegetation, relatively high species diversity is associated with these habitats (Clayton, 1986)(Table 2.11 and Figures 2.23 & 2.24, chapter 2), and it is clear from the animal biomass they support (Figure 2.25, chapter 2), that these mudflats are highly productive.

Based on calculations of microbial mat production within the coastal waters of Kuwait, it is clear that mudflats and their associated microphytobenthos are more productive in terms of gross primary production than rock, corals and seagrass (Jones *et al.*, 1998, 2002a). Nevertheless, no attempt has yet been made to define the sources of primary productivity that supply the marine food web within them. In the previous chapter, a preliminary assessment determined the source of dietary carbon in some faunal species inhabiting the mudflats of Sulaibikhat Bay using the classical techniques of gut content and faecal analysis, and feeding experimentation. However, such techniques might act as a limiting factor in the progress of food web studies due to the tremendous amount of work needed to gather the necessary data. The present study represents the first systematic application of stable carbon isotope approach to study food webs in the Arabian Gulf region, specifically along mudflats of the north-western Arabian Gulf, Kuwait, by determining the major source of dietary carbon supporting inhabitants of such systems.

METHODOLOGY

Sample Collection

Samples were randomly collected during the period from September 98-June 99, from 2 sites within Sulaibikhat Bay (see chapter 2). Different types of sampling methods were used depending on the nature of the sample, while the number was dependent on their availability:

Non-biotic matter (sediment)

A hand-operated corer (KAHLSICO, California, U.S.A.) with an internal diameter of 5cm diameter, was inserted to a depth of 5cm (below this point sediment becomes anoxic). Samples were transferred to the laboratory where the top 1cm of the sediment sample was removed and excluded, since it contains microphytobenthos. Samples were then thoroughly mixed with a homogeniser, and dried at 60°C for 24h.

Biotic

Phytoplankton was collected once during early 1998 by towing a 20µm mesh size plankton net (KAHLSICO, USA; model #013WA250) equipped with a calibrated flow meter at its opening (KAHLSICO, USA; model #005WB1000), for approximately 1 nautical mile (25-30min) using the Kuwait University boat for scientific fieldtrips "Oloom 3" (10m). Material was placed in a plastic jar kept in a cool box on board, and transported to the laboratory for processing.

Microbial mat samples were collected within a $100cm^2$ patch to a thickness of 1cm using a spatula. Because microphytobenthos normally occupies the top 5mm of the sediment, only that part of the mat was required for the analysis. A $1cm^2$ sub-sample was randomly chosen from each sample before drying to perform a qualitative inspection aiming to identify the most abundant components of the mats.

Halophytic plants where occurring, were collected by hand, placed in a pre-labelled aerated plastic bag and transferred to the laboratory where they were identified. Leaves of halophyte plants were used for the analysis.

Intertidal gastropods were randomly collected by hand, taken to the laboratory where their shell was cracked, and flesh extracted.

Intertidal crabs were obtained, either by digging burrows (macrofauna), or by sediment extraction (infauna) (see chapter II for method). Relatively large crabs were dissected and muscle tissue removed. However small infaunal crabs were too minute for dissection, and the whole animal was used.

Intertidal gobies were caught using a hand net. Samples were then placed in a pre-labelled bag and transferred to the laboratory where they were identified. Muscle tissue was removed and prepared for analysis.

Subtidal fish, shrimp & crabs and gobies were obtained by randomly placing fish traps along the sampling area during low tide, and collected the following day (left for 2 tidal cycles). Samples were then placed in a pre-labelled bag and transferred to the laboratory where they were identified and directly dissected removing muscle tissue for isotope determination.

All samples were washed with distilled water, dried at 60°C for 24h, placed in tightly sealed labelled vials and transferred for isotopic analysis to School of Ocean Sciences (SOS), University of Wales, Bangor, U.K.

Sample Preparation

At SOS, all precautionary measures were taken to prevent contamination of samples with organic carbon while under preparation. The pestle and mortar were thoroughly washed and air-dried prior to crushing the samples, while silver cups, tools and vycor tubes (quartz tubes) used during preparation were pre-combusted to prevent contamination with organic carbon that might interfere with the results.

Thoroughly dried samples were crushed and homogenised with a pestle and mortar, and small quantities (sub-sample approx. 10mg) were weighed into silver combustion cups (Ag boats, 1cm diameter). Sub-samples were treated with 50µl of 2N HCl (acidification) to remove carbonates, then dried at 60°C. An additional 50µl of HCl was added to sub-samples thought to still contain $CaCO_3$, then re-dried.

Each sample was mixed with an oxidant, usually cupric oxide, in a vycor (quartz) tube. An oxidising reagent made up of 1g of cupric oxide (CuO) and 0.5g of reduced copper (Cu), both in wire-form, was prepared for each sample. Since the sample must be intimate with the CuO, the reagent was dividing into 3 parts and placed strategically within the sample and in the tube. One third was placed within the inner tube (17mm I.D.). The second part was placed within the cup containing the sample, cup was folded and inserted into the tube. The remaining third of the reagent was placed on top of the sample. Pre-combusted glass-fiber filter paper (Whatmann GF/F) was inserted 1/4way down the tube sealing it. The inner tube containing the sample was then placed into the larger vycor tube inverted. Once all tubes are prepared, they are sealed under vacuum. The tubes were placed in a muffle furnace and combusted at 900°C for 2h, temperature was then reduced to 650°C and held at that for 2h. This ensured that all CO was converted to CO_2, that halogens and sulphur were removed, and that copper absorbed the excess oxygen. The furnace was then left to cool overnight to room temperature. After which the tubes were placed in the mass spectrometer for stable carbon isotope analysis.

The goal in stable carbon isotope analysis is to convert a sample quantitatively to a suitable purified gas, in this case CO_2, which can then be analysed by the mass spectrometer. The result given by spectrometry measures the ratio of the heavy to light isotopes in a sample ($R_{sa} = {}^{13}C/{}^{12}C$). The isotope ratio of the sample is compared to a reference calibrated to a standard, a marine limestone fossil, Pee Dee Belemnite ($R_{std} = {}^{13}C/{}^{12}C = 0.0112372$), so that any fluctuations will be reflected equally in both standard and sample. The difference in ratio are calculated in 'del' (δ) notation, and have units of mil (‰):

$$\delta\ (‰) = [(R_{sa} / R_{std}) - 1] \times 1000$$

RESULTS

The stable carbon isotopic ratios (δ ^{13}C) of sediment, major primary producers and dominating consumers on Sulaibikhat Bay mudflats are displayed in table 5.1 and figure 5.1.

The 3 major sources of primary production within the habitat were the halophyte, *Salicornia herbacea*, microbial mat/diatom complex (70% benthic diatoms, 30% cyanobacteria), and phytoplankton. The annual glasswort, *S. herbacea* was the lightest (-24.74‰), whereas phytoplankton was intermediate (-21.64‰), and microbial mat/diatom complexes had the heaviest δ^{13}C value (mean = -15.28 ± 0.35 ‰).

Sub-surface sediment showed a mean δ^{13}C value intermediate between phytoplankton and benthic micro-algae (- 17.71 ± 1.24 ‰).

All consumers were relatively enriched with δ^{13}C by comparison with the major primary producers. It was evident that δ^{13}C values of consumers were enriched by 6.3 to 12.3‰ relative to phytoplankton, and enriched by 9.4 to 15.4‰ relative to *S. herbacea*, but shows least enrichment (0.5 to 4‰) relative to benthic microbial mat (Figure 5.1). This indicates that both phytoplankton and *S. herbacea* are unlikely to be an important food source for these consumers.

Almost 53% of the consumers had δ^{13}C signatures close to that of microbial mats, with slight enrichment of 0.5 to 2‰. The remaining 47% were slightly more enriched by 2.6 to 6‰ relative to microbial mats (figure 5.1).

Approximately 73% of intertidal consumers were slightly more enriched (2.6 t0 6‰) relative to microbial mats, while the remaining 27% had δ^{13}C values corresponding with that of the mats (0.5 to 2‰ enrichment). The dominating mud snail, *Cerithidea cingulata*, had a mean δ^{13}C value of –12.18 ± 1.43‰, showing an approximate 3‰ enrichment. The endemic crab, *L. kuwaitense*, and the fiddler crab, *Uca annulipes albimana*, both inhabiting the upper intertidal zone, and the large mud crab, *Macrophthlamus dentipes* occupying the mid to lower intertidal area all showed ~6‰ enrichment relative to the microbial mats. The fiddler crab, *Uca sindensis*, occupying the upper intertidal, and the endemic, *Nasima dotilliformis*, present along the upper intertidal extending slightly into the mid-intertidal zone, were both less enriched (2.7‰) relative to the microbial mat, than the above mentioned brachyuran species. An enrichment of 1.8‰ was noticed for the carnivorous xanthid crab, *Eurycarcinus orientalis*, while the least enrichment within the brachyuran group was for *Metaplax indica* (~0.4‰), also a carnivore, both occurring towards low tide. On the other hand, the tiny ocypodid crab, *Tylodiplax indica*, had a $\delta^{13}C$ signature of -15.32‰ almost equal to that of the microbial mat (-15.28‰). Both of the intertidal gobies, *Periophthlamus waltoni*, and *Boleophthlaums boddarti*, had mean $\delta^{13}C$ values relatively more enriched than the mat (-12.05 ± 0.44‰ with 3.2‰ enrichment, and -10.49 ± 0.51‰ with 4.8‰ enrichment respectively).

Almost all subtidal species feeding intertidally at high tide were 1 to 2‰ enriched relative to the $\delta^{13}C$ signature of the microbial mat/diatom complex, except the goby, *Acentrogobius ornatus* which was more enriched by ~3‰ (-12.64 ± 0.09‰) relative to the mat (-15.28 ± 0.35‰). The edible blue crab, *Portunus pelagicus*, had a mean $\delta^{13}C$ value of –13.66 ± 0.50‰, thus bearing 1.6‰ enrichment. Juveniles of the commercial shrimp, *Metapenaeus affinis*, showed a considerably low enrichment (0.56‰) relative to the microbial mat/diatom complex. The highly consumed commercial fish species, the mullet *Liza macrolepis*, had the least enrichment relative to the mats (0.8‰) when compared with the other fish species (Table 5.1), while *Sillago sihama*, another commercial species, had highest enrichment of 2‰.

Table 5.1 δ ^{13}C values of samples from tidal mudflat habitats in Sulaibikhat Bay.

Sample	**Zonation**	**δ ^{13}C(‰)**	
		Range	**Mean (± S.E.)**
Sediment	I	-16.51 to -20.18	-17.71$^{(a)}$ (1.24)
Primary Producers			
Microbial mat/ diatom complex	U	-14.55 to -16.17	-15.28$^{(b)}$ (0.35)
Salicornia herbacea	U	-24.74	
Phytoplankton	P	-21.64	
Consumers			
Leptochryseus kuwaitense	U	-9.35	
Uca sindensis	U	-10.82	
Uca annulipes albimana	U	-9.26	
Nasima dotilliformis	U	-12.63	
Tylodiplax indica	U/M/	-15.32	
Macrophthalmus dentipes	M/L	-9.67	
Eurycarcinus orientalis	M/L	-13.43, -13.48	-13.46$^{(c)}$
Metaplax indica	M/L	-14.70, -15.14	-14.92$^{(c)}$
Portunus pelagicus	S	-12.06 to -15.19	-13.66$^{(d)}$ (0.50)
Metapenaus affinis	S	-14.65, -14.79	-14.72$^{(c)}$
Cerithidea cingulata	M/L	-10.74, -13.61	-12.18$^{(c)}$
Periophthlamus waltoni	U/M/L	-10.76 to -13.06	-12.05$^{(d)}$ (0.44)
Boleophthlamus boddarti	M/L	-8.79 to -11.73	-10.49$^{(d)}$ (0.51)
Acentrogobius ornatus	S	-12.48 to -12.78	-12.64$^{(a)}$ (0.09)
Rhonicus stridens	S	-13.65	
Sillago sihama	S	-13.18	
Acanthopagarus cuvieri	S	-13.52	
Synaptura orientalis	S	-14.15	
Liza macrolepis	S	-14.45	

Sample number: (a) 3 replicates, (b) 4 replicates, (c) 2 replicates, (d) 5 replicates.

(I) intertidal: (U) upper, (M) middle, (L) lower; (S) subtidal; (P) pelagic.

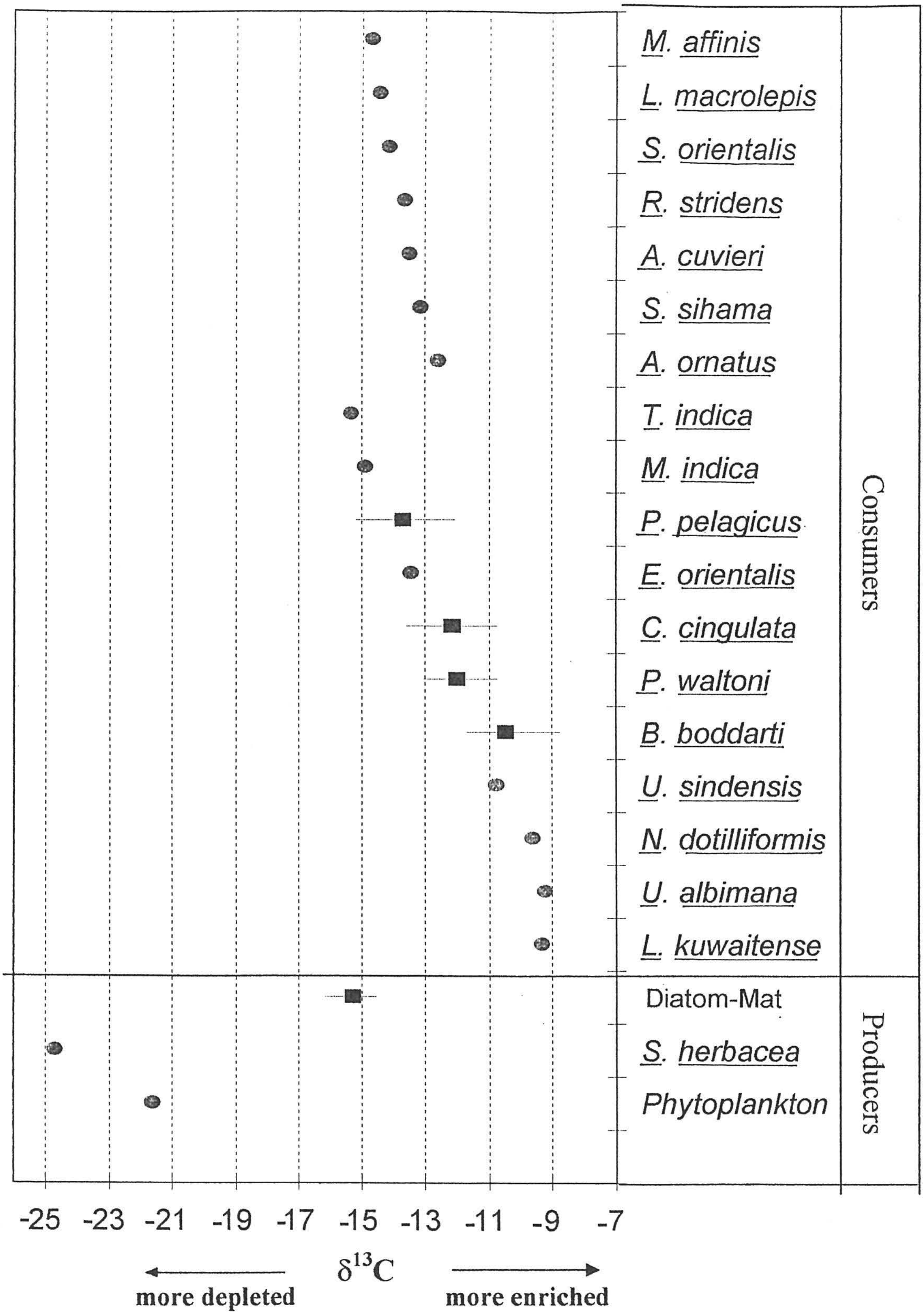

Figure 5.1 Summary of the distribution of δ^{13}C values (means, min., max. where occurring) for the major faunal species in relation to the major primary producers encountered on tidal mudflat habitats in Sulaibikhat Bay (● = single reading, — = range, ■ = mean value).

