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Fisheries and aspects of the biology of Penaeid shrimps of Bahrain.

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FISHERIES AND ASPECTS OF THE BIOLOGY OF PENAEID SHRIMPS OF BAHRAIN

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SUMMARY

Shrimp are the most valuable fish stock in Bahrain waters, the fishery being based on a single species *P. semisulcatus* which forms about 95 percent of the total landings. In 1993, shrimp landings formed 23.8 percent of the total Bahrain fish landing, which totalled 2,128 tonnes at a first sale value of 5.4 million Bahraini Dinars (1 US$=0.380 BD).

Beside the increased fishing effort, the marine habitat of Bahrain suffers from several sources of pollution. Most evident is dredging and reclamation which have altered most of the coastal areas. Despite the shrimp fishery importance and the development-related stresses on Bahrain coastal environments, there were limited basic data on this valuable stock. The current study aimed to provide as full an understanding as possible of the shrimp fishery of Bahrain.

Several surveys were conducted on the shrimp populations and their environment. A sediment survey was conducted from 9 August to 26 October. From May 1991 to May 1992, a regular sampling programme was initiated to record the physical properties of the sea water at fixed stations in Tubli Bay and off Mina Sulman. Physical properties of sea water were also recorded in the open sea during June 1980, October and December 1991. Plankton collection was conducted mainly through two sampling programmes. The first was conducted in the open sea from September 1991 to January 1992 (excluding November 1991). The second programme was restricted to Tubli Bay; samples were obtained over periods from May 1991 to June 1992 inclusive and from March to May 1993. Two major benthic surveys were completed. The first was conducted from June 1980 to June 1981 using an industrial trawler, covering the whole shrimping ground, except Tubli Bay. A second survey was carried out on the shrimp population in Tubli Bay from May 1991 to June 1993 in three time periods, from May 1991 to June 1992, November 1992 and from April to June 1993.

Based on the above surveys, physical properties of sea water and bottom sediment of the shrimping ground were described. Also the bionomics of the seven penaeid species found in Bahrain waters were determined. Benthic and plankton surveys revealed spawning activities of *P. semisulcatus* restricted to the offshore waters. Also prolonged spawning activity was determined for this species, which most significantly occurred from August to March. *P. semisulcatus* main recruits appeared in the shrimping grounds from April to July, originating from nurseries found within the areas A and E. Two migration patterns were determined for *P. semisulcatus* within Bahrain shrimping grounds throughout a season. The updated information on shrimp fishery generated by the current work provides a basis for identification of areas for further improvement of this fishery. Consequently, the work determines of future investigations necessary for Bahrain shrimp fishery.

CHAPTER ONE: INTRODUCTION

I. Shrimp Fishery of the Arabian Gulf

I.1 The Arabian Gulf

The Arabian Gulf is located between 24° to 30° North and 48° to 56° East (Figure 1). Based on its physical characteristics, the region has been differentiated into north west and south east portions (Brewer et al. 1978, FAO 1981a), separated by a line from the tip of the Qatari peninsula to Dayer on the Iranian coast (Figure 1). The north western portion comprises low energy areas characterized by high sedimentation, while moderate to high energy areas are found in the south east portion (Al-Ghadban et al. 1993).

The Arabian Gulf is enclosed by arid land masses, except for the Strait of Hormuz which opens into the Gulf of Oman. The whole area may be considered as a continental shelf with no adjacent oceanic province (FAO 1981a). Depth along the longitudinal axis increases gradually from the Shatt Al-Arab to the maximum about 116 m in the Strait of Hormuz, and along the transverse axis the depth increases northwards toward the Iranian coast (FAO 1981a).

Annual rainfall is highest in the northern region along the Iranian coast (124 mm per annum). Other source of fresh water include run-off from the Tigris and Euphrates rivers in the north, and numerous small streams along the Iranian coast (FAO 1981a). In general, Gulf water masses circulate in an anti-clockwise direction. Farmer and Ukawa (1986) estimated that 13.5 percent of the Arabian Gulf area supports penaeid shrimps, with *P. semisulcatus* being found in 10.7 percent.