DISCUSSION

The stable isotope ratio is for plants a tracer of the CO_2-system speciation in local seawater and of the carbon uptake metabolism, and for animals a tracer of the 'mean' diet (what it has eaten) rather than of currently ingested food. This ratio has proven especially useful in identifying the origin of plant carbon sources supporting food web of organisms at higher trophic levels (Fry & Sherr, 1984). Once carbon is fixed by a plant, the ratio of ^{13}C to ^{12}C remains relatively constant as it passes through the food chain (Fry & Sherr, 1984). Thus, when there are relatively few isotopically distinct plant groups in a system, it is possible to determine the primary plant carbon source(s) from which an animal directly or indirectly derived nourishment by measuring the carbon isotope ratio.

Primary producers

The major of plant groups impinging on the mudflats of Sulaibikhat Bay are represented by phytoplankton, the seasonally occurring salt marsh halophyte, *Salicornia herbacea*, and benthic microalgae in the form of microbial mats (micro-algal mats). Although these primary producers have relatively distinct $\delta^{13}C$ signatures, their isotopic values match $\delta^{13}C$ measurements for similar plant groups over a wide geographical range (Table 5.2).

Current measures of the stable carbon of micro-algal mats overlaps with values reported by others (Table 5.2). This variation in the stable isotope composition of benthic microalgae has been recognised for years (Fry & Sherr, 1984), although relatively few measurements have been made. The most frequently cited value (-17‰, Fry & Sherr, 1984) is lighter than the $\delta^{13}C$ composition of several benthic microalgal saltmarsh communities. Based on reports of heavier $\delta^{13}C$ values for pelagic cyanobacteria (Calder & Parker, 1973; Fry & Sherr, 1984) and benthic cyanobacteria (Calder & Parker, 1973; Pulich & Scalan, 1987; Des Marais *et al.*, 1989), $\delta^{13}C$ values heavier than –17‰ may be especially prevalent in environments where cyanobacteria make a significant contribution to benthic microalgal biomass. In the present case it was difficult to separate the benthic components of the mats from each other and from the sediment due to their cohesive nature (Höffmann, 1996). This difficulty in obtaining an effective separation of microscopic algae from sediment was found by Schwinghamer *et al.* (1983) and Hamilton *et al.* (1992). Observations made in the current study (see chapter 4) indicate that benthic diatoms and cyanobacteria are the major components of the mats, with approximately a 70% and 30% contribution by each respectively to the mat. Hence, the $\delta^{13}C$ value obtained for these microbial mats might be expected to support the proportion of the different mat components.

A compilation of estuarine benthic microalgal stable isotopic values from the literature (Table 5.2) produces a value of -16.24‰ for benthic diatoms and -10.93‰ for cyanobacteria, giving an average of–13.59‰, assuming an equal contribution of each. Using the cited $\delta^{13}C$ values for the calculated contributions of both mat components which dominate mats found during this study produces a $\delta^{13}C$ value of -15.40‰. This value is similar to the mean of $\delta^{13}C$ signatures actually measured for micro-algal mats in the current study (-15.28 ± 0.35‰) and the mean cited $\delta^{13}C$ values for benthic microalgae (-15.28 ± 0.82‰). Hence, it concluded that the $\delta^{13}C$ signature of the microbial mats of Sulaibikhat Bay is a proportional representation of the $\delta^{13}C$ signal for benthic diatoms and cyanobacteria. Nevertheless, a range and variety of $\delta^{13}C$ values can occur due to both community composition of microbial mats (Pulich & Scalan, 1987) and/or due to seasonal differences within a microalgal species (Schwinghamer *et al.*, 1983).

Table 5.2 Comparison between $\delta^{13}C$ values of primary producers obtained from a published literature on saltmarsh-estuarine systems in different geographical locations, and present values from the current study.

SAMPLE	LOCATION	$\delta^{13}C$ (‰)	REFERENCE
Phytoplankton	Malaysia	-19.6	Rodelli *et al.*, 1984
	Auke Bay, Alaska	-21.5, -20.6	Goering *et al.*, 1990
	S. California, USA	-22.4, -20.8	Kwak & Zedler, 1997
	Delaware Bay, USA	-22.0	Dittel *et al.*, 2000
Mean ± S.E.		**-21.15 ± 0.42**	
		-21.64	**Current study**
Salicornia virginica	Georgia, USA	-26.0	Haines, 1976a,b
	S. California, USA	-27.6, -26.7	Kwak & Zedler, 1997
	Santa Barbara, USA	-29.2, -25.9	Page, 1997
Mean ± S.E.		**-26.08 ± 0.61**	
Salicornia herbacea		**-24.74**	**Current study**
Benthic Flora			
Microalgae	Malaysia	-18.7	Rodelli *et al.*, 1984
	S. Carolina, USA	-13.5, -12.1	Couch, 1989
	N. Carolina, USA	-17.5, -13.0	Currin *et al.*, 1995
	Mallorca Isl., Spain	-16.5, -16, -14.9	Jennings *et al.*, 1997
Mean ± S.E.		**-15.28 ± 0.82**	
		-15.28 ± 0.35	**Current study**
Cyanobacteria	Arabia	-8.5	Calder & Parker, 1973
	Bahamas	-8.4	Barghoorn *et al.*, 1977
	Crane Key, Florida	-11.1	Barghoorn *et al.*, 1977
	Shark Bay, Australia	-12.7	Barghoorn *et al.*, 1977
	Virgin Islands	-9.4	Fry *et al.*, 1982
	Texas	-11.5	Pulich & Scalan, 1987
	Texas	-14.9	Pulich & Scalan, 1987
Mean ± S.E.		**-10.93 ± 0.90**	
Diatom			
***Euglena* sp.**	Georgia, USA	-17.0	Haines, 1976a,b
***Gyrosigma* sp.**	Georgia, USA	-17.9	Haines, 1976a,b
	Nova Scotia, Canada	-18.1, -13.6	Schwinghamer *et al.*, 1983
***Navicula* sp.**	Malaysia	-14.8	Rodelli *et al.*, 1984
Mean ± S.E.		**-16.24 ± 0.91**	

Consumers

In food web studies the maxim of "YOU ARE WHAT YOU EAT" has been tested by several scientists (DeNiro & Epstein, 1978; Haines & Montanague, 1979; Fry & Sherr, 1984). They concluded that the isotopic composition of the body of an animal reflects the isotopic composition of its diet, with slight enrichment relative to that in the diet. McConaughey and McRoy (1979) derived a preliminary estimate of 1.5‰ ^{13}C enrichment per trophic level in a study of Bering Sea fauna. Rau and others (1983) have refined this estimate to 0.7 to 1.4‰. Thayer *et al.* (1983) found consistent 0.8-2.2‰ ^{13}C enrichments for total zooplankton versus phytoplankton in off-shore Gulf of Mexico. Fry and Sherr (1984) concluded that the isotopic composition of an animal is enriched in $\delta^{13}C$ within about 2‰ relative to the diet, through higher trophic levels.

Table 5.3 shows a comparison between $\delta^{13}C$ values of some of the consumers in Sulaibikhat Bay (current study), and ecologically similar genera that derive their nutrition from a Malaysian mangal system (Rodelli *et al.*, 1984). It is quite clear that where mangroves dominate nutrition from the microbial mat/diatom complex seem insignificant. This supports our hypothesis which suggests that microbial mats act as a major nutritional source supporting inhabitants of the mudflat system of Sulaibikhat Bay. Virtually all of the consumers sampled during this study have $\delta^{13}C$ signatures falling within a narrow range of –15.3 to -9.3‰, showing least enrichment (0.5 to 4‰) relative to the signature of the microbial mat complex, rather than phytoplankton (6.3 to 12.3‰ $\delta^{13}C$-enrichment) and *S. herbacea* (9.4 to 15.4‰ $\delta^{13}C$-enrichment). However, it remains to explain intermediate enrichment in $\delta^{13}C$ values and/or increased enrichment in some of the primary consumers such as *L. kuwaitense* (-9.35‰), *U. sindensis* (-10.82‰), *U. albimana* (-9.26‰), *M. dentipes* (-9.67‰), and *B. boddarti* (-10.49‰), relative to the mats.

Selective herbivory can result in the differential transfer of carbon from preferred plant groups through the food chain (Boyd and Goodyear, 1971; Caswell *et al.*, 1973). Selective digestion can also result in differential carbon assimilation (Boyd

& Goodyear, 1971; Caswell & Reed, 1976). Selective assimilation of ^{13}C enriched foods has been suggested as a mechanism which could account for the progressive ^{13}C-enrichments observed in food webs. In 1973, Caswell and others hypothised that C_4 plants (plants using the Hatch-slack cycle photosynthetic pathway) were selectively avoided by herbivores because of their poor digestibility, due to relatively high fibre and lower nutritional value. Waslien (1979) stated that algal protein is highly nutritious and readily assimilated by most animals when compared to C_4 plants, which may explain selective assimilation. Selective assimilation of ^{13}C-enriched components in natural diets has been demonstrated for offshore shrimp by Fry, (1981). His studies showed that assimilated materials averaged 1.3‰ enrichment relative to total stomach contents, suggesting that selective assimilation accounts for the ^{13}C enrichment of offshore shrimp versus their diets.

Incze *et al.* (1982) found high ^{13}C enrichment for *M. balthica* ($\delta^{13}C$ =-9.7 ‰) relative to other suspension-feeding bivalves ($\delta^{13}C$ range –22.5 to –18.4‰). These authors postulated that this species was either selectively feeding upon, or assimilating with high efficiency a $\delta^{13}C$-enriched component in the sedimentary carbon pool. In a mangrove- seagrass ecosystem, the herbivorous gastropod, *Terebralia palustris* had a $\delta^{13}C$ signal (-24.23‰) close to mangrove leaves for the species *Ceriops tagal* (-24.28‰). This indicates that leaves of this mangrove species are the main carbon source for this gastropod. In the same ecosystem however, the gastropod *Cerithidea decollata*, and the crabs *Uca lactea* and *Metapograpsus thukuhar*, showed enrichment in ^{13}C. A possible explanation for this less negative ^{13}C signal is that they feed on a mixture of inwelled seagrass (range –16.34 to –19.82‰) and local mangrove detritus (Marguillier *et al.*, 1997). Page *et al.* (1997) found that the deposit-feeding bivalve *M. nastuta* inhabiting a Californian salt marsh was enriched in ^{13}C by 1.5 – 3‰ relative to other channel fauna, and suggested that selective assimilation of carbon from benthic micro-algae enriched in ^{13}C occurred rather than grazing on the detritus of vascular salt marsh plants.

A recent food web study conducted on salt marshes of Delaware Bay, USA (Dittel *et al.*, 2000), showed that *Callinectes sapidus* crabs fed on detritus and detritus-plus-meiofauna were depleted in $\delta^{13}C$ by 2.3 and 3.1‰ relative to the detritus and meiofauna diets respectively. This discrepancy in $\delta^{13}C$ between the crabs and their diet indicated that the $\delta^{13}C$ values of the bulk material did not reflect the material actually consumed by the crabs. Hence, they assumed that juvenile crabs fed detritus-plus-meiofauna diet probably selected the meiofauna from the detritus.

During the study of the structure of a forest community in France, Ponsard and others (2000) found that all the animal species examined showed ^{13}C values above the values found for the soil and litter, exceeding the expected enrichment of 0.4‰ compared to their diet. They stated that a possible explanation for these high $\delta^{13}C$ values is that detritivores are prevented from assimilating the ^{13}C-poor organic components of the litter and soil (Benner *et al.*, 1987), because they lack the enzymes necessary to digest them, and therefore preferentially assimilate ^{13}C-rich organic carbon pools.

Moncreiff & Sullivan (2001) used an omnivorous pinfish *Lagadon rhomboides* as an example for a 'mixing model' of diets, and assumed if seagrass and epiphytes contributed equally to the diet, this organism would have a $\delta^{13}C$ value of –14.8‰. Setting contributions of seagrass at 25% and that of epiphytes at 75% would yield a $\delta^{13}C$ value of –16.2‰, which is nearly identical to the measured value for this organism. Equal contributions to $\delta^{13}C$ from the sediment microflora and epiphyte would yield a $\delta^{13}C$ value if –16.60‰, again close to the measured value. Estimated $\delta^{13}C$ would be –15.2‰ if the organism consuming food items deriving nutrition equally from seagrass, epiphytes and sediment microflora, again less than the value observed for *L. rhomboides*, which can only be compensated for by increasing the relative contributions of epiphytes to the base of this fish's diet. Thus epiphytes would appear to make a larger contribution to this fish species diet than relative biomass values for the primary producers would indicate. This could be a result of preferential assimilation of algal material, selective grazing by organisms within the local food web, or greater available biomass during the year due to shorter turnover rates for epiphytes than the seagrasses (Borum, 1987). Applying similar assumptions using the herbivorous gastropod *Cerithidea cingulata* ($\delta^{13}C$= -12.20‰) as an example for a 'mixing model' for $\delta^{13}C$, and assuming contributions of 25% and 75% for mean cited $\delta^{13}C$ values for diatoms (-16.24‰) and cyanobacteria (-10.93‰) respectively (Table 5.2), this organism would have a $\delta^{13}C$ signature of -12.30‰, which is nearly identical to the measured $\delta^{13}C$ value for this organism.

The isotopic composition of virtually all consumers was consistent with that of the benthic microalgae represented in microbial mat complex. It is suggested that primary consumers (Table 5.1) which show slightly higher enrichment values, than that measured $\delta^{13}C$ for the nutritional source, either selectively feed, assimilate or digest the less negative $\delta^{13}C$ signature component of the microbial mats, represented by cyanobacteria. In turn, carnivores/omnivores species have isotopic ratios consistent with the $\delta^{13}C$ signal of microbial mats, with slight enrichment, which indicates that these species are feeding on species consuming this isotopically heavier carbon. Generally results support the hypothesis that the $\delta^{13}C$ values of consumers are similar to the isotopic composition of their diet, microbial mat complex, or are higher by 1 to 2‰.

The use of isotopic techniques in this chapter has proven its adequacy in yielding fast reliable results supporting those attained by using the classical techniques. Stomach contents of *C. cingulata, B. boddarti, M. affinis, Lisa* sp. revealed the presence of mat components either in their gut or faeces (chapter 4). The $\delta^{13}C$ values also indicated that these macrofaunal species assimilate this source of primary production. It is evident that several intertidal and subtidal macrofaunal species feed on the microphytobenthic community occurring along the sediment surface of the mudflats (Figure 5.1), not only herbivorous species, but also omnivorous and carnivorous species have $\delta^{13}C$ signatures similar to that of microbial mats.

Although some intertidal species feeding on the mats are not commercially important (Table 5.1), they serve as food for many species which are. Results of gut content analysis revealed the occurrence of the non-commercial intertidal crab *Tylodiplax indica* within the gut of the edible blue crab *Portunus pelagicus,* and the commercial fish *Sillago sihama* (chapter 4). This is supported by Jones *et al.* (2002b) and currently ongoing research (Al-Mohanna, pers. comm.), both showing that even offshore fish species of commercial importance, located higher in the food chain, have $\delta^{13}C$ signatures similar to that of mats. This gives indication that commercial offshore species or the fauna they consume feed on floating mat pieces, its re-suspended components (chapter 4), or they migrate with the rising tide feeding on the intertidally situated mats.

Sulaibikhat Bay is proven to be a unique entity due to its biodiverse nature harbouring endemic species supporting high abundance's of faunal species (chapter 2). This, coupled with the fact that the fauna it supports relies most heavily on locally produced carbon source represented in microbial mats (with the operation of isotopic fractionation in the food webs) makes it a vitally important habitat. Recent work (chapter 2 and 3) gives indication that the bay is undergoing several alterations associated with urbanisation and industrialisation reducing the biodiversity income in the area. Unless such actions are monitored and controlled, unique habitats will be subjected to non-repairable damaged, which can result in the total loss of biodiversity which sustains key national commercial fisheries, consequently affecting the human consumer.

Table 5.3 δ^{13}C signatures for a selection of consumers from present study, and those ecologically similar in a Malaysian mangrove/mudflat system (Rodelli *et al.*, 1984).

	δ^{13} C (‰)	
Consumer genera	**Un-vegetated mudflats (current study)**	**Mangrove-associated mudflats**
Cerithidea ^{D}	-12.05	-24.05
Metaplax ^{C}	-14.92	-22.35
Uca ^{O}	-10.04	-19.28
Metapenaeus ^{O}	-14.72	-20.35
Boleophthlamus ^{H}	-10.49	-15.70
Periophthalmus ^{C}	-12.05	-22.60
Liza ^{D}	-14.45	-22.50
Primary producer		
Microbial mat/diatom complex	-15.28	-17.82
Mangrove plants	-	-27.10

H= herbivore, C= carnivore, O= omnivore, D= deposit feeder

CHAPTER VI

GENERAL DISCUSSION

The intertidal mudflats of Sulabikhat Bay, a small tidal embayment in the south-western corner of Kuwait Bay, have the surface of the mud covered by a thin brown-to-green film of micro-algae, composed mainly of diatoms and cyanophyta. When the tide is out, crabs and gobies roam over the flat foraging, while mud snails plough through the surface of the mud in search of algal-rich areas. Juveniles of shrimp and several fish species swim in with the rising tide to feed on the rich intertidal community of the flats, while during winter, they are crowded with wading birds accumulating in large feeding flocks.