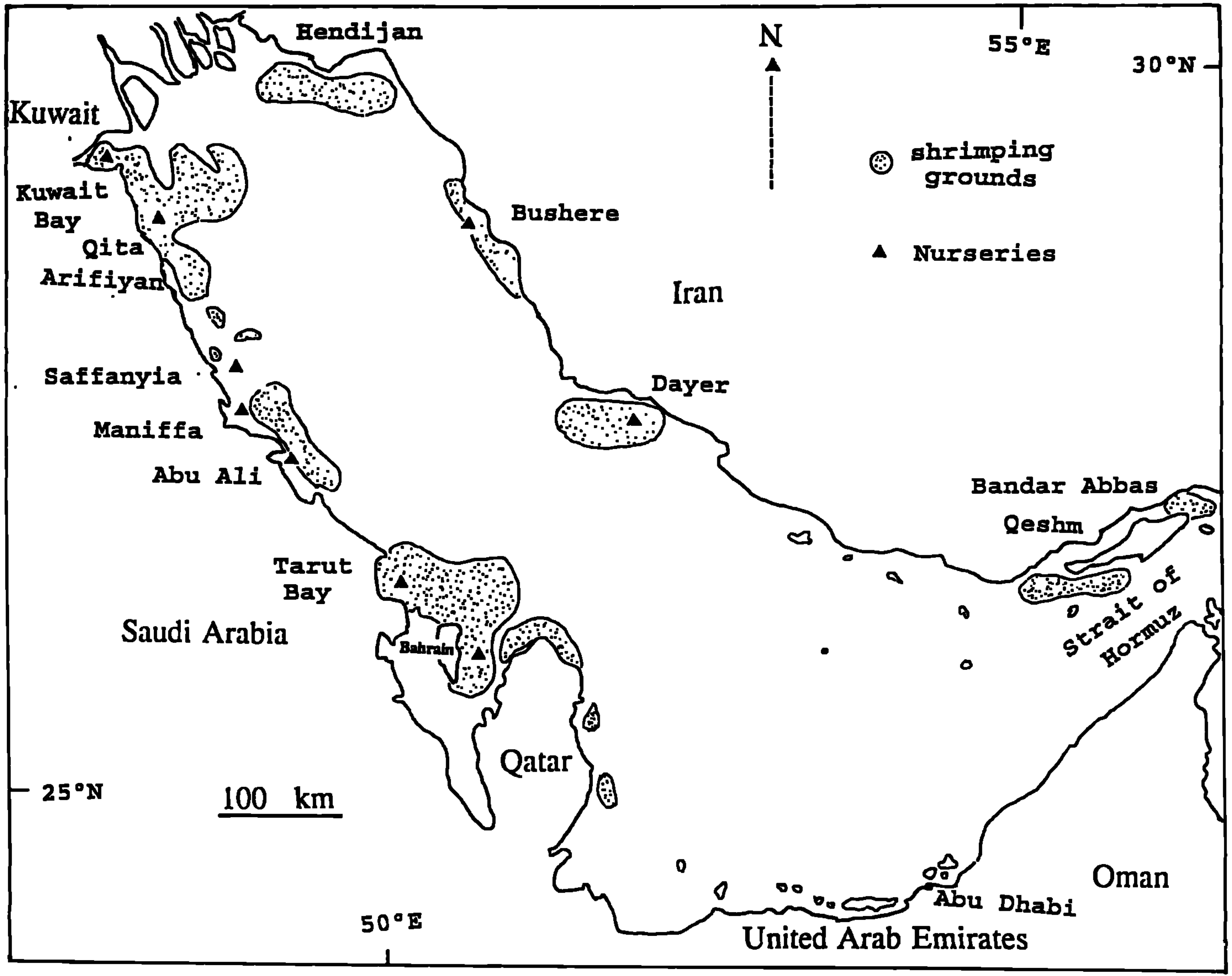

Figure 1. Fishing grounds and nurseries for the main penaeid shrimp *P. semisulcatus* in the Gulf region. (Source: FAO 1982)

I.2 Gulf shrimp fishery

Shrimp fishing in the Arabian Gulf has been practised by the land-based artisanal sector from time immemorial in coastal areas. Even until the mid-twentieth century fishing effort was low but substantial quantities of shrimp were caught, especially during recruitment periods in summer.

Commercial exploitation of the shrimp stocks by industrial fishery started in the Iranian water in 1959 (Boerema and Job 1968, Boerema 1969, FAO 1973). From 1963 onwards the industrial fleet size increased considerably. By 1968, ten fishing companies owned and operated 125 steel trawling boats in Iran, Saudi Arabia, Kuwait, Bahrain and Qatar (FAO 1973). The maximum total catch of this sector reached to 17200 tonnes in the 1967/68 season (Figure 2). During the 1960's most of the catch was exported to the USA and Japan (Boerema and Job 1968) as headless shrimp (Boerema 1969).

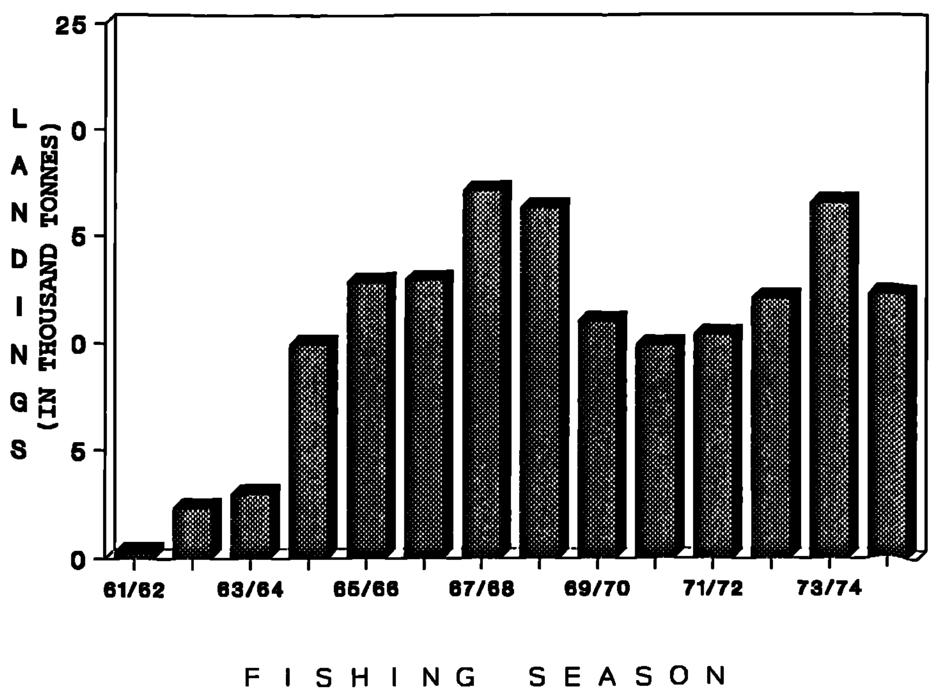

Figure 2. Total shrimp landings by all Gulf countries from 1961/62 to 1974/75 seasons, Solid square indicates the start of the artisanal sector. (source, FAO 1982)

An artisanal trawl fishery started in the 1971/72 season (FAO 1982) and expanded rapidly in the following seasons (Van Zalinge 1980). Landings by this sector enhanced those in the industrial sector so that in the 1973\74 season landings again increased to 16,700 tonnes (Figure 2). Complete shrimp landing statistics for the entire Gulf are available only up to the 1975/76 season (FAO 1982). Nevertheless, no doubt due to overfishing (FAO 1981b) there was a sharp decline in shrimp landings during the 1978/79 and early 1979/80 seasons, after which closure of several industrial companies in the Gulf was enforced (FAO 1981b). As a consequence of this collapse, a fishing ban period was imposed by all concerned Gulf countries from 1 February to 30 June (FAO 1981b). Subsequently in 1984, it was agreed by the concerned countries that each should determine its own ban periods according to its local environmental and social conditions (FAO 1985).

I.3 Gulf fishing areas

Most of the fishing grounds are located within the north west portion of the Arabian Gulf (Figure 1)*, grouped in these main areas: Kuwait, Saudi Arabia-Bahrain-Qatar, Bushehre-Dayer, but some are also located in the Hormuz area (Boerema 1969). Later reports separated Qatar grounds from Saudi-Bahrain grounds, and Hindijan from the Iranian grounds (FAO 1973). Currently, the region is characterized as having eight main shrimping grounds: Qatar, Bahrain-Damam (Saudi Arabia), Manifa-Abu Ali (Saudi Arabia), Al-Saffaniah (Saudi Arabia)- Kuwait, Hindijan (Iran), Bushere (Iran), Dayer (Iran) and Bandar-Abbas (Iran), in addition to several known and possible nursery areas (FAO 1982) (see Figure 1).

In addition, several small scale shrimp fisheries are recognized in sheltered areas of the United Arab Emirates (Figure 1). Abu Dhabi lagoon is the main shrimping ground of the United Arab Emirates, which has been estimated to

Footnote : * Figure numbers refer to the chapter in which they are cited.

yield 200 to 300 tonnes per annum (Messieh 1983).