Present work demonstrates for first time the abundance and biomass of key intertidal species occurring on the mudflats (Figures 2.22-2.26), which are comparable with fully tropical shores (Tables 2.17 and 2.18). Although these habitats and associated faunal species are subjected to harsh seasonal temperature and salinity regimes, both their high abundance and biomass provide good indications that these species are adapted. They burrow to seek shelter from the harsh environment, especially elevated air temperature during summer. Herbivores graze the surface surrounding their burrows, "i.e. garden", and can graze the same area again daily as the algae rapidly re-grows. This pattern of restricted foraging avoids environmental stress and predators. The intertidal fauna of these mudflats has a reproduction strategy similar to that seen in species occupying tropical areas (Alongi, 1990), characterised by a short life cycle and rapid turnover rate (Figures 3.21 and 3.24), this also contributes to the richness of the environment.

Although mudflats within the Bay lack mangroves, salt-marsh meadows and seagrass, the occurrence of such rich a fauna suggests that there must be an alternative source of primary production supporting food webs. Microbial mats cover vast surface area of the mudflats, and have a high estimated production (standing stock, 14.93 x 10^3mg Chl*a* m^{-2} y^{-1}; production, 190.97g C $m^{-2}y^{-1}$) in comparison to microbial production worldwide (Table 4.12) and other autotrophs within the region (Table 4.13). It accommodates grazing due to its rapid growth rate (6.70 mg Chl*a* m^{-2} d^{-1}). Results of laboratory grazing, gut and faecal analysis (chapter 4) have proven the essential role of mats in mudflats faunal food webs, with nine out of the thirteen species analysed demonstrating signs of mat consumption (5 intertidal and 4 commercially-important subtidal species). Variation in faecal contents in relation to mat components (diatom, cyanophyta) may be related to microbial availability along the intertidal gradient, selectivity in grazing by consumers or the differential assimilation efficiency of the different mat components.

The use of stable carbon isotope analysis, a recent technique used for detecting food webs, has provided scientific evidence that intertidal fauna selectively feed on microbial mats rather than other sources of primary production within the Bay (Figure 5.1). The intermediate or increased $\delta^{13}C$ signature of some primary consumers in relation to that of microbial mats may be attributable to selective grazing/digestion of the second-dominating enriched mat component (cyanophyta), or to the unequal contribution of either of the two dominating components to the diet ('mixing model' of diets). Further, this technique has demonstrated that nutrition derived from mats is passed up the food chain to commercial fish species consumed in the local market (Figure 6.1). Recent isotopic studies (Jones *et al.*, 2002a) have revealed that 14 out of 15 commercial fish species caught subtidally within the Bay have an isotopic signature indicating that their source of nutrition originates from microbial mat consumption. Such species may either be primary consumers feeding directly on the mat, or secondary consumers feeding on herbivorous organisms that graze on the mat.

The study of population dynamics of the two dominant brachyurans, *Tylodiplax indica* and *Ilyoplax stevensi*, reflects signs of habitat deterioration (chapter 3). The low occurrence of *T. indica* at a modified site (TII) suggests that anthropogenic disturbances (physical manipulation of habitat, and sewage discharge) may be affecting larval settlement of this species, since no juveniles were encountered throughout the investigation period. This variation in the *T. indica* population structure at the modified site in comparison to the pristine site (TI) was not seen in the population structure of *I. stevensi*. This may indicate that *T. indica* is more susceptible to environmental pollution and is likely to act as a bio-indicator. The absence of *T. indica* from habitats where it would normally dominate will not only provide indication of environmental stress, but will also affect the food web structure within such habitats, since it is a source of nutrition for many species including the edible crab *Portunus pelagicus* and the commercial fish *Sillago sihama* (Chapter 4).

Wright *et al.* (1988) found that significantly higher numbers and biomass of fish were concentrated in the intertidal zone of the Bay rather than in the subtidal, and postulated the importance of the intertidal zone as a refuge area from subtidal predators and/or as feeding grounds for juveniles. Bishop and Khan (1999) confirmed the use of intertidal mudflats by juvenile shrimp in Kuwait Bay. The intertidal migration of shallow water fish in Kuwait Bay was investigated by Wright *et al.* (1990), who found that some fish underwent tidal migration to the highest high water mark through a horizontal distance of up to 2km shore-wards. The current investigation found juvenile shrimp and fish in intertidal traps (chapter 2), in intertidal water pools, and mat consumption by shrimps has been demonstrated in the laboratory (Al-Mohanna, pers. comm.). These results suggest that the mudflat habitat within Sulaibikhat Bay is extremely rich, with mats supporting its benthic faunal production which supplies the energy requirements of commercial fish and crab, indirectly supporting top consumers such as humans.

Significant differences between a pristine and an impacted site (Table 2.19) in the Bay show that the community structure within the bay can be reduced as a result of perturbation by physical manipulation of the coast, loss of habitat or organic enrichment. Nearly all constructions are along Kuwait Bay, including Sulaibikhat Bay. In recent years the shoreline of Kuwait City has extended 60m into Kuwait Bay, and for a number of years the Municipality of Kuwait City has been considering proposals for further revitalisation of the Sulaibikhat Bay shoreline by construction of a waterfront similar to the 20km Kuwait Waterfront Project established along the entire coast of Kuwait south of Ras Al-Ardh (Abou Seeda and Al-Sarawi, 1990).

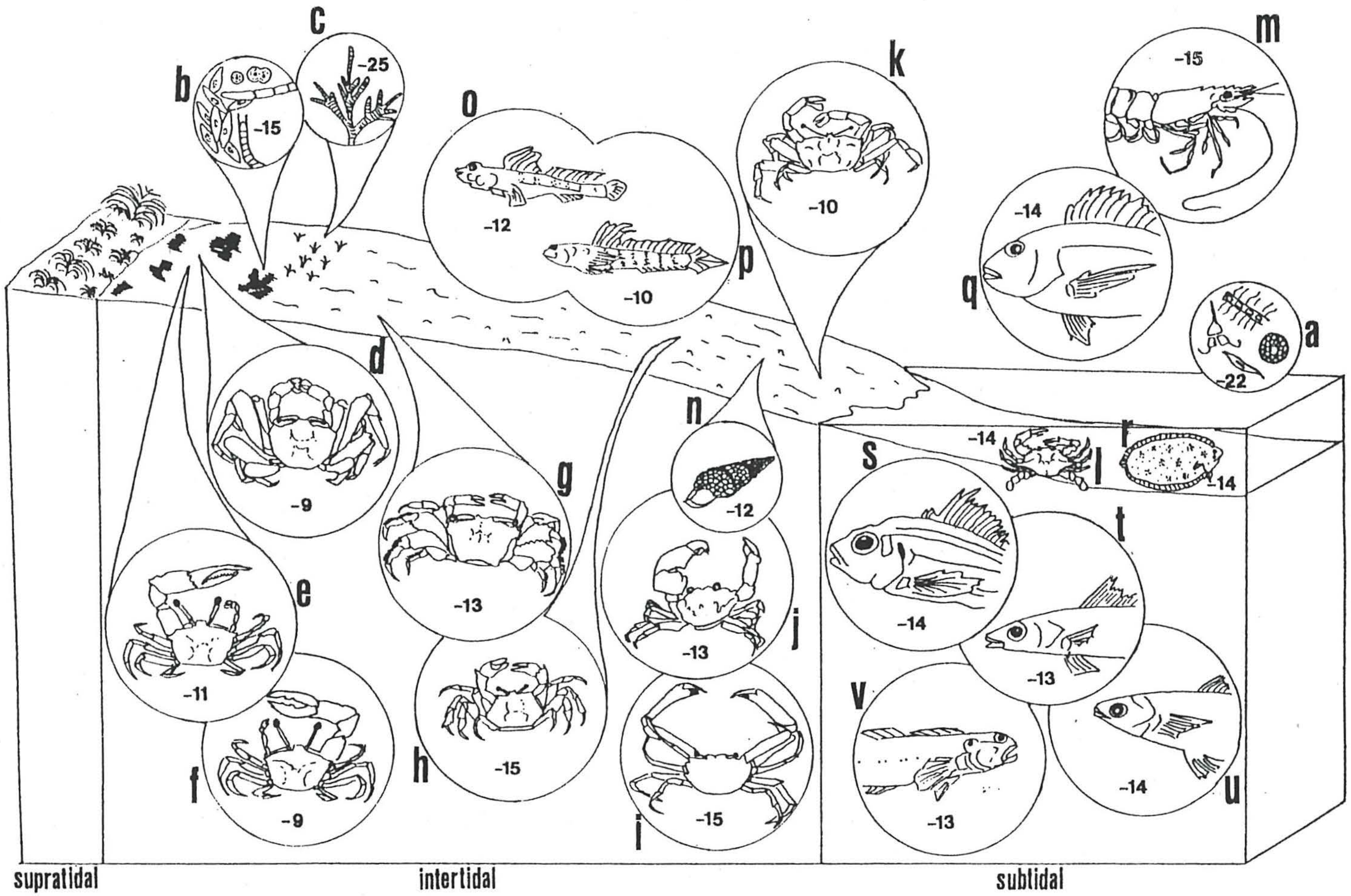

Figure 6.1 schematic distributions of primary producers and consumers along the mudflats of Sulaibikhat Bay, showing the $\delta^{13}C$ signature of each species:

(a) Phytoplankton	**(b)** Microbial mats	**(c)** *S. herbacea*	**(d)** *L. kuwaitense*	**(e)** *U. annulipes albimana*	**(f)** *U. sindensis*
(g) *N. dotilliformis*	**(h)** *T. indica*	**(i)** *M. indica*	**(j)** *E. orientalis*	**(k)** *M. dentipes*	**(l)** *P. pelagicus*
(m) *M. affinis*	**(n)** *C. cingulata*	**(o)** *P. waltoni*	**(p)** *B. boddarti*	**(q)** *A. cuvieri*	**(r)** *S. orientalis*
(s) *R. stridens*	**(t)** *S. sihama*	**(u)** *L. macrolepis*	**(v)** *A. ornatus.*		

Kana (2002) recently reviewed the historical trend of reclaiming coast for sustainable development in the Gulf region, with emphasis on Kuwait, and found that several sites within Sulaibikhat Bay already have many natural constraints. The tidal range and the dominance of mudflats constrain any development plan in the area. Naturally-occurring high-tide beaches tend to be narrow and unsuitable for bathing. Excavation of channels to accommodate boats or provide full tidal-cycle swimming are not feasible, as suspended sediment loads are high and wave action along the shoreline would quickly shoal such channels. Of the 12km of shoreline under consideration for development, perhaps only 15-25% is suitable for commercial development, thus it is unlikely that a commercial developer will have resources to make improvements that do not provide a reasonable return on the investment.

Despite these natural constraints, the unappealing panorama of mudflats and lack of scientific knowledge on such habitats have led to mudflats being treated as wastelands for the discharge of debris, sewage and industrial effluents, and are still viewed as areas for coastal development. These activities have already resulted in the loss of the upper intertidal salt marsh in many areas, and in the modification of the chemical and biological nature of the intertidal mudflat. The loss of these habitats and their associated source of primary production, will lead to the death or migration of the inhabitants such as juvenile shrimp and fish, and contribute to the decline in fish stocks.

Fisheries are important to the economy of Kuwait, and the shrimp fisheries of the Bay are the most valuable in Kuwaiti waters. Catch rates for shrimp declined rapidly from 1980, and although close seasons were introduced from the early 1980's, recruitment still decreased annually (Morgan, 1989). It was suggested that coastal infill might be a possible cause for declining recruitment in addition to over-fishing. Although the loss of these habitats in terms of economic loss to commercial fisheries has not yet been estimated, physical alteration of habitats represents one of the most serious ecological problems not only in Kuwait, but within the whole Gulf region (Price, 1993).

Total annual fish landing in Kuwait (Ministry of Planning, 1996-2000; table 6.1), shows that landings were steady throughout 1996-1999, but declined by 3300t during 2000. During the summer of the following year (August 2001) approximately 2600 tons of fish died in Kuwait Bay. These were mostly mullet which floated on the sea surface and were washed on shore. Investigations by EPA (Environmental Public Authority, Kuwait) and CEFAS (Centre for Environment, Fisheries and Aquaculture Science, UK) concluded that the fish kill was a direct result of a bacterial infection by *Streptococcus agalactiae* (Waldock and Algoët, 2002). While both sea temperature and salinity were within normal ranges, significant discharge of raw sewage had occurred periodically as the capacity of local sewage treatment plants was exceeded. Total organic matter measurements for the sediment revealed localised elevated levels within the area. High values for pH prior to the kill were also reported. Hence, it was suggested that sewage and industrial discharges might have contributed to a deterioration of the quality of the water in the Bay, providing all the necessary nutrients and favourable conditions for the survival and multiplication of the fish pathogen. To date the mullet, a fish species most consumed by locals, has been banned from the fish market, not only for health reasons but as a sustainability procedure to allow the fish to return to a normal standing stock level. The productivity and health of the mudflats remained normal during the period of this evenT (chapter 4).

Table 6.1 Annual fisheries landings (tonnes) derived from total quantities of fish sold in the Retail Fish Market from 1996-2000, (Data supplied by: Ministry of Planning, Central Statistical office, Kuwait)

YEAR **FISHERIES**	**1996**	**1997**	**1998**	**1999**	**2000**
Shrimp	2,209	1,569	1,685	1,244	1,153
Fin Fish	7,475	7,671	7,526	8,092	5,292
Others (crustacea/ mollusca)	1,122	1,179	1,183	1,224	819
Total	10,806	10,419	10,394	10,560	7,264

In addition to local anthropogenic impacts within the Bay represented by highly septic sewage discharges and industrial effluents associated with power and desalination plants, and inputs associated with Shuwaikh port, other regional incidents occurring within the Gulf also contribute additional impact and stress to Kuwait's coastal areas. The last two wars in the Gulf, Iran-Iraq war and Gulf war, have impacted the Gulf ecosystem, as a result of massive oil spill, oil fires, sunken ships, and other military activities such as extensive trenching and fencing of coastal areas. The estimated 6-8 million barrels of oil spilled during the Gulf War in 1990 was the largest in the history of mankind, and the atmospheric and terrestrial pollution resulting from hundreds of burning oil wells was unprecedented. The northern part of the Gulf, including Kuwait, is currently subjected to the consequences of the extensive draining of marshes in the Shatt Al-Arab delta, and the construction of the 3rd river. Habitat alterations on this scale may cause fundamental changes in the Gulf ecosystem, especially in Kuwait's territorial waters. Results of recent research indicate reduced salinity (Al-Yamani *et al.*, 1997) and increase in levels of finer sediments and oil-related pollutants (Al-Ghadban *et al.*, 1998) entering the northern part of Kuwait's territorial waters.

Global climate warming and sea level rise although gradual and significant, are as yet not catastrophic. However, when local, regional and global impacts act together, exceeding the toleration capacity of the ecosystem they will inevitably affect its productivity. While it is not possible to control impacts on a regional or global scale, it is feasible to prevent additional impacts on a local scale in an attempt to maintain sustainability of habitats.

Kuwait has already been ranked seventh in the world in terms of exploitation and environmental damage on its marine environment (Pearce, 1998; Figure 6.2). The southern shoreline of Sulaibikhat Bay, where TII (transect II, modified site) is located, has already been degraded by construction infill, and the discharge of numerous sewage outlets (approx. 19 outlets). Present results from transect I, located within Ashish Al-Doha along the north-western shoreline of the bay, demonstrate that this remains virtually pristine backed by one of the last salt marshes in Kuwait, due to the absence of such disturbances.

Current investigations provide scientific evidence which justifies the conservation of these highly productive mudflats within Sulaibikhat Bay. Habitats within the bay should be surveyed and monitored to identify and conserve unpolluted sites, and to create rehabilitation strategies for degraded sites. By protecting such sites, the economic resources (fisheries) within the bay, biodiversity and benthic production supporting the whole Bay ecosystem may be sustained.