I.4 Penaeid species composition in the Gulf

Penaeus semisulcatus De Haan 1844, is the main species commercially exploited in the main Arabian Gulf region (Boerema 1969, Van Zalinge 1980, FAO 1973 and 1978, Morgan 1985), where it comprises over 90 percent of the catches (FAO 1977). Farmer and Ukawa (1986) estimated 22,418 km^2 (10.7 percent of the total Gulf area) was used by this species.

In Hormuz Strait, *P. merguiensis* De Man 1888, is the most abundant shrimp species in the commercial catches (Boerema and Job 1968). This species is not found in the waters of Kuwait, Saudi Arabia and Bahrain, and is most probably absent in the Qatar region (Lewis et al. 1973, FAO 1978, Mohammed et al. 1981)

P. japonicus Bate 1888, is a fairly common species in commercial catches from both Kuwaiti and Iranian waters (Farmer and Ukawa 1986). However, this species is very rare in Bahraini waters (personal observations) and is not found in commercial catches from Saudi Arabian waters (Lewis et al. 1973).

P. latisulcatus Kishinouye 1896, occurs in commercial catches from Saudi Arabia, Bahrain and United Arab Emirates (Lewis et al. 1973, FAO 1978, Department of Fisheries 1984, Abdulqader 1986), but it comprises only 1 percent of the total Bahrain shrimp landings (per. observ.). This species is rare in Kuwaiti waters (Al-Hossaini M., personal communication).

Parapenaeopsis stylifera Milne Edwards 1837, contributes significantly to the artisanal landing from Kuwaiti waters (Enomoto 1971, Mohammed et al. 1981). This species is not found in Bahrain water (personal observation) and has not been recorded in Saudi waters (Lewis et al. 1973, Price and Jones 1975).

Metapenaeus kutchensis George, George and Rao 1963, was recently identified in Bahrain waters based on diagnostic features outlined by George et al. 1963 (Buqais and Abdulqader 1993). It had previously been mis-identified as *M. affinis* H. Milne Edwards, which is a commercially important species in Pakistan, India, Sri Lanka, Malaysia, Hong Kong and Bangladesh (Holthuis 1980). *M. affinis* occurs in backwaters and estuaries during their juvenile stage (George, 1969), low salinity habitats which are not found along the southern coast of the Arabian Gulf. Despite this, *M. affinis* had been recorded in the Arabian Gulf by a number of workers (FAO 1980, Holthuis 1980, Mohammed et al. 1981, Van Zalinge et al. 1981, Mathews 1989, Water Resources and Environment Division 1990). Earlier samples of *M. affinis* collected from Kuwait water have been re-identified as *M. kutchensis* (M. S. Muthu, personal communication). Accordingly, it is most likely that *M. kutchensis* is the species found at least along the southern coast of the Arabian Gulf, and not *M. affinis* (Buqais and Abdulqader 1993).

Of other penaeids recorded in the Gulf, *M. stebbingi* Nobili 1904, of low commercial value, has been recorded along the southern coast of the Arabian Gulf (Price and Jones 1975, Farmer and Ukawa 1986, Mohammed et a. 1981, Buqais and Abdulqader 1993), and *M. dobsoni* Miers 1878 is reportedly quite common in commercial catches from Kuwaiti and Saudi waters (Enomoto 1971, Lewis et al. 1973). In addition *M. monoceros* Fabricius has been reported in Bahrain water (FAO 1978), and *Trachypenaeus curvirostris* Stimpson 1860, *T. granulosus* Haswell 1879, and *Metapenaeopsis stridulans* Alcock 1905, are found in commercial catches along the southern coast from south of Kuwait to Bahrain (Buqais and Abdulqader 1993). *M. mogiensis* Rathbun 1902, is the least abundant species in the Bahrain water (personal observations). Finally, *Solenocera subnuda* Kubo 1949, and *S. crassicornis* Milne Edwards, have been reported in Bahrain and Kuwait waters (FAO 1978, Mohammed et al. 1981), but were not recorded during a 1980/81 shrimp survey (personal observations).

II. Bahrain Shrimp Fishery

Bahrain total fishing grounds are located between 25° 30′ to 27° North, between Saudi Arabia and Qatar (Figure 3) covering about 6,800 km^2 (RDA International, Inc. 1992). Shrimping grounds are located between 25° 55′ to 26° 30′ North and 50° 25′ to 50° 55′ East (Figure 3), within the north west, low energy portion of the Gulf (Al-Ghadban et al. 1993).

II.1 Bahrain fishing seasons and grounds

Based on their locations, Bahrain shrimping grounds can be differentiated into three areas as: (1) southern ground found in the south to Fasht Al-Adhom reef, (2) the northern or main ground and (3) the western ground found from north of Manama to west of Fasht Al-Jarim reef (Figure 4). The depth of the southern grounds varies from 2 to 12 m and those grounds include large areas of sea-grass (Atkins and partners 1985). In these grounds, huge aggregations of small to medium size shrimps usually appear by May indicating the start of the fishing season, while small shrimps appear in abundance from February. The best shrimp catches usually occur from May to June, with a considerable decline in July to August (FAO 1978), followed by good catches again from September to December.