As many abiotic and biotic factors may fluctuate dramatically in time and space within an area such as Sulaibikhat Bay, the results of the present study can only provide an initial indication of the importance of this mudflat system. However, these results do provide an ecological baseline against which future perturbations can be measured. For comprehensive monitoring of the condition of the Bay, long term investigations covering both biological and physiochemical changes are required. Therefore the following is recommended:

1. A more detailed community analysis of the Bay, extending to the lower intertidal levels of mudflats, and to mudflats located further north on the Kuwaiti coast.

2. Identification of other bio-indicator species and their responses to pollution-induced disturbances.

3. Research into the effect of nutrient loading, eutrophication and associated hypoxia on community structure, growth and reproduction of key biota and commercially important species in the Bay.

4. Detailed studies on the contribution of mat productivity to secondary production within the Bay, and quantification of the food web structure for this system.

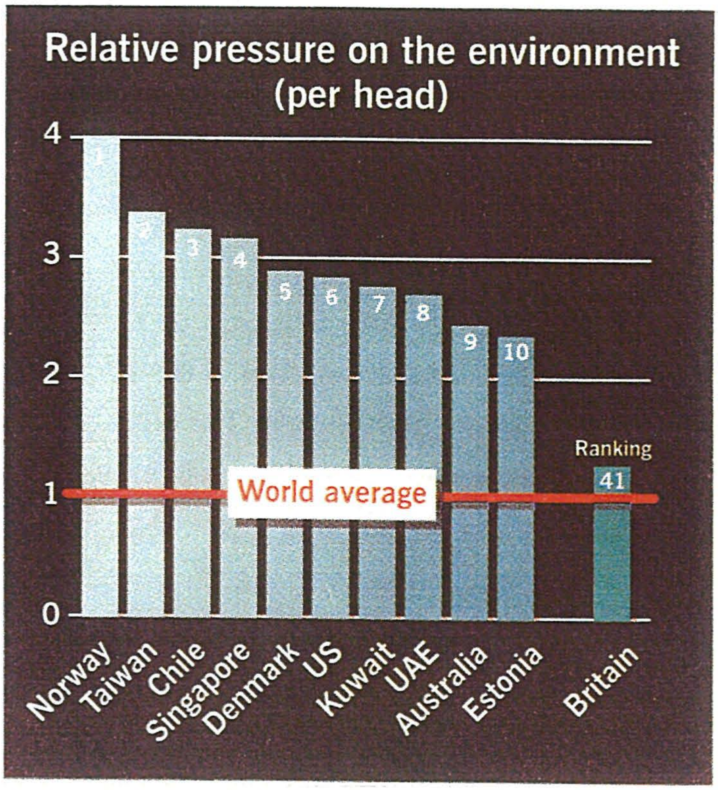

Figure 6.2 Ranking of Kuwait in relation to other countries concerning pressure on the Marine environment (Pearce, 1998).

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APPENDICES

APPENDIX 2.1

Predicted tidal levels during the bimonthly sampling periods at transect I- Ashish Al-Doha (I), and transect II- Sulaibikhat (II) from June 98-June 99.

(I)

		Lowest predicted Tide (LT)				Highest predicted Tide (HT)			
Date	**Arrival Time**	**AM**		**PM**		**AM**		**PM**	
		Time	Level (m)	Time	Level (m)	Time	Level (m)	Time	Level (m)
11/06/98	5:30	6:25	1.53	7:29	0.31	1:23	2.90	11:50	3.58
25/06/98	5:15	6:27	1.50	7:31	0.07	1:12	3.24	11:44	3.81
09/07/98	4:28	5:16	1.71	6:37	1.42	0.23	2.90	10:50	3.60
23/07/98	4:30	5:22	1.70	6:07	0.26	0.18	3.21	10:52	3.68
06/08/98	4:15	3:55	1.84	5:31	0.64	9:40	3.46	11:57	-
20/08/98	4:14	4:14	1.80	5:40	0.50	9:57	3.42	11:59	-
10/09/98	7:20	8:29	0.6	8:55	0.6	2:03	3.67	2:31	3.50
24/09/98	8:20	8:07	0.84	8:14	1.02	1:37	3.35	2:03	3.15
08/10/98	7:50	7:33	0.25	7:52	0.65	0:50	3.76	1:43	3.50
22/10/98	7:45	7:16	0.60	7:16	1.15	0:29	3.37	1:25	3.05
05/11/98	8:10	6:35	0.10	6:46	0.86	-	-	12:55	3.37
18/11/98	8:10	5:53	0.68	5:45	1.34	12:08	2.89	11:25	3.36
03/12/98	7:30	5:37	0.20	5:35	1.17	12:05	3.13	11:05	3.80
17/12/98	8:10	5:35	0.63	4:59	1.60	11:57	2.73	11:38	3.33
14/01/99	13:35	4:24	0.92	3:14	2.79	10:50	2.46	9:12	3.17
28/01/99	13:15	3:10	0.77	2:35	1.68	9:59	2.58	8:16	3.40
11/02/99	11:25	3:42	0.99	2;22	1.89	8:57	2.22	7:08	3.04
25/02/99	11:05	1:16	0.83	12:52	1.66	8:22	2.46	6:25	3.28
11/03/99	8:20	11:18	1.60	-	-	6:35	2.26	5:03	3.12
25/03/99	9:45	11:27	1.52	-	-	6:33	2.60	4:50	3.35
08/04/99	8:00	10:03	1.48	11:05	0.86	5:05	2.48	3:33	3.28
22/04/99	8:05	10:18	1.41	11:20	0.42	5:12	2.89	3:33	3.50
06/05/99	8:30	9:05	1.50	9:55	9.57	4:07	2.69	2:57	3.42
20/05/99	7:30	9:16	1.39	10:10	0.14	4:05	3.14	2:27	3.69
03/06/99	7:00	8:08	1.61	9:05	0.39	3:16	2.86	1:20	3.53
24/06/99	5:35	2:08	1.47	3:33	1.31	8:40	3.31	9:37	2.62

(II)

		Lowest predicted Tide (LT)				Highest predicted Tide (HT)			
Date	**Arrival Time**	**AM**		**PM**		**AM**		**PM**	
		Time	Level (m)	Time	Level (m)	Time	Level (m)	Time	Level (m)
12/06/98	6:15	7:07	1.54	8:05	0.23	2:05	2.94	12:22	3.63
26/06/98	6:28	7:12	1.51	8:12	0.09	1:59	3.28	12:25	3.77
10/07/98	5:10	6:05	1.66	7:14	0.26	1:05	2.90	11:29	3.67
24/07/98	5:24	6:12	1.63	7:20	0.22	1:01	3.01	11:37	3.68
07/08/98	4:14	4:53	1.74	6:12	0.42	10:31	3.30	-	-
21/08/98	4:32	5:14	1.67	6:25	0.41	10:38	3.58	-	-
11/09/98	7:40	9:16	0.58	9:35	0.58	2:33	3.70	3:25	3.31
25/09/98	8;00	8:35	0.82	8:40	1.12	1:53	3.27	2:42	3.04
09/10/98	7:45	8:16	0.16	8:31	0.83	1:22	3.80	2:35	3.39
23/10/98	8:05	7:46	0.53	7:42	1.21	0:46	3.39	2:03	3.00
06/11/98	8:00	7:22	0.07	7:27	0.95	0:12	3.85	1:46	3.36
19/11/98	8:00	6:27	0.51	6:14	1.36	12:46	2.92	11:44	3.39
04/12/98	8:15	6:27	0.07	6:23	1.19	12:57	3.23	11:42	3.85
18/12/98	8;05	6:12	0.43	5:38	1.58	12:38	2.84	11:07	3.39
15/01/99	1;00	5:12	0.66	4:14	1.78	11:42	2.63	9:55	3.25
29/01/99	1:05	4:27	0.47	3:52	1.72	11:07	2.82	9:25	3.43
12/02/99	10:20	3:42	0.99	2:22	1.89	10:20	2.39	8:14	3.05
26/02/99	10:50	2:53	0.72	2:14	1.82	9:52	2.65	6:46	3.18
12/03/99	8:45	1:07	1.11	12:20	1.81	8:16	2.26	5:59	3.01
26/03/99	9:10	00:55	0.70	12:37	1.77	8:08	2.64	5:55	3.13
09/04/99	7:50	10:50	1.68	-	-	6:16	2.40	4:14	3.16
23/04/99	8:00	11:16	1.65	-	-	6:25	2.84	4:27	3.26
07/05/99	7:30	9:42	1.64	10:38	0.67	4:55	2.64	2:57	3.34
21/05/99	7;10	10:07	1.55	11:03	0.38	5:01	3.11	3:16	3.47
04/06/99	6:50	8:46	1.67	9:40	0.48	3:55	2.85	1:55	3.50
25/06/99	5:30	3:03	1.61	4:33	1.09	9:22	3.34	12:44	2.69

APPENDIX 2.2

Results of physical and chemical parameters measured at transect I- Ashish Al-Doha **(I)**, and at transect II- Sulaibikhat **(II)** during the bi-monthly sampling periods, from June 1998 - June 1999)

(I)

		Temperature (°C)						
Sampling period	Zone	Air	Mud surface (MS)	15cm below MS	25cm below MS	Water pool	Salinity (‰)	pH
11/06/98	ZI	32	29	29	31	20.5	70	7.6
	ZII	32	26	27	28	20	70	7.65
	ZIII	32	22	25	27	20	70	7.69
25/6/98	ZI	30	28	28	31	21	55	7.95
	ZII	30	25	26	27	21	55	7.95
	ZIII	30	22	26	28	21	55	7.95
9/7/98	ZI	28	30	29	30	21	140	7.77
	ZII	28	26	26	27	21	75	7.85
	ZIII	28	26	26	27	20	62	7.9
23/7/98	ZI	31	24	30	31	26	55	7.85
	ZII	31	26	29	30	27	44	7.94
	ZIII	31	29	30	30	29	38	7.8
6/8/98	ZI	33	33	31	32	28	78	7.63
	ZII	33	28	29	30	28	50	7.4
	ZIII	33	26	29	31	27	45	7.62
20/8/98	ZI	33	27.5	31	33	28	58	7.35
	ZII	33	28	31	33	28	49	7.3
	ZIII	33	28	30	32	28	44	7.2
10/09/98	ZI	32	29	27	30	27	48	7.4
	ZII	32	28	27	29	27	46	7.32
	ZIII	32	27	26	29	25	43	7.15
24/09/98	ZI	35	30	29	31	29	63	7.48
	ZII	35	31	28	29	28	58	7.38
	ZIII	35	31	29	30	29	50	7.58
8/10/98	ZI	32	31	29	30	28	52	7.46
	ZII	32	30	28	29	29	50	7.55
	ZIII	32	31	29	30	29	53	7.84
22/10/98	ZI	24	22	20	21	19	85	7.95
	ZII	24	21	19	21	20	82	8.02
	ZIII	24	22	19	21	20	60	8.15
5/11/98	ZI	25	24	22	23	19	65	7.83
	ZII	25	22	20	22	19	65	7.95
	ZIII	25	23	21	22	20	55	8.19
18/11/98	ZI	20	22	19	21	18	68	7.91
	ZII	20	21	17	19	18	65	8.04
	ZIII	20	21	18	21	18	57	8.22

Contd.

3/12/98	ZI	18	18	19	18	16	65	7.83
	ZII	18	17	18	17	15	61	7.98
	ZIII	18	16	18	17	15	55	8.18
17/12/98	ZI	17	18	18	17	16	65	7.88
	ZII	17	18	19	16	15	60	8.06
	ZIII	17	16	15	16	14	52	8.2
14/1/99	ZI	21	21	18	18	20	62	7.93
	ZII	21	21	17	16	19	60	8.03
	ZIII	21	22	16	15	18	54	8.25
28/1/99	ZI	21	22	16	15	22	61	8.14
	ZII	21	21	17	15	22	61	8.32
	ZIII	21	23	17	17	22	55	8.53
11/2/99	ZI	20	21	16	16	21	65	8.11
	ZII	20	21	16	15	20	65	8.33
	ZIII	20	23	15	15	22	55	8.47
25/2/99	ZI	19	22	17	16	21	58	8.08
	ZII	19	23	16	16	22	54	8.41
	ZIII	19	23	15	16	22	51	8.55
11/3/99	ZI	21	22	17	17	22	65	7.98
	ZII	21	24	17	17	22	55	8.43
	ZIII	21	23	16	17	20	55	8.54
25/03/99	ZI	24	25	19	19	26	62	8.07
	ZII	24	25	18	18	24	60	8.41
	ZIII	24	26	18	19	25	58	8.49
8/4/99	ZI	24	25	20	20	22	63	8.13
	ZII	24	25	19	20	21	60	8.46
	ZIII	24	27	19	20	22	55	8.53
22/4/99	ZI	28	28	23	22	25	70	8.08
	ZII	28	27	22	22	25	55	8.39
	ZIII	28	25	21	22	23	52	8.45
6/5/99	ZI	33	34	25	25	25	75	8.24
	ZII	33	32	21	22	25	65	8.44
	ZIII	33	32	21	22	26	58	8.55
20/5/99	ZI	33	32	25	26	29	72	8.17
	ZII	33	29	25	25	27	55	8.44
	ZIII	33	31	25	26	27	56	8.53
3/6/99	ZI	34	31	27	27	29	75	8.25
	ZII	34	30	27	27	28	56	8.43
	ZIII	34	30	27	27	28	58	8.49
24/6/99	ZI	42	36	31	29	28	87	8.23
	ZII	42	34	30	28	28	79	8.41
	ZIII	42	36	32	29	28	70	8.54

(II)

		Temperature (°C)						
Sampling period	Zone	Air	Mud surface (MS)	15cm below MS	25cm below MS	Water pool	Salinity (‰)	pH
12/6/98	ZI	31	20	25	27	21	59	7.87
	ZII	31	20	25	27	20	57	7.90
	ZIII	31	19	24	25	21	57	7.91
26/6/98	ZI	32	26	25	28	20	57	8.10
	ZII	32	25	25	27	20	52	8.11
	ZIII	32	25	25	27	20	57	8.13
10/7/98	ZI	30	19	26	28	18	87	7.78
	ZII	30	20	25	26	17.5	80	7.68
	ZIII	30	20	23	25	17.5	80	7.57
24/7/98	ZI	31	26	28	29	26	46	7.66
	ZII	31	23	28	29	25.	44	7.75
	ZIII	31	23	28	28	25	36	7.78
7/8/98	ZI	34	25	29	31	24	51	7.64
	ZII	34	24	28	30	24	42	7.71
	ZIII	34	24	28	29	25	41	7.72
21/8/98	ZI	34	27	30	32	25	46	7.46
	ZII	34	24	29	32	24	44	7.51
	ZIII	34	24	29	31	25	44	7.54
11/09/98	ZI	33	27	29	30	24	55	7.59
	ZII	33	26	28	29	25	50	7.55
	ZIII	33	25	28	28	26	40	7.62
25/09/98	ZI	35	28	28	29	25	47	7.68
	ZII	35	29	28	28	27	47	7.61
	ZIII	35	30	27	28	28	45	7.7
9/10/98	ZI	31	28	27	28	26	54	8.15
	ZII	31	27	27	28	27	51	7.95
	ZIII	31	29	28	29	28	50	8.35
23/10/98	ZI	23	21	18	19	18	55	8.03
	ZII	23	19	17	20	18	54	8.15
	ZIII	23	20	18	20	18	55	8.41
6/11/98	ZI	22	21	19	20	18	60	7.96
	ZII	22	19	18	19	18	61	8.09
	ZIII	22	21	19	20	18	60	8.35
19/11/98	ZI	19	19	18	19	17	56	8.06
	ZII	19	20	18	19	17	58	8.17
	ZIII	19	19	18	19	17	56	8.42
4/12/98	ZI	16	16	17	18	17	59	8.03
	ZII	16	15	16	17	16	56	8.18
	ZIII	16	15	17	18	15	58	8.38
18/12/98	ZI	16	14	14	15	13	55	8.08
	ZII	16	15	15	16	13	56	8.17
	ZIII	16	14	15	15	12	55	8.42
15/1/99	ZI	19	21	16	16	19	46	8.11
	ZII	19	22	17	16	21	50	8.23
	ZIII	19	21	15	16	19	53	8.41

Contd.

29/1/99	ZI	21	23	17	16	23	50	8.05
	ZII	21	23	16	16	23	55	8.31
	ZIII	21	22	16	16	23	50	8.49
12/2/99	ZI	16	14	15	16	13	52	8.00
	ZII	16	14	14	15	14	53	8.29
	ZIII	16	15	14	16	14	48	8.53
26/2/99	ZI	21	23	18	17	22	50	8.08
	ZII	21	23	17	17	22	50	8.32
	ZIII	21	24	17	17	23	51	8.55
12/3/99	ZI	17	17	17	17	16	36	8.14
	ZII	17	17	18	18	16	35	8.36
	ZIII	17	17	18	18	17	35	8.61
26/3/99	ZI	24	21	18	18	19	58	8.33
	ZII	24	23	18	18	18	55	8.41
	ZIII	24	22	18	18	19	55	8.53
9/4/99	ZI	23	20	18	19	19	54	8.31
	ZII	23	20	17	19	19	55	8.4
	ZIII	23	21	19	19	20	58	8.55
23/4/99	ZI	28	26	23	22	25	55	8.27
	ZII	28	25	22	22	24	52	8.4
	ZIII	28	25	22	22	24	49	8.43
7/5/99	ZI	30	24	22	23	24	57	8.32
	ZII	30	24	23	23	23	55	8.41
	ZIII	30	24	23	23	23	55	8.49
20/5/99	ZI	28	22	25	25	19	67	8.35
	ZII	28	23	23	25	17	70	8.39
	ZIII	28	23	23	23	16	71	8.44
4/6/99	ZI	35	28	27	27	26	55	8.37
	ZII	35	29	27	27	26	58	8.42
	ZIII	35	30	27	27	27	55	8.48
25/6/99	ZI	41	32	29	28	27	70	8.36
	ZII	41	32	28	27	27	71	8.45
	ZIII	41	33	28	27	27	73	8.55

APPENDIX 2.3

Sedimentary characteristics of the 3 zones along both transects (I: Ashish Al-Doha, II: Sulaibikhat) within Sulaibikhat Bay, where grain size is classified according to the Wentworth scale. Values represent mean %weight in 5g of sediment sample.

	Ashish Al-Doha (TI)			
Grain size (μm)	**ZI**	**ZII**	**ZIII**	**Mean of 3 zones**
G (>2000)	0.09 ± 0.06	0.20 ± 0.05	1.16 ± 1.02	0.49 ± 0.34
VCS (2000-1000)	0.85 ± .033	1.36 ± 0.26	1.22 ± 0.59	1.14 ± 0.20
MCS (1000-250)	32.99 ± 7.35	53.25 ± 4.56	66.20 ± 3.95	50.81 ± 5.56
FS (250-63)	13.80 ± 1.77	12.80 ± 1.16	8.75 ± 1.55	11.78 ± 1.08
CS (63-15.6)	24.83 ± 1.75	11.31 ± 1.33	10.54 ± 1.27	15.56 ± 2.43
FSI (15.6-3.9)	14.33 ± 2.90	13.56 ± 2.30	7.46 ± 1.87	11.77 ± 1.63
C (<3.9)	13.11 ± 6.73	7.53 ± 0.73	4.64 ± 2.33	8.49 ± 2.41
Organic matter	4.27 ± 0.64	6.3 ± 0.41	5.60 ± 1.30	5.39 ± 0.59
Calcium carbonate	2.07 ± 0.18	1.53 ± 0.41	0.87 ± 0.24	1.49 ± 0.35

	Sulaibikhat (TII)			
Grain size (μm)	**ZI**	**ZII**	**ZIII**	**Mean of 3 zones**
G (>2000)	1.92 ± 0.21	-	-	0.64 ± 0.33
VCS (2000-1000)	2.75 ± 0.26	-	-	0.92 ± 0.47
MCS (1000-250)	21.25 ± 0.99	23.14 ± 0.35	5.71 ± 0.28	16.70 ± 2.78
FS (250-63)	19.68 ± 0.88	19.68 ± 0.31	10.83 ± 0.42	16.73 ± 1.50
CS (63-15.6)	13.86 ± 0.21	18.31 ± 0.21	24.53 ± 0.62	19.57 ± 1.31
FSI (15.6-3.9)	32.78 ± 0.49	25.75 ± 1.18	44.25 ± 0.75	34.26 ± 2.73
C (<3.9)	5.76 ± 1.36	13.12 ± 1.35	14.67 ± 0.43	12.29 ± 2.08
Organic matter(%)	10.51 ± 0.92	21.98 ± 1.12	3.90 ± 0.49	12.13 ± 5.28
Calcium carbonate	6.72 ± 0.63	7.84 ± 0.42	4.21 ± 0.36	6.26 ± 1.07

APPENDIX 2.4

Abundance of infaunal species (0.05 m^{-2}), obtained in sediment extracts, during the bimonthly sampling period at transect I, Ashish Al-Doha (I) and transect II, Sulaibikhat (II).

1. *Tylodiplax indica*
2. *Ilyoplax stevensi*
3. *Nasima dotilliformis*
4. *Cerithidea cingulata*

1. *Tylodiplax indica*

(I)

	visit	ZIa	ZIb	ZIc	ZIIa	ZIIb	ZIIc	ZIIIa	ZIIIb	ZIIIc
June 1998	**A**	0	0	0	44	35	17	30	1	1
	B	0	0	0	11	25	25	22	25	1
July	**A**	0	0	0	0	15	20	26	12	14
	B	0	0	0	0	24	31	18	1	46
August	**A**	0	0	0	0	3	19	51	1	28
	B	0	0	0	0	47	65	23	2	18
September	**A**	0	0	0	71	2	73	8	0	31
	B	0	0	5	0	23	63	5	0	0
October	**A**	0	0	0	7	59	0	2	16	8
	B	0	0	0	22	44	27	19	8	10
November	**A**	0	0	0	30	50	61	10	0	8
	B	0	0	0	61	68	28	14	0	11
December	**A**	0	0	0	106	19	81	3	0	0
	B	0	0	0	25	52	8	0	8	0
January 1999	**A**	0	0	0	25	107	20	20	19	1
	B	0	0	19	66	29	6	15	5	14
February	**A**	0	0	9	26	131	38	43	8	0
	B	0	0	7	100	69	62	3	5	2
March	**A**	0	0	3	35	58	23	4	2	14
	B	0	0	0	54	22	28	1	1	4
April	**A**	0	0	0	31	76	22	13	0	0
	B	0	0	8	50	88	12	3	0	7
May	**A**	0	0	0	43	18	12	0	1	0
	B	0	0	0	33	1	53	29	15	0
June	**A**	0	0	16	42	19	10	1	0	0
	B	0	0	12	17	34	11	1	0	2

(II)

	visit	ZI	ZII	ZIII
June 1998	**A**	0	0	0
	B	0	0	0
July	**A**	0	0	0
	B	0	0	0
August	**A**	5	0	0
	B	0	0	0
September	**A**	0	0	0
	B	0	0	0
October	**A**	12	0	0
	B	0	0	0
November	**A**	0	0	0
	B	2	0	0
December	**A**	2	0	0
	B	0	0	0
January 1999	**A**	3	0	5
	B	2	0	0
February	**A**	0	0	0
	B	4	0	0
March	**A**	0	0	0
	B	0	0	0
April	**A**	5	0	0
	B	16	0	0
May	**A**	9	0	0
	B	22	0	2
June	**A**	6	0	1
	B	0	3	10

2. *Ilyoplax stevensi*

(I)

	visit	ZIa	ZIb	ZIc	ZIIa	ZIIb	ZIIc	ZIIIa	ZIIIb	ZIIIc
June 1998	**A**	0	0	0	4	6	5	6	7	4
	B	0	0	0	3	8	6	1	2	3
July	**A**	0	0	0	0	1	0	3	1	0
	B	0	0	0	3	4	0	5	5	1
August	**A**	0	0	0	0	0	2	4	0	6
	B	0	0	0	0	2	4	6	0	0
September	**A**	0	0	0	4	2	0	1	0	4
	B	0	0	3	2	1	4	0	0	6
October	**A**	0	0	0	3	7	0	0	3	3
	B	0	0	0	0	3	1	1	0	1
November	**A**	0	0	0	0	0	4	0	0	1
	B	0	0	0	4	6	10	1	0	1
December	**A**	0	0	0	4	5	17	7	0	5
	B	0	0	0	0	13	0	0	1	0
January 1999	**A**	0	0	0	7	9	12	18	7	1
	B	0	0	3	14	8	10	5	4	2
February	**A**	0	0	0	9	28	8	2	2	1
	B	0	0	11	12	18	4	5	6	1
March	**A**	0	0	0	14	13	3	0	4	5
	B	0	0	0	13	8	5	0	2	5
April	**A**	0	0	0	8	6	8	2	1	1
	B	0	0	0	13	6	13	0	4	2
May	**A**	0	0	1	5	5	14	4	4	1
	B	0	0	0	0	13	18	1	4	0
June	**A**	0	0	1	8	6	6	8	2	0
	B	0	0	0	1	8	4	0	3	0

(II)

	visit	ZI	ZII	ZIII
June 1998	**A**	9	5	4
	B	1	0	4
July	**A**	0	4	0
	B	2	5	1
August	**A**	2	1	0
	B	4	2	0
September	**A**	0	0	0
	B	6	7	0
October	**A**	3	1	2
	B	0	0	0
November	**A**	6	4	2
	B	14	3	0
December	**A**	18	0	3
	B	0	0	0
January 1999	**A**	16	0	1
	B	18	0	0
February	**A**	12	2	1
	B	8	4	0
March	**A**	15	3	0
	B	0	0	0
April	**A**	6	1	2
	B	15	2	2
May	**A**	9	3	4
	B	11	7	2
June	**A**	15	7	8
	B	6	7	5

3. *Nasima dotilliformis*

(I)

	visit	ZIa	ZIb	ZIc	ZIIa	ZIIb	ZIIc	ZIIIa	ZIIIb	ZIIIc
June 1998	**A**	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0
July	**A**	0	0	0	0	0	0	0	0	0
	B	0	0	0	2	1	0	0	0	0
August	**A**	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0
September	**A**	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0
October	**A**	0	0	0	0	1	0	0	0	0
	B	0	0	0	0	1	0	0	0	0
November	**A**	0	0	0	1	0	0	0	0	0
	B	0	0	0	4	0	0	0	0	0
December	**A**	0	0	0	2	0	0	0	0	0
	B	0	0	2	3	0	0	0	0	0
January 1999	**A**	0	0	0	5	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0
February	**A**	0	0	0	2	0	0	0	0	0
	B	0	0	9	6	0	0	0	0	0
March	**A**	0	0	1	14	2	0	0	0	0
	B	0	0	0	0	1	0	0	0	0
April	**A**	0	0	0	0	3	0	0	0	0
	B	0	0	0	0	0	0	0	0	0
May	**A**	0	0	0	1	0	0	0	0	0
	B	0	0	1	8	0	0	0	0	0
June	**A**	0	0	2	0	0	0	0	0	0
	B	0	0	3	0	0	0	0	0	0

(II)

	visit	ZI	ZII	ZIII
June 1998	**A**	2	1	2
	B	0	0	0
July	**A**	0	1	0
	B	0	0	0
August	**A**	3	0	0
	B	0	0	0
September	**A**	0	0	0
	B	0	0	0
October	**A**	17	0	0
	B	0	0	0
November	**A**	0	0	0
	B	0	0	0
December	**A**	1	0	0
	B	0	0	0
January 1999	**A**	0	3	0
	B	0	0	0
February	**A**	0	0	0
	B	0	0	0
March	**A**	0	0	0
	B	0	0	0
April	**A**	1	0	0
	B	1	0	0
May	**A**	2	0	0
	B	2	4	0
June	**A**	0	0	0
	B	4	6	0

4. *Cerithidea cingulata*

(I)

	visit	ZIa	ZIb	ZIc	ZIIa	ZIIb	ZIIc	ZIIIa	ZIIIb	ZIIIc
June 1998	**A**	0	0	0	0	0	0	1	19	43
	B	0	0	0	0	0	0	30	0	4
July	**A**	0	0	0	0	0	0	0	8	0
	B	0	0	0	0	0	0	0	4	0
August	**A**	0	0	0	0	0	0	3	0	4
	B	0	0	0	0	0	0	0	4	31
September	**A**	0	0	0	0	0	0	50	0	3
	B	0	0	0	0	0	0	22	0	0
October	**A**	0	0	0	0	0	0	14	0	0
	B	0	0	0	0	0	0	0	0	90
November	**A**	0	0	0	0	0	0	0	0	1
	B	0	0	0	0	0	0	9	0	0
December	**A**	0	0	0	0	0	0	26	0	26
	B	0	0	0	0	0	0	65	2	3
January 1999	**A**	0	0	0	0	0	0	0	0	4
	B	0	0	0	0	0	0	0	1	15
February	**A**	0	0	0	0	0	0	1	0	13
	B	0	0	0	0	0	0	2	11	0
March	**A**	0	0	0	0	0	0	4	0	10
	B	0	0	0	0	0	0	6	1	16
April	**A**	0	0	0	0	0	0	1	11	3
	B	0	0	0	0	0	0	7	18	4
May	**A**	0	0	0	0	0	0	23	27	5
	B	0	0	0	0	0	0	0	16	6
June	**A**	0	0	0	0	0	0	16	4	7
	B	0	0	0	0	0	0	84	30	1

APPENDIX 2.5

Abundance of macrofaunal species ($9m^{-2}$), obtained by burrow count, during the bimonthly sampling period at transect I, Ashish Al-Doha (I) and transect II, Sulaibikhat (II).

1. *Leptochryseus kuwaitense*
2. *Boleophthlamus boddarti*
3. *Periophthalmus waltoni*

1. *Leptochryseus kuwaitense*

(I)

	visit	ZIa	ZIb	ZIc
June 1998	**A**	15	18	25
	B	34	53	54
July	**A**	30	36	41
	B	43	51	52
August	**A**	40	65	55
	B	95	99	83
September	**A**	47	43	61
	B	54	49	68
October	**A**	67	55	72
	B	34	49	62
November	**A**	46	52	66
	B	44	51	56
December	**A**	43	48	53
	B	46	51	55
January 1999	**A**	57	44	53
	B	44	53	58
February	**A**	44	52	62
	B	41	49	57
March	**A**	38	50	55
	B	41	55	61
April	**A**	43	55	54
	B	42	53	60
May	**A**	39	47	55
	B	37	46	52
June	**A**	37	49	57
	B	39	54	61

2. Boleophthalmus boddarti

(I)

	visit	ZIa	ZIb	ZIc	ZIIa	ZIIb	ZIIc	ZIIIa	ZIIIb	ZIIIc
June 1998	**A**	0	0	1	6	8	1	13	0	10
	B	0	0	0	2	5	5	15	4	0
July	**A**	0	0	1	4	6	9	5	0	3
	B	0	0	0	6	7	12	13	0	0
August	**A**	0	0	0	4	4	7	3	2	4
	B	0	0	4	5	9	12	15	0	14
September	**A**	0	0	0	3	8	9	20	3	5
	B	0	0	0	6	9	8	14	4	8
October	**A**	0	0	0	5	9	7	16	3	11
	B	0	0	0	5	9	10	12	4	10
November	**A**	0	0	0	4	8	11	13	2	9
	B	0	0	0	5	9	9	11	3	8
December	**A**	0	0	0	4	9	10	13	1	9
	B	0	0	0	4	9	9	11	2	8
January 1999	**A**	0	0	0	3	5	9	12	0	9
	B	0	0	0	3	6	6	13	0	8
February	**A**	0	0	0	2	4	5	11	0	8
	B	0	0	0	4	4	6	8	0	5
March	**A**	0	0	0	4	5	10	7	0	7
	B	0	0	0	4	6	8	7	0	6
April	**A**	0	0	0	3	6	6	8	0	7
	B	0	0	0	4	5	6	8	0	8
May	**A**	0	0	0	4	4	5	6	0	7
	B	0	0	0	2	6	7	5	0	6
June	**A**	0	0	0	2	5	5	9	0	5
	B	0	0	0	3	4	5	5	0	5

3. *Periophthalmus waltoni*

(I)

	visit	ZIa	ZIb	ZIc	ZIIa	ZIIb	ZIIc	ZIIIa	ZIIIb	ZIIIc
June 1998	**A**	1	3	61	29	10	6	3	3	0
	B	0	1	1	5	23	13	6	6	0
July	**A**	0	2	4	98	28	20	5	5	0
	B	0	1	10	85	25	15	4	6	0
August	**A**	5	16	18	83	39	12	3	3	0
	B	4	5	115	207	18	12	6	3	3
September	**A**	3	6	2	196	20	13	9	2	4
	B	2	8	4	188	21	12	8	2	5
October	**A**	5	12	4	175	27	19	10	0	4
	B	6	14	8	161	21	15	8	1	3
November	**A**	7	17	9	154	19	14	9	0	5
	B	10	21	14	149	17	12	8	1	5
December	**A**	12	18	11	15	18	15	9	0	7
	B	10	16	14	144	16	13	7	0	6
January 1999	**A**	7	14	9	153	17	1	8	4	6
	B	6	18	12	163	14	15	6	5	6
February	**A**	4	15	12	149	17	13	5	3	5
	B	6	16	14	159	20	12	4	2	5
March	**A**	4	17	17	162	19	11	5	0	4
	B	3	13	16	176	21	12	4	3	3
April	**A**	5	12	14	169	19	14	4	0	4
	B	5	12	16	123	18	4	5	0	3
May	**A**	3	10	15	141	19	1	5	0	4
	B	5	12	14	153	21	12	3	0	4
June	**A**	7	13	13	161	19	11	5	0	3
	B	6	14	16	149	23	11	6	1	3

(II)

	visit	ZI	ZII	ZIII
June 1998	**A**	222	195	159
	B	132	129	183
July	**A**	90	72	63
	B	357	195	180
August	**A**	252	93	129
	B	621	477	405
September	**A**	411	261	195
	B	435	279	210
October	**A**	153	318	234
	B	459	345	306
November	**A**	438	333	279
	B	462	348	267
December	**A**	441	327	291
	B	432	330	309
January 1999	**A**	513	402	345
	B	459	405	315
February	**A**	477	393	294
	B	459	381	303
March	**A**	417	342	276
	B	444	348	294
April	**A**	441	339	285
	B	462	357	303
May	**A**	420	342	291
	B	468	357	315
June	**A**	465	369	327
	B	456	369	309

APPENDIX 2.6

Monthly Biomass of key faunal species (g m^{-2}) at transect I, Ashish Al-Doha (I) [TI, *Tylodiplax indica*; IS, *Ilyoplax stevensi*; ND, *Nasima dotilliformis*; CC, *Cerithidea cingulata*; LK, *Leptochryseus* kuwaitense; BB, *Boleophthlamus boddarti*; PW, *Periophthalmus waltoni*].