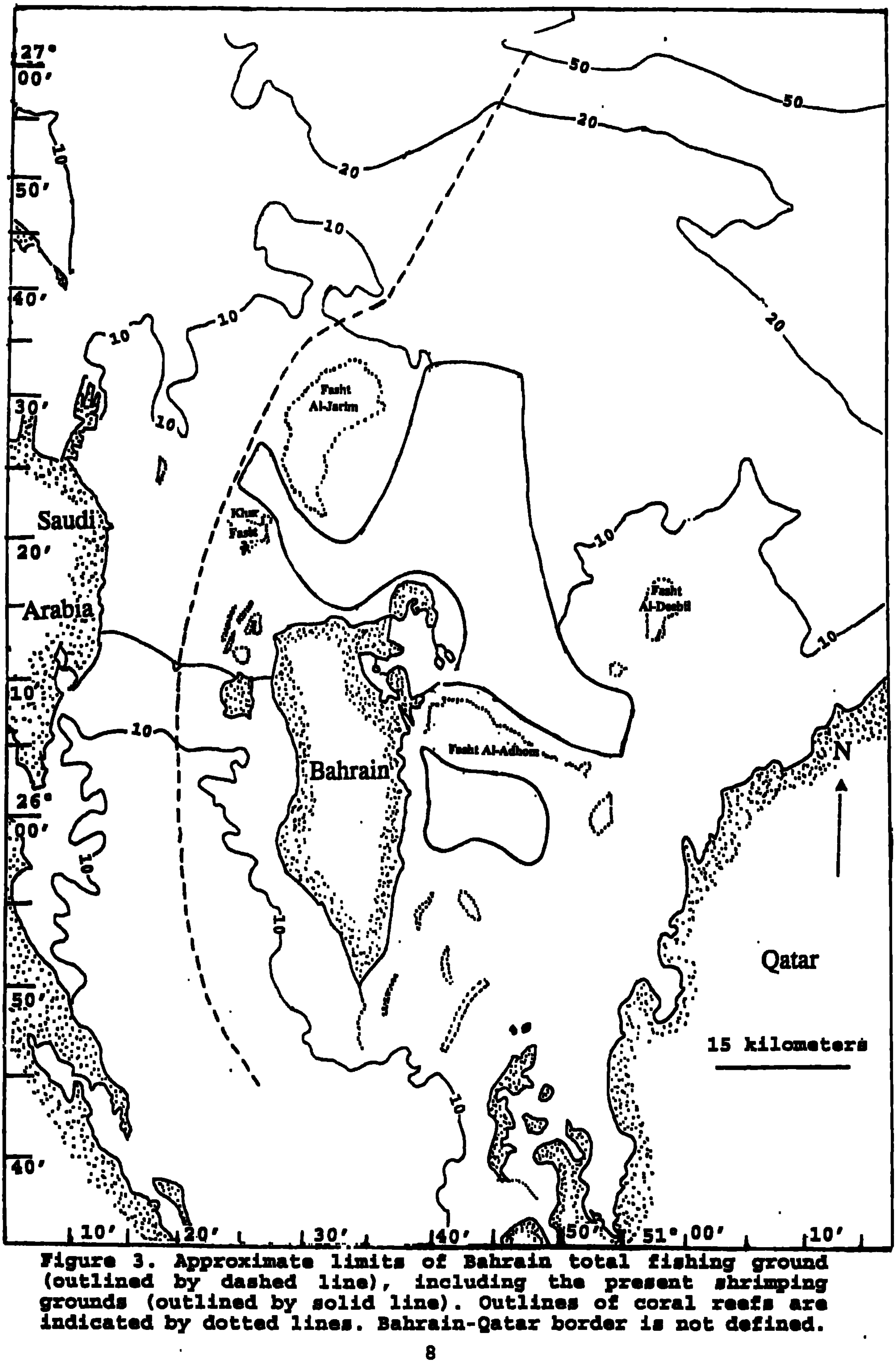

Figure 3. Approximate limits of Bahrain total fishing ground (outlined by dashed line), including the present shrimping grounds (outlined by solid line). Outlines of coral reefs are indicated by dotted lines. Bahrain-Qatar border is not defined.

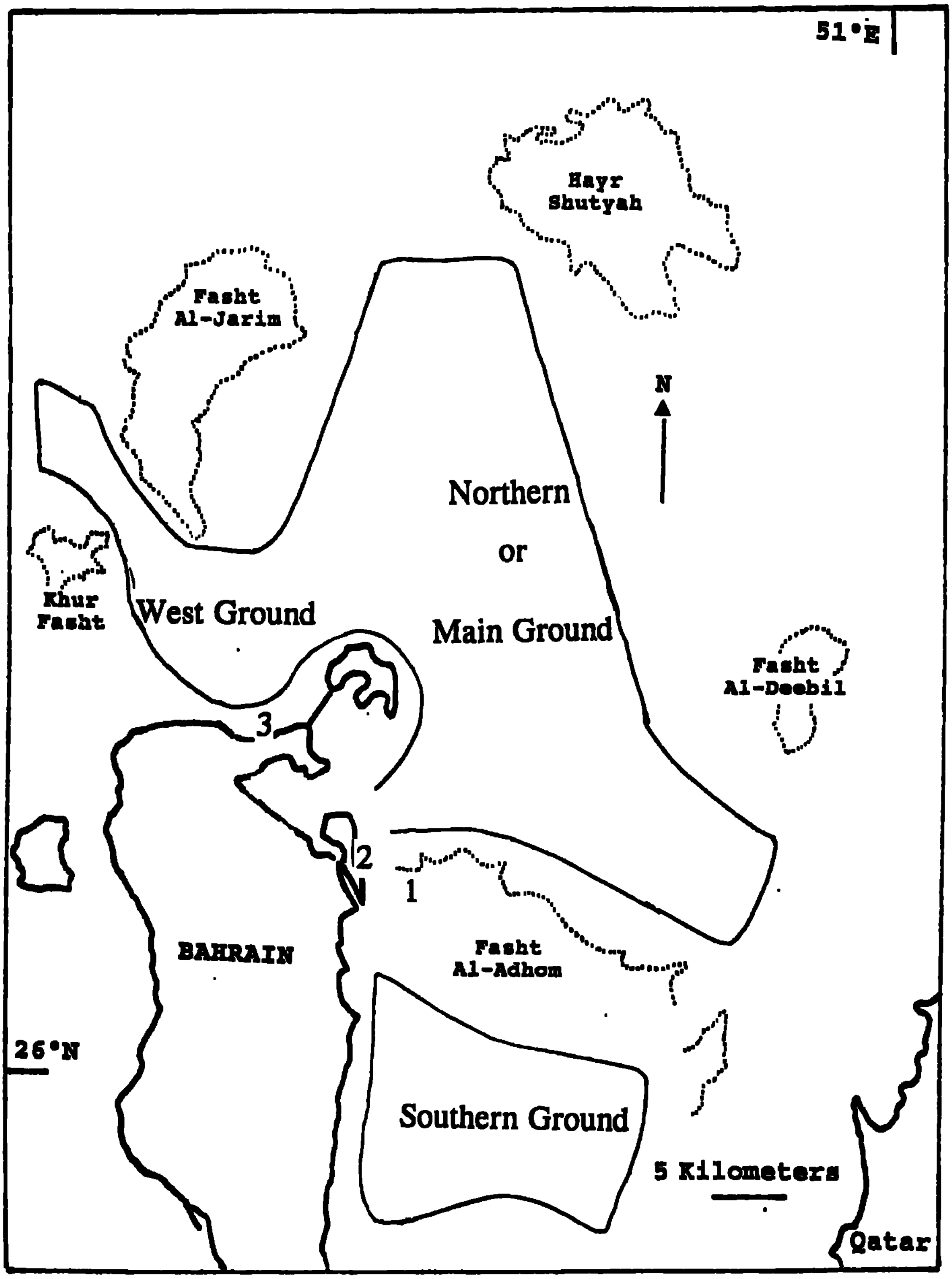

Figure 4. Bahrain main shrimping grounds and landings sites 1) Satwat Al-Hajarah, 2) Sitrah landings site, 3) Manama landing site. Outlines of coral reefs indicated by dotted lines.

The northern ground contains the deepest fishing areas, where the larger size shrimp are usually found. Fishing on this ground usually extends from June to March. Fishing in the western ground usually starts in June/July and continues to November/December; shrimp in this area are usually small to medium in size.

II.2 The fishery

Shrimp fishing has a long history in Bahrain, barrier traps being the traditional gear used by the artisanal sector in coastal waters. The most important area around Bahrain for such traps is along the east coast, particularly at Satwat Al-Hajarah sea area (Figure 4).

Experimental shrimp trawling started by the end of 1966 and the Bahrain Fishing Company started regular commercial fishing in March 1967 (FAO 1978). This was the first trawling fleet operated in Bahraini waters, and its operation began before the artisanal sector trawling was established. As with other Gulf fishing companies, the Bahrain Fishing Company was dependent on international export markets for marketing their products. USA and Japanese markets were the main purchasers of shrimp catches, most of which were exported as headless shrimp (Boreama and Job 1968). Prior to that time, shrimp exports from Bahrain were very small; they started in 1962 with only small quantities (23 tonnes per annum).

In the first two years of Bahrain Fishing Company operations, eight trawlers of 15.2 m length were operated; eight were added in 1968 and two more in 1973 (FAO 1978). In 1976 some of these trawlers were replaced and the total number were reduced to 15 boats of 15.2 to 22.6 m length; all were double rigged with Mexican type trawl nets of mesh size 30 mm (FAO 1978). The fishing season of this company usually started in the Maniffa grounds off Saudi Arabia (Figure 1) during July and August. From September to February, both Saudi and Bahrain grounds were fished (FAO

1978). Total landings of this sector included the catches from both Bahrain and Saudi waters (Boerema and Job 1968, Boerema 1969, FAO 1973, FAO 1978).

After a sharp decline of catches in the 1978/79 season and in the early 1979/80 season, shrimp trawling became uneconomical and the Bahrain Fishing Company ceased fishing in August 1979 (Abdulqader 1983). A revival of the industrial sector of the Bahrain shrimp fishery started in 1980/81 with low catch levels, operated by 4 steel hulled trawlers. The artisanal sector was already established by that time (Abdulqader 1983).

The artisanal shrimp trawl fishery was started in 1971 by fishermen involved previously as barrier trap operators. In 1976, there were 26 full time shrimp trawlers in this category mainly operating from Sitrah jetty (Figure 4). All of these boats were made of wood known locally as "Banoush". Registration and a licensing scheme were introduced by the start of 1983/84 shrimping season (Abdulqader 1988). At this stage 68 boats of various sizes had been registered and licensed. By the start of the 1985/86 season, this number had been increased to 495, with small boats forming 54 percent of the total. By 1993, low shrimp catches resulted in many of these boats being withdrawn from the fishery, so that only about 190 registered trawlers remained in this sector in that year (Abdulqader 1993).

From 1971 to 1985, on the artisanal vessels all trawl nets were manually deployed and retrieved, but by 1990/91 about 90 percent were equipped with hydraulic winches. From the 1990/91 season, the swept area per unit of time was increased by adding extra weights on the foot rope of the trawl nets and increasing the trawling speed of the boat. Thus in recent years the fishing power of the present artisanal fleet has increased significantly and is now competing with that of the industrial fleet.

Since the start of the artisanal shrimp fishery, the Sitrah landing site (Figure 4) was the main landing site for this sector. This was due to the closeness of this site to the main fishing grounds of the artisanal fisheries south of Fasht Al-Adhom. After the implementation of a fishing ban period in 1980/81 (Abdulqader 1982) and in following seasons, the northern grounds became more important to the artisanal fleet. With that change the Manama landing site (Figure 4) also became an important shrimp landing centre in Bahrain. The fishing ban resulted in a change in the behaviour of the artisanal fleet toward exploiting the deeper waters.

II.3 Fisheries statistics

From 1979, reliable fishery statistics were regularly collected and published by the Directorate of Fisheries of the Ministry of Commerce and Agriculture. These statistics related to all commercial fish and shellfish species landed in Bahrain. For shrimp fishery statistics, two collection procedures have been adopted. The first is the stratified random sampling scheme (Abdulqader 1983) which was mainly developed for the artisanal sector. The second is the log-book/reporting scheme which was introduced in 1976 for the industrial fishery. The log-book/reporting scheme expanded in 1985 to include all the artisanal and industrial shrimp trawlers (Abdulqader 1988). At present both sampling and reporting schemes are applied in the collection of statistics of the artisanal landings.

Shrimp landings in Bahrain from 1967/68 to 1992/93 are shown in Figure 5. The industrial fleet began fishing both Bahraini and Saudi waters in 1967/68 when the total landings were about 900 tonnes from the virgin stock (Figure 5). Unfortunately, descriptive information about the virgin status of the stock was limited. The maximum landing of this sector reached 2,733 tonnes in 1973/74 season (Figure 5). After the collapse of the fishery in 1979 (Figure 5), a second period of the fishery began with both artisanal and industrial fleets included. During this period, the first shrimp survey was carried out from June 1980 to June 1981 the results of which are discussed in the current work.

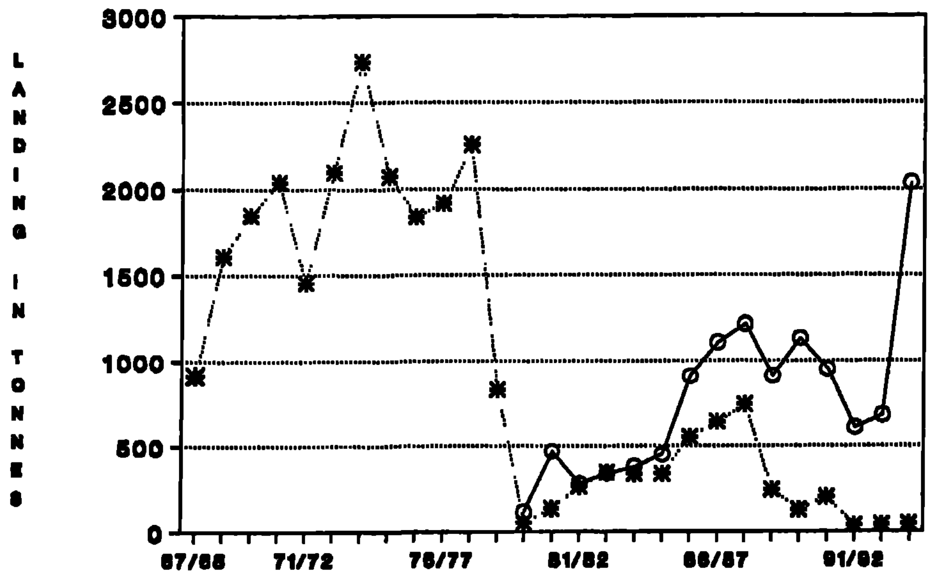

Figure 5. Shrimp landings in Bahrain from artisanal (open circle) and industrial (star) sectors for each season from 1967/68 to 1993/94. (source, FAO 1978 and Fisheries Statistical Services)

During the 1980's catches of industrial and artisanal fisheries showed similar annual variation (Figure 5), suggesting that both sectors were competing for the same stock. However, the artisanal sector was more important in terms of total shrimp landings, out-competing the industrial sector which rose less sharply and declined earlier than the artisanal catches throughout that period. The particularly low catches in the 1991/92 season coincided with the consequences of the Gulf War. After a series of low catch seasons, 1993/94 landings recorded the best season since 1979/80, seen only in the landings of the artisanal sector (Figure 5).