	TI	IS	ND	CC	LK	BB	PW
June 1998	9.2	4.0	0.0	4.4	1.8	0.92	2.2
July	10.4	2.4	0.5	0.5	2.3	0.9	3.8
August	9.0	2.1	0.0	1.9	3.9	1.2	6.9
September	16.9	3.7	0.0	3.4	2.9	1.2	6.2
October	10.6	2.4	0.3	4.7	3.1	1.4	6.0
November	18.2	3.0	0.0	0.5	2.9	1.2	5.7
December 1999	14.8	4.1	0.3	5.5	2.6	1.2	4.0
January	23.4	11.8	0.3	0.9	2.8	0.9	5.7
February	28.0	7.9	0.4	1.2	2.8	0.7	5.7
March	21.7	7.8	0.4	1.7	2.8	0.9	6.0
April	29.5	9.5	0.3	2.0	2.8	0.7	5.3
May	16.5	10.0	4.5	3.5	2.4	0.7	5.1
June	17.7	6.4	0.0	6.4	2.8	0.7	5.7

APPENDIX 2.7

Monthly Biomass of key faunal species (g m^{-2}) at transect II, Sulaibikhat (II) [TI, *Tylodiplax indica*; IS, *Ilyoplax stevensi*; ND, *Nasima dotilliformis*; CC, *Cerithidea cingulata*; LK, *Leptochryseus* kuwaitense; BB, *Boleophthlamus boddarti*; PW, *Periophthalmus waltoni*].

	TI	IS	ND	PW
June 1998	0.0	2.9	0.3	37.6
July	0.3	1.3	0.0	35.1
August	0.0	1.3	0.3	73.0
September	0.0	2.5	0.0	66.1
October	0.9	2.7	5.3	67.0
November	0.1	4.7	0.0	78.5
December 1999	0.2	5.1	0.5	78.5
January	0.5	4.5	0.6	90.0
February	0.4	3.9	0.0	85.1
March	0.3	2.0	0.0	78.2
April	2.0	5.3	0.5	80.7
May	5.6	5.6	3.0	80.9
June	2.7	8.5	0.8	84.7

APPENDIX 4.1

Predicted tidal levels during experiments I, II, II and IV at KI site

		Lowest predicted Tide (LT)				Highest predicted Tide (HT)			
EXP.	**Sample day**	**AM**		**PM**		**AM**		**PM**	
		Time	Level (m)	Time	Level (m)	Time	Level (m)	Time	Level (m)
	0h	6:08	0.03	5:59	1.19	12:29	3.32	11:33	3.51
I (9/3/01)	24h	6:50	0.04	6:48	0.89	-	-	1:03	3.47
	48h	7:27	0.00	7:35	0.66	12:27	3.54	1:35	3.55
	72h	8:03	0.14	8:18	0.50	1:18	3.51	2:05	3.59
	96h	8:37	0.34	9:01	0.45	2:07	3.40	2:33	3.59
	120h	9:10	0.61	9:46	0.48	2:55	3.22	2:59	3.55
II (3/10/01)	0h	6:31	1.06	6:57	0.77	12:27	3.33	12:27	3.22
	24h	7:03	0.88	7:13	0.82	12:44	3.36	1:05	3.21
	48h	7:35	0.73	7:52	0.92	1:03	3.40	1:44	3.14
	72h	8:07	0.64	8:22	1.06	1:22	3.47	2:25	3.03
	96h	8:40	0.59	8:52	1.24	1:42	3.54	3:10	2.88
	120h	9:18	0.60	9:27	1.45	2:07	3.60	4:03	2.70
III (16/3/02)	0-6h	7:48	0.48	7:52	0.98	1:05	3.08	1:44	3.25
IV (29/5/02)	0-3h	7:35	1.52	8:38	0.20	2:25	3.10	12:44	3.75

APPENDIX 4.2

Diatom count versus concentration of different chlorophyll pigments (a, b & c)

Sample	Wave length measurements using spectrophotometer (nm 1ml^{-1})				Mean Chlorophyll concentration (µg 5ml^{-1})			Diatom count (5ml^{-1})
	W750	W663	W645	W630	CHL*a*	CHL*b*	CHL*c*	cell number x 10^6
A	0.001	0.067	0.018	0.014	**4.24**	**0.245**	**0.615**	17.6
	0.001	0.08	0.021	0.017				
	0.001	0.085	0.022	0.018				
B	0	0.031	0.008	0.006	**2.39**	**0.15**	**0.345**	5.15
	0.001	0.044	0.012	0.01				
	0.002	0.057	0.016	0.013				
C	0.001	0.066	0.016	0.014	**4.265**	**0.035**	**0.765**	17.9
	0.001	0.089	0.021	0.019				
	0.001	0.077	0.018	0.016				
D	0	0.047	0.011	0.01	**2.975**	**0.075**	**0.57**	10.6
	0.001	0.055	0.014	0.012				
	0.001	0.06	0.015	0.013				
E	0.001	0.052	0.013	0.012	**2.34**	**0.055**	**0.54**	7.55
	0.001	0.034	0.009	0.008				
	0.001	0.043	0.011	0.01				
F	0.001	0.023	0.006	0.005	**2.09**	**0.125**	**0.41**	7.45
	0.001	0.038	0.011	0.009				
	0.002	0.056	0.016	0.014				
G	0	0.024	0.006	0.005	**1.63**	**0.08**	**0.275**	5.45
	0	0.029	0.007	0.006				
	0	0.035	0.009	0.007				
H	0	0.027	0.006	0.005	**2.03**	**0.03**	**0.275**	8.5
	-0.001	0.037	0.008	0.007				
	0	0.044	0.01	0.008				

Continued…..

Sample	Wave length measurements using spectrophotometer (nm 1ml^{-1})				Mean Chlorophyll concentration (µg 5ml^{-1})			Diatom count (5ml^{-1})
	W750	W663	W645	W630	CHL*a*	CHL*b*	CHL*c*	cell number x 10^{6}
I	-0.002	0.038	0.007	0.005	**2.555**	**0**	**0.1**	5.9
	-0.002	0.046	0.008	0.006				
	-0.002	0.047	0.008	0.006				
J	-0.001	0.015	0.003	0.002	**1.175**	**0**	**0.16**	4.15
	-0.001	0.019	0.003	0.003				
	-0.001	0.026	0.005	0.004				
K	0	0.028	0.006	0.005	**2.295**	**0**	**0.28**	6.65
	-0.001	0.037	0.007	0.006				
	-0.002	0.055	0.011	0.009				
L	-0.002	0.015	0.003	0.002	**1.165**	**0.065**	**0.2**	4.9
	-0.001	0.02	0.004	0.003				
	-0.002	0.023	0.004	0.003				
M	-0.001	0.025	0.005	0.004	**1.54**	**0.05**	**0.28**	3.6
	-0.002	0.026	0.005	0.004				
	-0.002	0.027	0.005	0.004				
N	-0.001	0.017	0.003	0.002	**1.265**	**0.04**	**0.065**	3.2
	-0.002	0.022	0.004	0.003				
	-0.001	0.025	0.005	0.003				
O	-0.001	0.048	0.011	0.009	**3.345**	**0.1**	**0.535**	9.7
	-0.001	0.063	0.014	0.012				
	-0.001	0.066	0.015	0.012				
P	-0.001	0.061	0.014	0.012	**4.23**	**0.175**	**0.765**	19.85
	0	0.081	0.02	0.017				
	0	0.085	0.021	0.017				

APPENDIX 4.3

Wave length measurements and concentration of chlorophyll '*a*' for replicate samples obtained from exclusions without *Cerithidea* (WC) and exclusions with *Cerithidea* (C during the 5-day sampling period (EXP I)

WC: exclusions without *Cerithidea*

24HR

REP I	W750	W663	W645	W630	CHLA
A	0.001	0.035	0.01	0.008	0.37702
	0.001	0.053	0.014	0.011	0.5782
	0.002	0.078	0.021	0.017	0.8451
B	0.002	0.06	0.017	0.013	0.64382
	0.002	0.061	0.017	0.013	0.65546
	0.002	0.068	0.019	0.015	0.73282
C	0.001	0.059	0.016	0.013	0.64392
	0.002	0.074	0.02	0.016	0.8006
	0.001	0.075	0.02	0.016	0.82182
REP II	W750	W663	W645	W630	CHLA
A	0	0.045	0.012	0.009	0.49878
	0.001	0.058	0.015	0.012	0.63434
	0.001	0.061	0.016	0.013	0.6672
B	0.001	0.05	0.014	0.011	0.54328
	0.001	0.057	0.015	0.012	0.6227
	0.001	0.058	0.015	0.012	0.63434
C	0	0.044	0.012	0.009	0.48714
	0	0.058	0.015	0.012	0.64392
	0.001	0.06	0.016	0.012	0.65546
REP III	W750	W663	W645	W630	CHLA
A	0.001	0.041	0.011	0.009	0.4448
	0.001	0.046	0.013	0.01	0.49878
	0.001	0.047	0.013	0.01	0.51042
B	0.001	0.044	0.012	0.009	0.47756
	0.001	0.052	0.014	0.011	0.56656
	0.001	0.053	0.014	0.011	0.5782
C	0	0.053	0.014	0.01	0.58768
	0.001	0.077	0.02	0.015	0.845
	0.001	0.079	0.02	0.016	0.86838

48HR

REP I	W750	W663	W645	W630	CHLA
A	0.001	0.059	0.016	0.013	0.64392
	0.001	0.065	0.017	0.014	0.7117
	0.001	0.066	0.018	0.014	0.72118
B	0.001	0.051	0.014	0.011	0.55492
	0.001	0.053	0.015	0.011	0.57604
	0	0.053	0.014	0.011	0.58778
C	0.003	0.06	0.018	0.015	0.63228
	0.003	0.066	0.02	0.016	0.6979
	0.004	0.067	0.02	0.017	0.70006
REP II	W750	W663	W645	W630	CHLA
A	0.001	0.068	0.018	0.014	0.74446
	0.002	0.069	0.019	0.015	0.74446
	0.001	0.068	0.018	0.014	0.74446
B	0.001	0.09	0.024	0.018	0.98798
	0.001	0.1	0.027	0.02	1.0981
	0.001	0.102	0.027	0.021	1.12148
C	0.002	0.074	0.021	0.016	0.79844
	0.002	0.077	0.022	0.017	0.8313
	0.002	0.077	0.022	0.017	0.8313
REP III	W750	W663	W645	W630	CHLA
A	0	0.063	0.016	0.013	0.70006
	0	0.071	0.019	0.015	0.7869
	0.001	0.071	0.019	0.015	0.77732
B	0.001	0.06	0.017	0.013	0.6534
	0.001	0.062	0.017	0.013	0.67668
	0.001	0.062	0.017	0.013	0.67668
C	0	0.038	0.01	0.008	0.42152
	0	0.054	0.015	0.012	0.59736
	0.001	0.058	0.016	0.012	0.63218

72 HR

REP I	W750	W663	W645	W630	CHLA
A	0	0.052	0.012	0.009	0.58026
	0	0.066	0.016	0.012	0.73488
	0	0.067	0.016	0.012	0.74652
B	0	0.041	0.01	0.007	0.45634
	0	0.056	0.014	0.011	0.6227
	0	0.058	0.015	0.011	0.64382
C	-0.001	0.048	0.011	0.008	0.54534
	-0.001	0.061	0.015	0.011	0.68832
	0	0.066	0.016	0.012	0.73488

REP II	W750	W663	W645	W630	CHLA
A	0	0.071	0.017	0.013	0.79102
	0.001	0.08	0.02	0.015	0.87992
	0.001	0.082	0.02	0.016	0.9033
B	0	0.057	0.014	0.01	0.63424
	0	0.07	0.017	0.013	0.77938
	0	0.071	0.018	0.014	0.78896
C	-0.001	0.034	0.008	0.006	0.38866
	0	0.054	0.014	0.01	0.59932
	0.001	0.056	0.015	0.011	0.61096

REP III	W750	W663	W645	W630	CHLA
A	-0.001	0.035	0.008	0.006	0.4003
	0	0.074	0.018	0.014	0.82388
	0	0.081	0.02	0.015	0.90114
B	0	0.055	0.014	0.01	0.61096
	0	0.061	0.015	0.012	0.67884
	0	0.063	0.016	0.012	0.69996
C	-0.001	0.041	0.01	0.007	0.46592
	-0.001	0.053	0.013	0.01	0.59942
	-0.001	0.054	0.014	0.01	0.6089

96HR

REP I	W750	W663	W645	W630	CHLA
A	0.001	0.047	0.012	0.01	0.51258
	0.001	0.056	0.015	0.011	0.61096
	0.001	0.059	0.016	0.012	0.64382
B	0	0.044	0.011	0.009	0.4893
	0	0.053	0.014	0.011	0.58778
	0.001	0.054	0.014	0.011	0.58984
C	0	0.038	0.01	0.007	0.42142
	0	0.046	0.012	0.009	0.51042
	0	0.048	0.013	0.009	0.53154

REP II	W750	W663	W645	W630	CHLA
A	0.001	0.055	0.015	0.012	0.59942
	0.001	0.069	0.019	0.014	0.75394
	0.001	0.072	0.02	0.015	0.7868
B	0.001	0.041	0.012	0.009	0.44264
	0.002	0.047	0.014	0.011	0.49878
	0.002	0.048	0.014	0.011	0.51042
C	0.003	0.048	0.015	0.012	0.49878
	0.003	0.069	0.022	0.018	0.7287
	0.003	0.072	0.023	0.019	0.76156

REP III	W750	W663	W645	W630	CHLA
A	0	0.041	0.011	0.008	0.45428
	0	0.053	0.014	0.011	0.58778
	0.001	0.054	0.014	0.011	0.58984
B	0	0.034	0.009	0.007	0.37702
	0.001	0.056	0.016	0.012	0.6089
	0.001	0.059	0.016	0.013	0.64392
C	0.001	0.053	0.015	0.011	0.57604
	0.001	0.055	0.016	0.012	0.59726
	0.001	0.056	0.016	0.012	0.6089

120HR

REP I	W750	W663	W645	W630	CHLA
A	0	0.052	0.014	0.011	0.57614
	0.001	0.061	0.016	0.013	0.6672
	0.001	0.064	0.017	0.013	0.69996
B	0.001	0.069	0.017	0.013	0.75816
	0.001	0.074	0.018	0.014	0.8143
	0.001	0.076	0.019	0.015	0.83552
C	0	0.051	0.013	0.01	0.56656
	0.001	0.069	0.017	0.014	0.75826
	0.001	0.079	0.02	0.016	0.86838
REP II	W750	W663	W645	W630	CHLA
A	-0.001	0.021	0.005	0.004	0.24362
	0	0.037	0.01	0.008	0.40988
	0	0.045	0.013	0.01	0.49672
B	0	0.034	0.009	0.007	0.37702
	0	0.046	0.012	0.01	0.51052
	0	0.048	0.012	0.01	0.5338
C	-0.001	0.024	0.006	0.005	0.27648
	0	0.034	0.009	0.007	0.37702
	0	0.058	0.016	0.012	0.64176