Total catch, standard effort and catch per unit of effort are shown in Figure 6 from 1980/81 to 1993/94. The standard effort was calculated by converting the industrial fishing hours to artisanal hours using the following equation:

$$F = F_A + (F_I \times (U_I / U_A))$$

Where, F total standard effort.
F_A artisanal effort.
F_I industrial effort.
U_I industrial catch rate.
U_A artisanal catch rate.

Due to the changing fishing behaviour of the artisanal sector throughout the period since its start (see section II.2), standard effort was calculated based on the ratios for each season.

Catch per unit effort throughout this period showed a general decline, with the lowest rates attained in the 1991/92 season. Fishing effort increased markedly after 1986/87 and has remained high since then. The 1988/89 peak of 185,000 trawl hours is equivalent to 82 full time artisanal boats, based on the assumption that a fishing vessel fishes for 10 hours per a day, for 25 days per a month and for 9 months per a season. The increase in the 1993/94 catch coincided with further increase in effort, which resulted in small increase in the catch rates (Figure 6).

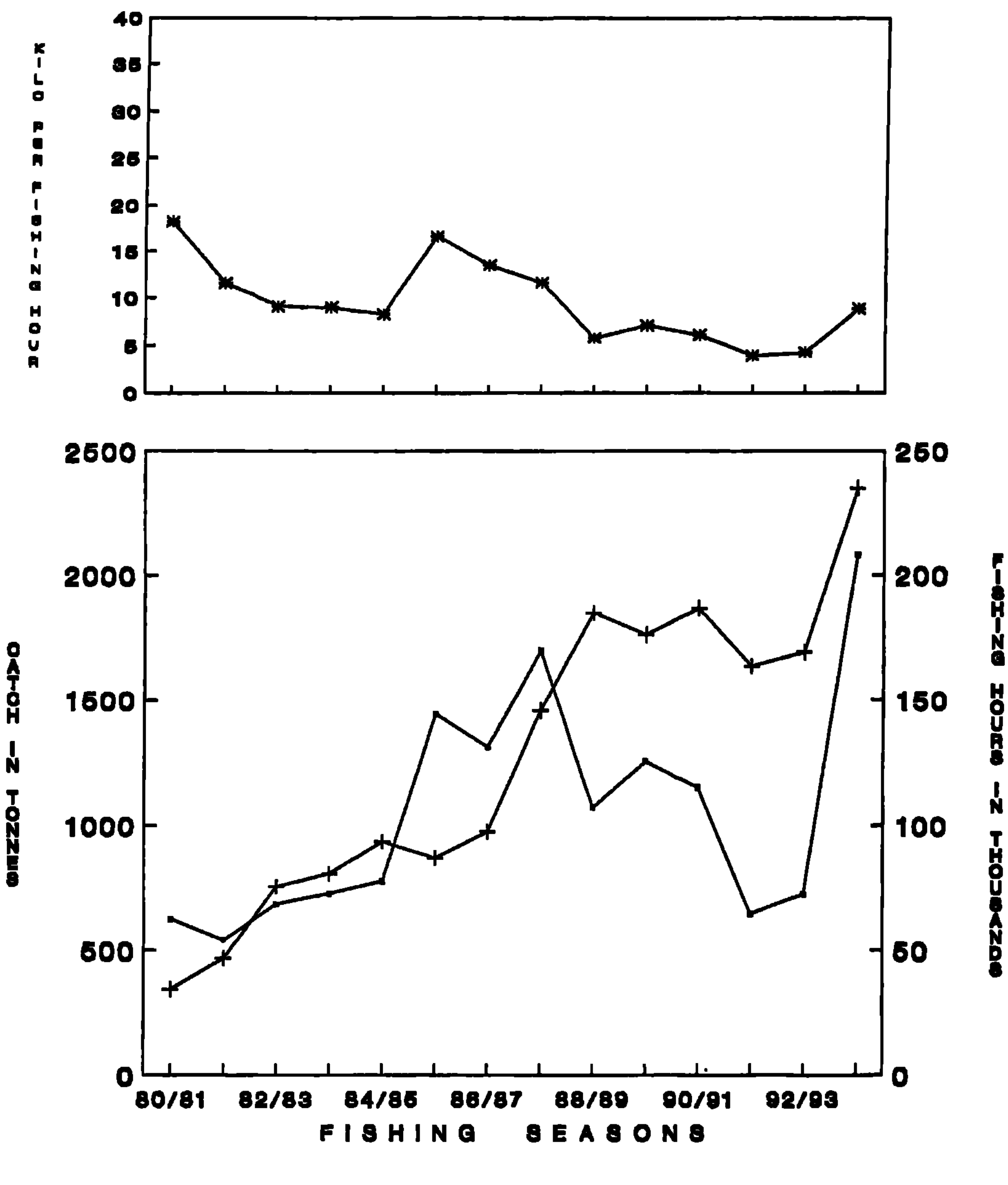

Figure 6. Catch (•), standard effort (+) and catch rate (*) for Bahrain shrimp fishery from 1980/81 to 1993/94.

II.4 Fishing regulations.

A decree promulgating a law controlling Bahrain fishing was declared in 1981 and there have been no major changes to the law since that date. However, based on the law, a number of ministerial decrees were issued subsequently to develop management procedures for the shrimp stock, as follows:-

(1) Decree No. 16 (1981) concerns the registration of all fishing boats at the Directorate of Fisheries.

(2) Decree No. 17 (1981) concerns fishing licensing, application forms and fees.

(3) Decree No. 9 (1986) concerns the minimum allowed mesh sizes for number of gears including shrimp trawl.

(4) Several decrees had been issued to declare the start and the end of shrimp fishing ban periods. These are made on an annual basis usually restricting forcing to a period from mid-March to mid-June.

The current focus of shrimp fisheries management is based on: (1) control of the number of fishing boats, (2) enforcement of fishing ban periods, and (3) increasing the selectivity of net by increasing the minimum mesh size.