C: exclusions with *Cerithidea*

24HR

REP I	W750	W663	W645	W630	CHLA
A	0.001	0.04	0.011	0.008	0.43306
	0.001	0.052	0.014	0.011	0.56656
	0.001	0.054	0.014	0.011	0.58984
B	0.001	0.056	0.016	0.012	0.6089
	0.001	0.062	0.018	0.013	0.67452
	0.002	0.063	0.018	0.014	0.67668
C	0	0.043	0.012	0.009	0.4755
	0	0.057	0.016	0.012	0.63012
	0	0.058	0.016	0.012	0.64176
REP II	W750	W663	W645	W630	CHLA
A	0.001	0.065	0.017	0.014	0.7117
	0.001	0.067	0.018	0.014	0.73282
	0.001	0.069	0.018	0.015	0.7562
B	0	0.045	0.012	0.009	0.49878
	0.001	0.049	0.014	0.011	0.53164
	0	0.05	0.014	0.01	0.55276
C	0.001	0.045	0.013	0.01	0.48714
	0.001	0.051	0.014	0.011	0.55492
	0.002	0.053	0.015	0.012	0.56656
REP III	W750	W663	W645	W630	CHLA
A	0	0.045	0.012	0.01	0.49888
	0.001	0.054	0.015	0.012	0.58778
	0.001	0.057	0.016	0.012	0.62054
B	0.005	0.043	0.015	0.013	0.42152
	0.005	0.051	0.019	0.015	0.5062
	0.005	0.052	0.019	0.015	0.51784
C	0	0.043	0.011	0.009	0.47766
	0	0.048	0.013	0.01	0.53164
	0	0.048	0.013	0.01	0.53164

48HR

REP I	W750	W663	W645	W630	CHLA
A	0.001	0.057	0.016	0.012	0.62054
	0.001	0.058	0.016	0.013	0.63228
	0.001	0.059	0.016	0.013	0.64392
B	0	0.046	0.012	0.01	0.51052
	0.001	0.046	0.013	0.01	0.49878
	0	0.046	0.012	0.01	0.51052
C	0	0.047	0.013	0.01	0.52
	0	0.05	0.013	0.01	0.55492
	0	0.05	0.013	0.011	0.55502
REP II	W750	W663	W645	W630	CHLA
A	0	0.039	0.011	0.008	0.431
	0	0.04	0.011	0.008	0.44264
	0	0.04	0.011	0.008	0.44264
B	0	0.054	0.014	0.011	0.59942
	0	0.061	0.016	0.013	0.67678
	0	0.063	0.016	0.013	0.70006
C	0	0.046	0.012	0.009	0.51042
	0.002	0.052	0.015	0.012	0.55492
	0.002	0.053	0.015	0.012	0.56656
REP III	W750	W663	W645	W630	CHLA
A	0.001	0.059	0.016	0.012	0.64382
	0.001	0.065	0.018	0.013	0.70944
	0.001	0.065	0.017	0.013	0.7116
B	0.003	0.048	0.015	0.013	0.49888
	0.004	0.046	0.015	0.013	0.46602
	0.004	0.046	0.015	0.013	0.46602
C	0.004	0.052	0.017	0.014	0.53164
	0.004	0.058	0.019	0.015	0.59726
	0.004	0.06	0.019	0.016	0.62064

72HR

REP I	W750	W663	W645	W630	CHLA
A	0.002	0.033	0.009	0.007	0.34622
	0.002	0.052	0.014	0.011	0.55698
	0.003	0.075	0.021	0.017	0.8006
B	0.001	0.051	0.013	0.011	0.55708
	0.002	0.065	0.017	0.014	0.70212
	0.002	0.067	0.018	0.014	0.72324
C	0.001	0.052	0.013	0.011	0.56872
	0.001	0.057	0.015	0.012	0.6227
	0.002	0.058	0.015	0.012	0.62476
REP II	W750	W663	W645	W630	CHLA
A	0	0.037	0.009	0.007	0.41194
	0	0.048	0.012	0.009	0.5337
	0	0.049	0.012	0.009	0.54534
B	0	0.038	0.009	0.007	0.42358
	0	0.062	0.015	0.012	0.69048
	0	0.066	0.016	0.013	0.73498
C	0	0.05	0.012	0.009	0.55698
	0	0.05	0.012	0.009	0.55698
	0	0.05	0.012	0.009	0.55698
REP III	W750	W663	W645	W630	CHLA
A	0	0.057	0.014	0.01	0.63424
	0.001	0.073	0.018	0.014	0.80266
	0.001	0.076	0.019	0.014	0.83542
B	-0.003	0.059	0.012	0.009	0.69048
	0	0.066	0.017	0.013	0.73282
	0.001	0.067	0.017	0.013	0.73488
C	0	0.063	0.015	0.011	0.70202
	0	0.08	0.019	0.015	0.89166
	0	0.082	0.02	0.015	0.91278

96HR

REP I	W750	W663	W645	W630	CHLA
A	0.001	0.045	0.011	0.009	0.49136
	0.001	0.061	0.015	0.013	0.66936
	0.001	0.07	0.018	0.015	0.76784
B	0.001	0.058	0.015	0.012	0.63434
	0.001	0.06	0.015	0.012	0.65762
	0.001	0.06	0.015	0.012	0.65762
C	0	0.05	0.012	0.01	0.55708
	0	0.053	0.013	0.01	0.58984
	0.001	0.059	0.014	0.011	0.64804
REP II	W750	W663	W645	W630	CHLA
A	0	0.029	0.007	0.006	0.32304
	0.001	0.048	0.013	0.011	0.52216
	0.002	0.051	0.014	0.011	0.54534
B	0.001	0.043	0.011	0.009	0.46808
	0.001	0.048	0.013	0.01	0.52206
	0.002	0.049	0.013	0.011	0.52422
C	0	0.035	0.009	0.007	0.38866
	0	0.047	0.012	0.009	0.52206
	0.001	0.048	0.013	0.01	0.52206
REP III	W750	W663	W645	W630	CHLA
A	0.001	0.057	0.015	0.012	0.6227
	0	0.056	0.015	0.012	0.62064
	0.001	0.057	0.015	0.012	0.6227
B	0.001	0.039	0.011	0.008	0.42142
	0.001	0.051	0.014	0.011	0.55492
	0.001	0.052	0.014	0.011	0.56656
C	0.001	0.037	0.011	0.008	0.39814
	0.002	0.047	0.013	0.01	0.50084
	0.002	0.049	0.014	0.011	0.52206

120HR

REP I	W750	W663	W645	W630	CHLA
A	0.001	0.032	0.009	0.007	0.34416
	0.001	0.046	0.013	0.01	0.49878
	0.001	0.049	0.014	0.011	0.53164
B	0	0.032	0.008	0.006	0.3558
	0	0.039	0.01	0.008	0.43316
	0	0.049	0.012	0.01	0.54544
C	0	0.038	0.009	0.007	0.42358
	0	0.047	0.012	0.009	0.52206
	0	0.047	0.012	0.009	0.52206
REP II	W750	W663	W645	W630	CHLA
A	-0.001	0.046	0.012	0.009	0.52
	0	0.044	0.011	0.008	0.4892
	-0.001	0.043	0.011	0.008	0.48714
B	-0.001	0.031	0.007	0.005	0.3558
	-0.001	0.035	0.008	0.006	0.4003
	-0.001	0.039	0.01	0.007	0.44264
C	0	0.036	0.009	0.007	0.4003
	0	0.042	0.011	0.008	0.46592
	0	0.046	0.012	0.009	0.51042

APPENDIX 4.4

Wave length measurements for determination of chlorophyll '*a*' concentrations for replicate samples obtained from the 3 zones along KI site, during the 5-day sampling period (EXP II)

BEFORE SCRAPPING (0hr*)

ZONE I	W750	W663	W645	W630
A	0.002	0.018	0.006	0.006
	0.003	0.023	0.008	0.007
	0.003	0.023	0.008	0.007
B	0.001	0.028	0.008	0.006
	0.001	0.033	0.009	0.007
	0.002	0.034	0.009	0.008
C	0.001	0.02	0.006	0.005
	0.001	0.025	0.007	0.006
	0.001	0.027	0.007	0.006
D	0.003	0.024	0.008	0.007
	0.003	0.029	0.009	0.008
	0.004	0.029	0.01	0.008
E	0.001	0.022	0.006	0.005
	0.002	0.027	0.008	0.006
	0.001	0.027	0.008	0.006
F	0.001	0.032	0.009	0.007
	0.001	0.037	0.01	0.008
	0.002	0.038	0.011	0.008

ZONE II	W750	W663	W645	W630
A	0.002	0.02	0.007	0.006
	0.002	0.02	0.007	0.006
	0.002	0.02	0.007	0.006
B	0.001	0.014	0.005	0.004
	0.001	0.017	0.006	0.005
	0.001	0.021	0.007	0.006
C	0.001	0.009	0.004	0.003
	0.001	0.012	0.004	0.003
	0.001	0.013	0.005	0.004
D	0.001	0.021	0.006	0.005
	0.001	0.021	0.007	0.005
	0.001	0.022	0.007	0.005
E	0.001	0.015	0.005	0.005
	0.001	0.018	0.006	0.005
	0.001	0.019	0.006	0.005
F	0	0.014	0.005	0.004
	0.001	0.023	0.007	0.006
	0.001	0.026	0.008	0.006

ZONE III	W750	W663	W645	W630
A	0.001	0.016	0.005	0.005
	0.001	0.02	0.007	0.005
	0.001	0.022	0.007	0.006
B	0.001	0.008	0.003	0.002
	0	0.01	0.004	0.003
	0	0.013	0.005	0.004
C	0	0.006	0.002	0.002
	0	0.007	0.002	0.002
	0	0.007	0.003	0.002
D	0	0.011	0.003	0.002
	0	0.013	0.004	0.003
	0	0.015	0.004	0.003
E	0	0.015	0.004	0.003
	0	0.015	0.004	0.003
	0	0.014	0.004	0.003
F	0	0.017	0.005	0.004
	0	0.02	0.005	0.004
	0	0.022	0.006	0.005

AFTER SCRAPING (0hr)

ZONE I	W750	W663	W645	W630
A	0.001	0.003	0.002	0.002
	0.002	0.006	0.004	0.004
	0.002	0.006	0.004	0.004
B	0	0.006	0.002	0.001
	0	0.007	0.002	0.001
	0	0.007	0.003	0.002
C	0.003	0.015	0.007	0.005
	0.004	0.016	0.008	0.006
	0.004	0.017	0.007	0.006
D	0.001	0.004	0.003	0.002
	0.001	0.004	0.003	0.002
	0.001	0.004	0.003	0.002
E	0	0.01	0.003	0.002
	0.001	0.011	0.005	0.003
	0.001	0.013	0.005	0.004
F	0.004	0.02	0.009	0.008
	0.004	0.021	0.01	0.008
	0.005	0.022	0.01	0.009

ZONE II	W750	W663	W645	W630
A	0.001	0.008	0.004	0.004
	0.001	0.01	0.005	0.005
	0.002	0.014	0.007	0.006
B	0.002	0.012	0.006	0.005
	0.002	0.012	0.006	0.005
	0.002	0.012	0.006	0.005
C	0.002	0.01	0.006	0.005
	0.002	0.011	0.006	0.005
	0.002	0.01	0.006	0.005
D	0.001	0.007	0.004	0.003
	0.001	0.007	0.004	0.003
	0.001	0.008	0.004	0.003
E	0.002	0.009	0.005	0.004
	0.001	0.009	0.005	0.004
	0.001	0.009	0.005	0.004
F	0.002	0.014	0.006	0.005
	0.002	0.014	0.006	0.005
	0.002	0.016	0.007	0.006

ZONE III	W750	W663	W645	W630
A	0.001	0.005	0.003	0.002
	0.001	0.004	0.003	0.002
	0.001	0.005	0.003	0.003
B	0.001	0.007	0.004	0.003
	0.001	0.006	0.004	0.003
	0.001	0.007	0.004	0.003
C	0	0.002	0.001	0.001
	0	0.004	0.002	0.001
	0	0.009	0.004	0.003
D	0	0.006	0.003	0.002
	0	0.006	0.003	0.002
	0	0.006	0.003	0.002
E	0	0.005	0.003	0.002
	0	0.006	0.003	0.002
	0.001	0.007	0.003	0.003
F	0.002	0.01	0.006	0.005
	0.002	0.01	0.006	0.005
	0.002	0.01	0.006	0.005

AFTER 24HR

ZONE I	W750	W663	W645	W630
A	-0.001	0.059	0.014	0.01
	-0.001	0.081	0.019	0.014
	-0.001	0.1	0.024	0.018
B	-0.001	0.034	0.008	0.006
	-0.001	0.054	0.014	0.01
	-0.001	0.062	0.016	0.012
C	-0.001	0.028	0.007	0.005
	0	0.06	0.016	0.011
	0	0.068	0.018	0.013
D	-0.002	0.064	0.014	0.01
	-0.002	0.071	0.016	0.012
	-0.002	0.105	0.024	0.018
E	-0.002	0.06	0.014	0.01
	-0.001	0.077	0.018	0.014
	-0.001	0.114	0.028	0.021
F	-0.002	0.084	0.02	0.015
	-0.002	0.089	0.021	0.016
	-0.002	0.091	0.022	0.016

ZONE II	W750	W663	W645	W630
A	-0.003	0.008	0.001	0
	0	0.009	0.003	0.002
	0	0.009	0.003	0.002
B	-0.002	0.01	0.002	0
	-0.002	0.011	0.002	0
	-0.002	0.011	0.002	0.001
C	-0.002	0.006	0.001	0
	-0.003	0.009	0.001	0
	-0.003	0.011	0.002	0
D	-0.002	0.012	0.003	0.001
	-0.002	0.014	0.003	0.002
	-0.002	0.014	0.003	0.002
E	-0.002	0.009	0.002	0.001
	-0.001	0.013	0.003	0.002
	-0.001	0.013	0.003	0.002
F	-0.002	0.008	0.001	0.001
	-0.002	0.011	0.003	0.002
	-0.001	0.013	0.003	0.002

ZONE III	W750	W663	W645	W630
A	-0.002	0.006	0.001	0
	-0.002	0.007	0.001	0.001
	-0.002	0.008	0.002	0.001
B	0	0.006	0.002	0.002
	0	0.007	0.003	0.002
	0	0.009	0.004	0.003
C	-0.002	0.004	0.001	0
	-0.002	0.004	0	-0.001
	-0.002	0.014	0.003	0.002
D	-0.002	0.006	0.001	0
	-0.002	0.007	0.001	0
	-0.001	0.009	0.002	0.001
E	-0.002	0.006	0.001	0
	-0.002	0.007	0.001	0
	-0.002	0.007	0.001	0
F	-0.001	0.004	0.001	0
	0	0.009	0.004	0.002
	0.001	0.012	0.005	0.004

AFTER 48HR

ZONE I	W750	W663	W645	W630
A	0.003	0.064	0.019	0.015
	0.004	0.077	0.022	0.017
	0.004	0.077	0.022	0.017
B	0.003	0.049	0.015	0.011
	0.003	0.068	0.02	0.015
	0.003	0.073	0.021	0.016
C	0.002	0.034	0.01	0.008
	0.004	0.06	0.018	0.015
	0.005	0.072	0.022	0.018
D	0.001	0.055	0.015	0.011
	0.002	0.065	0.018	0.013
	0.002	0.079	0.021	0.016
E	0.001	0.025	0.006	0.005
	0.002	0.043	0.012	0.009
	0.003	0.073	0.02	0.016
F	0.002	0.053	0.015	0.011
	0.002	0.083	0.022	0.017
	0.003	0.098	0.027	0.02

ZONE II	W750	W663	W645	W630
A	0	0.013	0.003	0.002
	0.001	0.017	0.005	0.004
	0.001	0.02	0.006	0.005
B	-0.001	0.009	0.001	0
	-0.001	0.012	0.002	0.001
	-0.001	0.016	0.003	0.002
C	-0.001	0.009	0.002	0.001
	0	0.013	0.003	0.002
	0	0.019	0.005	0.004
D	-0.001	0.01	0.002	0.001
	0.001	0.021	0.006	0.004
	0.001	0.025	0.008	0.006
E	-0.001	0.015	0.003	0.002
	-0.001	0.017	0.003	0.002
	-0.001	0.018	0.004	0.003
F	-0.001	0.019	0.004	0.003
	-0.003	0.021	0.003	0.001
	-0.003	0.023	0.004	0.002