III. Rationale of the present study

Shrimp comprise the most valuable fish stock in Bahrain waters, the fishery being based largely on a single species (*Penaeus semisulcatus*) which forms about 95 percent of the total shrimp landings. In 1993 shrimp landing comprised 23.8 percent of the total Bahrain fisheries landings (Fisheries Statistical Service 1993 and 1994), which totalled 2,128 tonnes at a first sale value of 5.4 million Bahraini Dinars (1 US$ = 0.380 BD). In that year shrimp had become the main fresh food export of Bahrain.

The marine habitat of Bahrain suffers from several sources of pollution. Based on 1984 statistics, the total sewage discharge was estimated to be 2.84 million m^3 per annum and the industrial thermal effluent was 2.4 million m^3 per day (UNEP 1987). Oil source pollution from marine transport was estimated for the same year to be 1.98 million tonnes per annum, while the industrial waste discharge was given as 4,538 tonnes per annum (UNEP 1987). Dredging also causes direct alteration of marine habitats. It is usually carried out extensively in Bahrain waters to reclaim coastal and reef areas, clean the shipping channels and for sand retrieval for construction purposes. Between 1976 and 1992 the total land area of the state of Bahrain increased by 4.8 percent through land reclamation (Directorate of Statistics 1993).

Despite, the shrimp fishery importance and the development-related stresses on Bahrain coastal environments, there were limited basic data on this valuable stock. The current study aimed to provide as full an understanding as possible of the shrimp fishery of Bahrain. First it was seen to be important to determine the topography and physical characteristics of the shrimp natural habitat (see chapter 2). Secondly, since it is known that the penaeid shrimp spent the first part of their life cycle in the plankton, this necessitated a study of plankton in relation to spawning seasons and areas (see chapter 3). Then requirement for vital life history data necessitated the study of penaeids bionomics (see chapter 4). Further, due to their importance in fisheries management consideration the migration patterns of shrimp in the area were also studied (see chapter 5). The updated information on Bahrain shrimp stock acquired during the study was seen as essential to stimulate the development of management plans for this important fishery (see chapter 6).

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CHAPTER ONE
INTRODUCTION

SUMMARY

The aim of this chapter was to develop background information, which is essential for understanding the context of the remaining chapters of this thesis. First, the shrimp fishery of the Arabian Gulf is briefly presented through its history, fishing areas and penaeid species composition. Secondly, the Bahrain shrimp fishery is reviewed through its history, fishing season and ground, fishery statistics and fishery regulations. Lastly the rationale of the current study is highlighted.

CHAPTER TWO

TOPOGRAPHY AND PHYSICAL CHARACTERISTICS OF BAHRAIN SHRIMP FISHING GROUNDS

I. INTRODUCTION

Spatial and temporal variations in the commercial stocks of fish and invertebrates are clearly dependent not only on fishing pressure but also on changes in environmental factors. For penaeid shrimps, maturation and spawning patterns have been found to be associated with particular temperature characteristics (Al-Attar and Ikenoue 1974, Laubier and Laubier 1979, Caubere et al. 1979, Aquacop 1975 & 1979, Price 1979, Penn 1980), and some species have been shown to exhibit preferences for certain bottom sediments (Branford 1981, Somers 1987 and 1994, Penn 1980). Tidal currents have also been shown to influence the distribution of the penaeid shrimp, consequently affecting their catch rates (Garcia and Le Reste 1981). Despite the importance of such environmental data, hitherto there has been only limited work carried out on the physical environment of Bahrain shrimp fishing grounds. Present work therefore aimed to describe some of the environmental parameters of the fishing grounds of Bahrain and to assess their significance in relation to commercially fished penaeid shrimp stocks.

Coincidentally during this study the Bahrain region was influenced by smoke emanating from Kuwait oil well fires during the Gulf war in early 1991. Smoke affected the area for 45 percent of the time between March and September 1991 (Shaw 1992) and an opportunistic study of the effects of this smoke on air and sea temperature, hence on shrimp biology, was carried out.

II. MATERIALS AND METHODS

II.1 Physical properties of sea water

II.1.1 Open sea area

During June 1980, surface temperature and salinity were measured at twenty two stations (Figure 1) within the known Bahrain shrimping grounds. Temperature was determined by ordinary thermometer, salinity by a Beckman conductivity bridge (model RC-19) and dissolved oxygen by a portable oxygen meter (Karl Kolb WTW OXI 57).

During October 1991, temperature, salinity and dissolved oxygen at 5 meter depth intervals were recorded in 9 plankton sampling stations (Figure 1) located within the Bahrain fishing grounds. In December 1991 similar measurements were taken at some of these stations, where only the records of the sea surface were collected. The multi-probe system (Hydrolab surveyor II, as used by Nayar and Al-Rumaidh 1993) was used to measure the above mentioned physical properties of the sea water.

II.1.2 Tubli Bay and Mina Sulman

From May 1991 to May 1992, a regular sampling programme was initiated to record temperature and salinity of sea water from fixed stations inside Tubli Bay and off Mina Sulman (Figure 2). Surface and bottom temperatures and surface salinity records were obtained biweekly at all stations during day and at night. For most of the sampling period, temperature was measured by precision underwater thermometer (Kahlsico model No. 36AM340) and salinity was measured by refractometer (range 0 to 100 part per thousand). In addition, from December 1991 to February 1992, a multi-probe system (Hydrolab surveyor II, as used by Nayar and Al-Rumaidh 1993) was used to measure temperature, salinity and dissolved oxygen. During March 1992 an ordinary thermometer (accuracy to 1° C) was used to measure the surface temperature. For each parameter, the average of all data collected in a month for a station was used to represent a monthly value. For the two stations off Mina Sulman data were pooled.