ZONE III	W750	W663	W645	W630
A	-0.002	0.009	0	0
	-0.002	0.01	0.001	0
	-0.002	0.012	0.002	0.001
B	-0.004	0.004	-0.002	-0.003
	-0.004	0.006	-0.001	-0.002
	-0.003	0.007	-0.001	-0.002
C	-0.003	0.005	-0.001	-0.002
	-0.003	0.008	0	-0.001
	-0.003	0.008	0	-0.001
D	-0.004	0.004	-0.002	-0.003
	-0.003	0.01	0	-0.001
	-0.003	0.019	0.003	0.001
E	-0.003	0.008	-0.001	-0.001
	-0.002	0.012	0.001	0
	-0.002	0.017	0.003	0.001
F	-0.004	0.003	-0.002	-0.003
	-0.003	0.007	-0.001	-0.002
	-0.003	0.009	0	-0.001

72 HR

ZONE I	W750	W663	W645	W630
A	0.001	0.076	0.02	0.016
	0.002	0.124	0.032	0.027
	0.002	0.135	0.035	0.029
B	0.001	0.079	0.02	0.016
	0.001	0.1	0.025	0.021
	0.001	0.109	0.028	0.023
C	0	0.025	0.007	0.005
	0	0.031	0.008	0.006
	0	0.034	0.009	0.007
D	0	0.021	0.005	0.004
	0	0.03	0.008	0.006
	0	0.031	0.008	0.006
E	0.001	0.011	0.003	0.002
	0.001	0.014	0.004	0.003
	0.001	0.015	0.004	0.003
F	-0.001	0.036	0.008	0.006
	-0.001	0.047	0.011	0.008
	0	0.048	0.012	0.009

ZONE II	W750	W663	W645	W630
A	0	0.035	0.009	0.007
	0	0.044	0.011	0.008
	0	0.049	0.013	0.01
B	0	0.051	0.013	0.01
	0.001	0.069	0.018	0.014
	0	0.07	0.018	0.014
C	0	0.037	0.01	0.007
	0	0.048	0.012	0.009
	0	0.051	0.014	0.01
D	0	0.027	0.007	0.006
	0	0.039	0.01	0.008
	0	0.04	0.011	0.008
E	-0.001	0.033	0.008	0.006
	0	0.041	0.011	0.008
	0	0.042	0.011	0.008
F	0	0.045	0.011	0.008
	0	0.05	0.013	0.009
	0	0.051	0.013	0.01

ZONE III	W750	W663	W645	W630
A	0	0.03	0.008	0.006
	0	0.037	0.01	0.008
	0	0.039	0.011	0.008
B	-0.001	0.019	0.005	0.003
	-0.001	0.027	0.007	0.005
	-0.001	0.028	0.007	0.005
C	-0.001	0.029	0.008	0.006
	-0.001	0.026	0.007	0.005
	0	0.027	0.008	0.006
D	0	0.04	0.011	0.008
	-0.001	0.054	0.014	0.01
	-0.001	0.058	0.015	0.011
E	-0.001	0.026	0.007	0.005
	0	0.033	0.009	0.007
	-0.001	0.034	0.009	0.007
F	0.001	0.02	0.005	0.003
	0.003	0.04	0.011	0.008
	0.003	0.045	0.012	0.009

96HR

ZONE I	W750	W663	W645	W630
A	0	0.037	0.009	0.007
	0.001	0.047	0.012	0.01
	0.001	0.051	0.013	0.011
B	0	0.053	0.013	0.01
	0.001	0.066	0.016	0.013
	0.001	0.067	0.017	0.014
C	-0.001	0.049	0.011	0.009
	-0.001	0.051	0.011	0.009
	-0.001	0.052	0.012	0.009
D	-0.002	0.032	0.006	0.004
	-0.002	0.032	0.006	0.004
	-0.002	0.032	0.006	0.004
E	-0.001	0.038	0.008	0.006
	-0.001	0.037	0.008	0.006
	-0.001	0.038	0.008	0.006
F	0.001	0.037	0.01	0.008
	0.003	0.061	0.017	0.014
	0.003	0.071	0.02	0.017

ZONE II	W750	W663	W645	W630
A	-0.003	0.025	0.005	0.003
	0.001	0.045	0.012	0.01
	0.002	0.049	0.014	0.011
B	0.001	0.017	0.005	0.004
	0.002	0.028	0.009	0.007
	0.002	0.033	0.01	0.008
C	-0.003	0.027	0.005	0.003
	-0.003	0.034	0.007	0.005
	-0.003	0.035	0.008	0.005
D	0.003	0.03	0.01	0.009
	0.004	0.043	0.014	0.012
	0.004	0.044	0.014	0.012
E	0.001	0.019	0.005	0.004
	0.001	0.026	0.008	0.006
	0.001	0.029	0.008	0.007
F	0.001	0.032	0.009	0.01
	0.002	0.045	0.013	0.011
	0.002	0.048	0.014	0.01

ZONE III	W750	W663	W645	W630
A	0.002	0.025	0.009	0.007
	0.003	0.034	0.012	0.01
	0.003	0.036	0.012	0.01
B	0.001	0.016	0.005	0.005
	0.002	0.021	0.007	0.006
	0.002	0.023	0.008	0.006
C	0.001	0.019	0.006	0.005
	0.002	0.024	0.008	0.006
	0.002	0.024	0.008	0.006
D	0.002	0.024	0.007	0.006
	0.002	0.027	0.009	0.007
	0.002	0.027	0.009	0.007
E	0.002	0.023	0.008	0.007
	0.002	0.023	0.008	0.006
	0.002	0.023	0.008	0.006
F	0.002	0.018	0.007	0.005
	0.002	0.018	0.007	0.006
	0.002	0.019	0.007	0.006

120HR

ZONE I	W750	W663	W645	W630
A	0.001	0.037	0.011	0.008
	0.001	0.055	0.015	0.012
	0.002	0.068	0.019	0.014
B	0.002	0.06	0.017	0.013
	0.001	0.071	0.019	0.014
	0.001	0.071	0.019	0.014
C	0.001	0.063	0.017	0.013
	0.001	0.068	0.018	0.014
	0.002	0.069	0.019	0.015
D	0.001	0.071	0.019	0.014
	0.001	0.075	0.019	0.015
	0.001	0.076	0.02	0.015
E	0.001	0.036	0.01	0.007
	0.002	0.064	0.017	0.013
	0.001	0.087	0.023	0.017
F	0.001	0.053	0.017	0.011
	0.001	0.072	0.022	0.015
	0.001	0.074	0.023	0.015

ZONE II	W750	W663	W645	W630
A	0.001	0.015	0.005	0.004
	0.001	0.024	0.007	0.006
	0.001	0.029	0.009	0.007
B	0	0.029	0.008	0.006
	0	0.031	0.009	0.007
	0.001	0.031	0.009	0.007
C	0	0.03	0.008	0.006
	0	0.03	0.008	0.006
	0	0.03	0.008	0.006
D	0.001	0.023	0.007	0.005
	0.001	0.03	0.009	0.007
	0.002	0.036	0.011	0.008
E	0.001	0.023	0.007	0.005
	0	0.035	0.01	0.007
	0.001	0.039	0.011	0.008
F	0	0.026	0.007	0.005
	0.001	0.057	0.016	0.012
	0.001	0.07	0.02	0.015

ZONE III	W750	W663	W645	W630
A	0	0.014	0.004	0.003
	0.001	0.02	0.006	0.005
	0.001	0.022	0.007	0.005
B	0.001	0.017	0.005	0.004
	0.001	0.025	0.008	0.006
	0.001	0.027	0.008	0.006
C	0.001	0.012	0.004	0.003
	0.001	0.017	0.006	0.005
	0.001	0.018	0.006	0.005
D	0	0.027	0.007	0.006
	0.001	0.03	0.008	0.006
	0.001	0.03	0.008	0.006
E	0	0.022	0.006	0.005
	0.001	0.028	0.008	0.006
	0.001	0.034	0.01	0.007
F	0	0.028	0.008	0.006
	0	0.027	0.008	0.006
	0.001	0.027	0.008	0.006

APPENDIX 4.5

Wave length measurements for determination of chlorophyll '*a*' concentrations for replicate samples obtained from the 3 zones along KI site, during the 6hr period (emersion & submersion)(EXP III)

0HR: as tide receded

ZONE I	W750	W663	W645	W630
A	0.001	0.014	0.004	0.003
	0.002	0.022	0.007	0.005
	0.002	0.023	0.007	0.006
B	0.002	0.027	0.008	0.006
	0.002	0.028	0.008	0.006
	0.002	0.028	0.008	0.006
C	0.001	0.031	0.008	0.006
	0.001	0.031	0.008	0.006
	0.002	0.031	0.009	0.006
D	0	0.016	0.004	0.006
	0	0.016	0.004	0.003
	0	0.016	0.004	0.003
E	0	0.011	0.003	0.003
	0	0.012	0.003	0.002
	0	0.012	0.003	0.002
F	0.001	0.022	0.006	0.005
	0.001	0.023	0.007	0.005
	0.001	0.023	0.007	0.005

ZONE II	W750	W663	W645	W630
A	-0.001	0.013	0.002	0.001
	-0.001	0.024	0.005	0.004
	0	0.027	0.007	0.005
B	0	0.041	0.01	0.008
	0	0.043	0.011	0.008
	0	0.024	0.006	0.004
C	0	0.025	0.006	0.004
	0	0.027	0.007	0.005
	0	0.027	0.006	0.004
D	0	0.027	0.006	0.004
	0	0.027	0.006	0.004
	-0.001	0.026	0.006	0.004
E	0.002	0.033	0.01	0.008
	0.001	0.035	0.01	0.008
	0.001	0.019	0.006	0.005
F	0.001	0.029	0.008	0.007
	0.001	0.031	0.009	0.007
	0.001	0.031	0.009	0.007

ZONE III	W750	W663	W645	W630
A	0.001	0.01	0.004	0.004
	0.001	0.009	0.003	0.003
	0.001	0.009	0.003	0.003
B	-0.001	0.008	0.002	0.001
	-0.001	0.008	0.002	0.001
	-0.001	0.008	0.002	0.001
C	0	0.028	0.007	0.005
	-0.001	0.032	0.007	0.005
	-0.001	0.033	0.008	0.006
D	-0.001	0.015	0.003	0.002
	-0.001	0.019	0.004	0.003
	-0.001	0.019	0.004	0.003
E	-0.001	0.012	0.002	0.001
	-0.001	0.019	0.004	0.003
	-0.001	0.019	0.004	0.003
F	-0.001	0.015	0.004	0.002
	-0.002	0.015	0.003	0.002
	-0.002	0.015	0.003	0.002

6HR: as 2nd tide receded

ZONE I	W750	W663	W645	W630
A	0.001	0.024	0.006	0.005
	0.001	0.041	0.011	0.009
	0.001	0.045	0.012	0.01
B	0.001	0.022	0.006	0.005
	0.001	0.028	0.008	0.007
	0.002	0.04	0.011	0.009
C	0.001	0.016	0.004	0.004
	0.001	0.027	0.008	0.006
	0.001	0.031	0.008	0.007
D	0.001	0.034	0.009	0.007
	0	0.044	0.011	0.009
	0.001	0.063	0.016	0.013
E	0.001	0.017	0.005	0.004
	0.002	0.025	0.007	0.006
	0	0.031	0.008	0.006
F	0	0.013	0.003	0.002
	0	0.028	0.007	0.006
	0.001	0.033	0.009	0.007

ZONE II	W750	W663	W645	W630
A	0	0.021	0.006	0.005
	0.001	0.038	0.01	0.008
	0.001	0.055	0.014	0.012
B	0	0.023	0.006	0.005
	0.001	0.032	0.009	0.007
	0.001	0.036	0.01	0.008
C	0	0.037	0.009	0.007
	0	0.044	0.011	0.009
	0	0.046	0.011	0.01
D	0	0.034	0.009	0.007
	0.001	0.034	0.009	0.007
	0.001	0.034	0.009	0.007
E	0	0.023	0.006	0.005
	0	0.035	0.009	0.007
	0.001	0.038	0.01	0.008
F	0	0.024	0.006	0.005
	0	0.032	0.008	0.008
	0	0.038	0.01	0.008

ZONE III	W750	W663	W645	W630
A	0.002	0.017	0.006	0.005
	0.003	0.026	0.009	0.008
	0.004	0.035	0.012	0.011
B	0	0.023	0.006	0.005
	0.001	0.029	0.008	0.007
	0.001	0.03	0.008	0.007
C	0.001	0.025	0.007	0.006
	0	0.024	0.006	0.005
	0	0.024	0.007	0.005
D	0	0.023	0.006	0.004
	0	0.034	0.009	0.007
	0	0.037	0.009	0.007
E	0	0.02	0.005	0.004
	0	0.025	0.007	0.005
	0	0.025	0.007	0.006
F	0	0.02	0.006	0.005
	0	0.025	0.007	0.006
	0	0.026	0.007	0.006

APPENDIX 4.6

Wave length measurements for determination of chlorophyll '*a*' concentrations for replicate samples obtained from the 3 zones along KI site, during the 3hr period (emersion)(EXP IV)

0HR: as tide receded

ZONE I	W750	W663	W645	W630
A	0	0.056	0.012	0.01
	-0.001	0.066	0.014	0.011
	-0.001	0.071	0.015	0.012
B	-0.001	0.057	0.012	0.01
	-0.001	0.071	0.015	0.012
	0	0.077	0.017	0.014
C	0	0.055	0.012	0.01
	-0.001	0.067	0.014	0.011
	-0.002	0.068	0.014	0.011
D	-0.001	0.067	0.014	0.011
	-0.002	0.094	0.02	0.016
	-0.002	0.098	0.021	0.017
E	-0.002	0.05	0.01	0.008
	-0.002	0.075	0.016	0.012
	-0.002	0.077	0.016	0.012
F	-0.002	0.059	0.012	0.009
	-0.002	0.083	0.018	0.014
	-0.002	0.085	0.018	0.014

ZONE II	W750	W663	W645	W630
A	-0.001	0.075	0.017	0.014
	-0.001	0.094	0.021	0.016
	-0.001	0.099	0.022	0.017
B	-0.001	0.066	0.014	0.011
	-0.001	0.087	0.019	0.015
	-0.001	0.089	0.019	0.015
C	-0.001	0.081	0.017	0.014
	-0.002	0.098	0.021	0.017
	-0.001	0.098	0.021	0.017
D	-0.001	0.081	0.018	0.014
	-0.001	0.09	0.02	0.016
	-0.001	0.092	0.02	0.016
E	-0.001	0.077	0.017	0.013
	-0.001	0.082	0.018	0.014
	-0.001	0.085	0.018	0.015
F	-0.001	0.09	0.02	0.016
	-0.001	0.095	0.021	0.017
	-0.001	0.096	0.021	0.017

3HR: just before tide coverage

ZONE I	W750	W663	W645	W630
A	0	0.081	0.018	0.015
	-0.001	0.093	0.021	0.017
	0	0.098	0.022	0.018
B	-0.001	0.065	0.014	0.011
	-0.002	0.084	0.018	0.014
	-0.001	0.087	0.019	0.015
C	-0.002	0.048	0.01	0.007
	-0.002	0.071	0.015	0.011
	-0.002	0.073	0.015	0.011
D	0	0.075	0.016	0.013
	0	0.082	0.019	0.015
	0	0.086	0.019	0.015
E	-0.002	0.072	0.015	0.012
	-0.002	0.087	0.018	0.015
	-0.002	0.114	0.024	0.02
F	-0.001	0.093	0.02	0.016
	-0.002	0.112	0.024	0.019
	-0.002	0.117	0.026	0.02

ZONE II	W750	W663	W645	W630
A	-0.002	0.079	0.016	0.013
	-0.002	0.098	0.012	0.016
	-0.002	0.103	0.022	0.017
B	-0.002	0.074	0.015	0.012
	-0.002	0.093	0.019	0.015
	-0.002	0.095	0.02	0.016
C	-0.002	0.118	0.025	0.02
	-0.002	0.123	0.026	0.021
	-0.002	0.13	0.027	0.022
D	-0.002	0.101	0.021	0.016
	-0.002	0.117	0.024	0.019
	-0.002	0.126	0.026	0.021
E	-0.003	0.083	0.016	0.012
	-0.003	0.085	0.017	0.013
	-0.003	0.087	0.019	0.015
F	-0.003	0.101	0.021	0.016
	-0.002	0.101	0.022	0.017
	-0.001	0.102	0.022	0.017