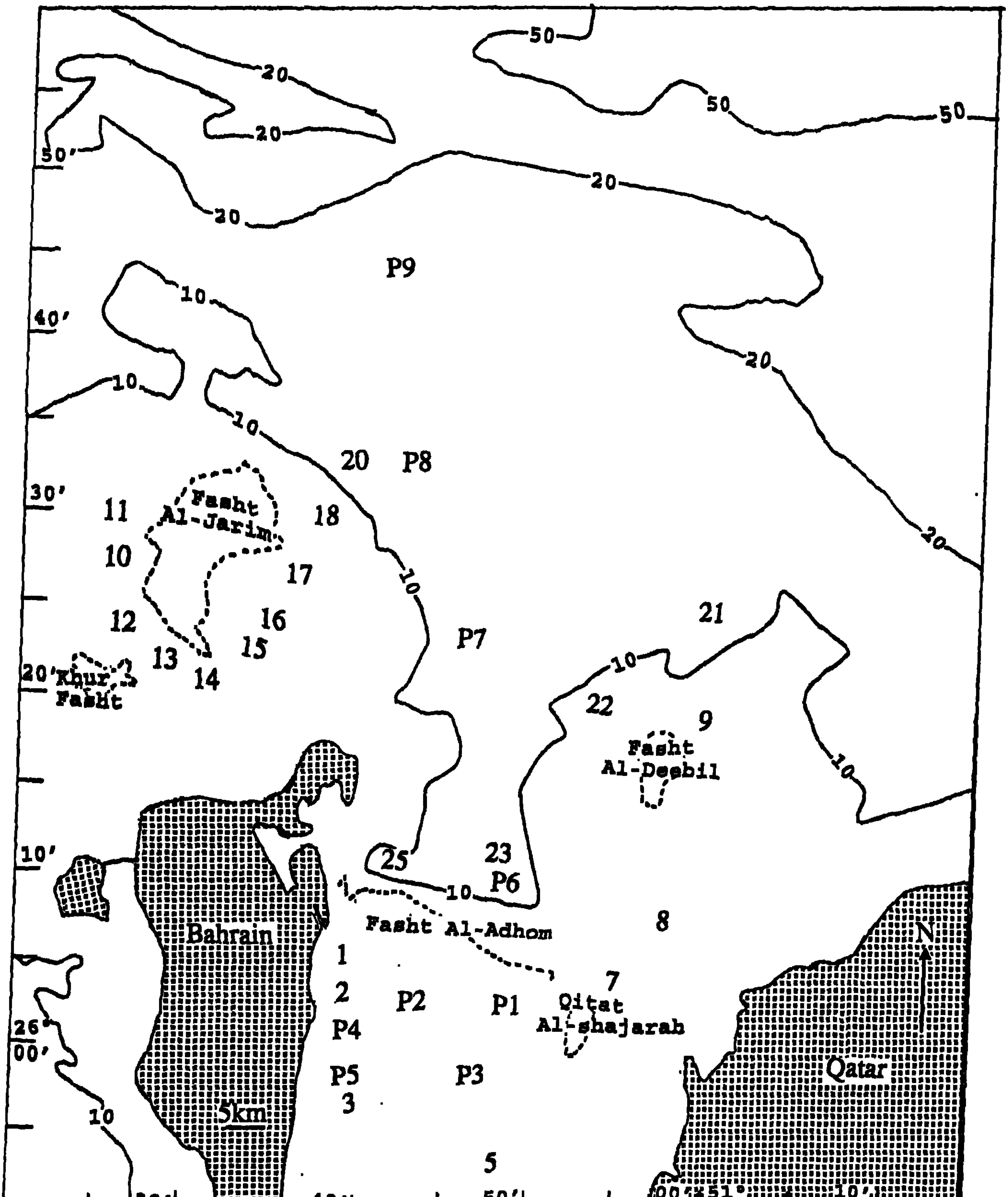

Figure 1. Location of 21 sampling stations at the open sea location during June 1980, and of 9 plankton sampling stations during September, October and December 1991, and January 1992 (indicated by P). Areas enclosed by dotted lines are coral reefs.

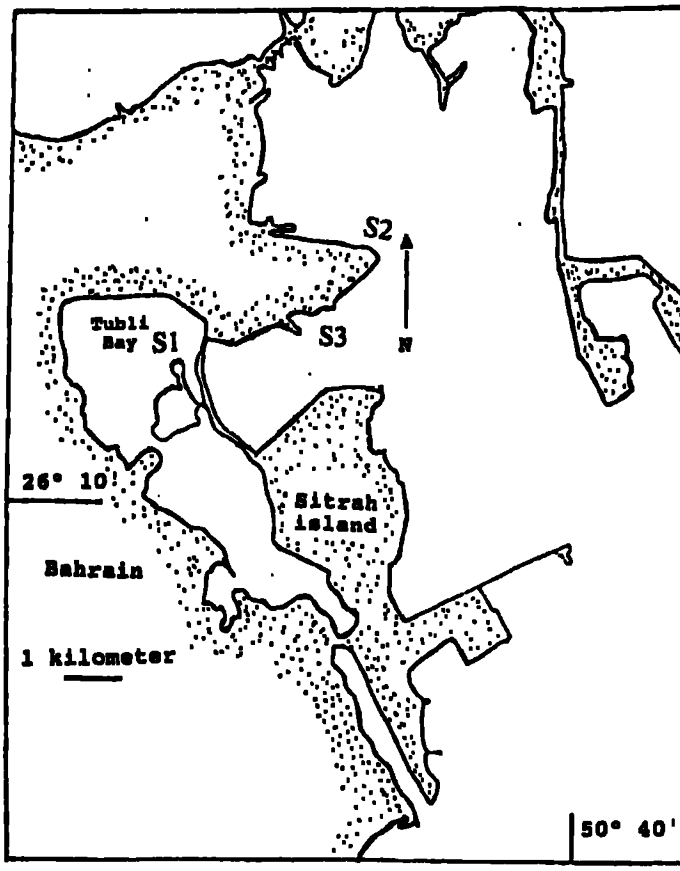

Figure 2. Sampling stations for temperature and salinity, inside Tubli Bay (S1) and in Mina Sulman area (S2 and S3).

II. 2 Sediment survey

A sediment survey was conducted within the area extending from latitude 25° 50' to 27° 00' North and longitude 50° 20' to 51° 15' East. North of Fasht Al-Adhom sampling stations were fixed at 5 nautical mile intervals, and south of that area at 3 nautical mile intervals (Figure 3). Stations with hard bottom are indicated by a 999 code in Figure 3 and consequently ignored as data points. There were 17 such station in the total of 129 stations sampled. No stations within Saudi and Qatari waters were sampled (Figure 3).

Sediment collections were obtained from 9 August to 26 October 1990 and Van Veen grabs were used for most collections. At the offshore stations heavier grabs (Van Veen 2 and 3) were used from an industrial trawler, but small grabs (Van Veen 1 and Birge-Ekman) were used to sample the inshore areas. In each case about 1 kg of sediment was then taken for analysis.

At each station two grab samples were taken, providing two replicate sub-samples each taken from the top of the sample to a depth of several centimetres inside each grab.

In the laboratory, sediment samples were processed to determine the grain size composition. This was done following the procedure adopted by the Environmental Protection Committee (Bahrain) outlined below;

1. Sediment sample dried in weighed aluminum containers and kept in the an oven overnight at 110°C.

2. Sample cooled in a desiccator for at least 2 hours.

3. First dry weight of the sample obtained.

4. Samples washed through 63 μ sieve to break up the lumps.

5. Sample dried in an oven at 110°C overnight.

6. Sample cooled in a desiccator for at least 2 hours.

7. Second dry weight obtained.

8. Weight of particles less than 63 μ calculated from the differences between the second and first weights.

9. Sample sieved through a sieve set for at least 10 minutes.

10. Sample fraction in each sieve weighed.

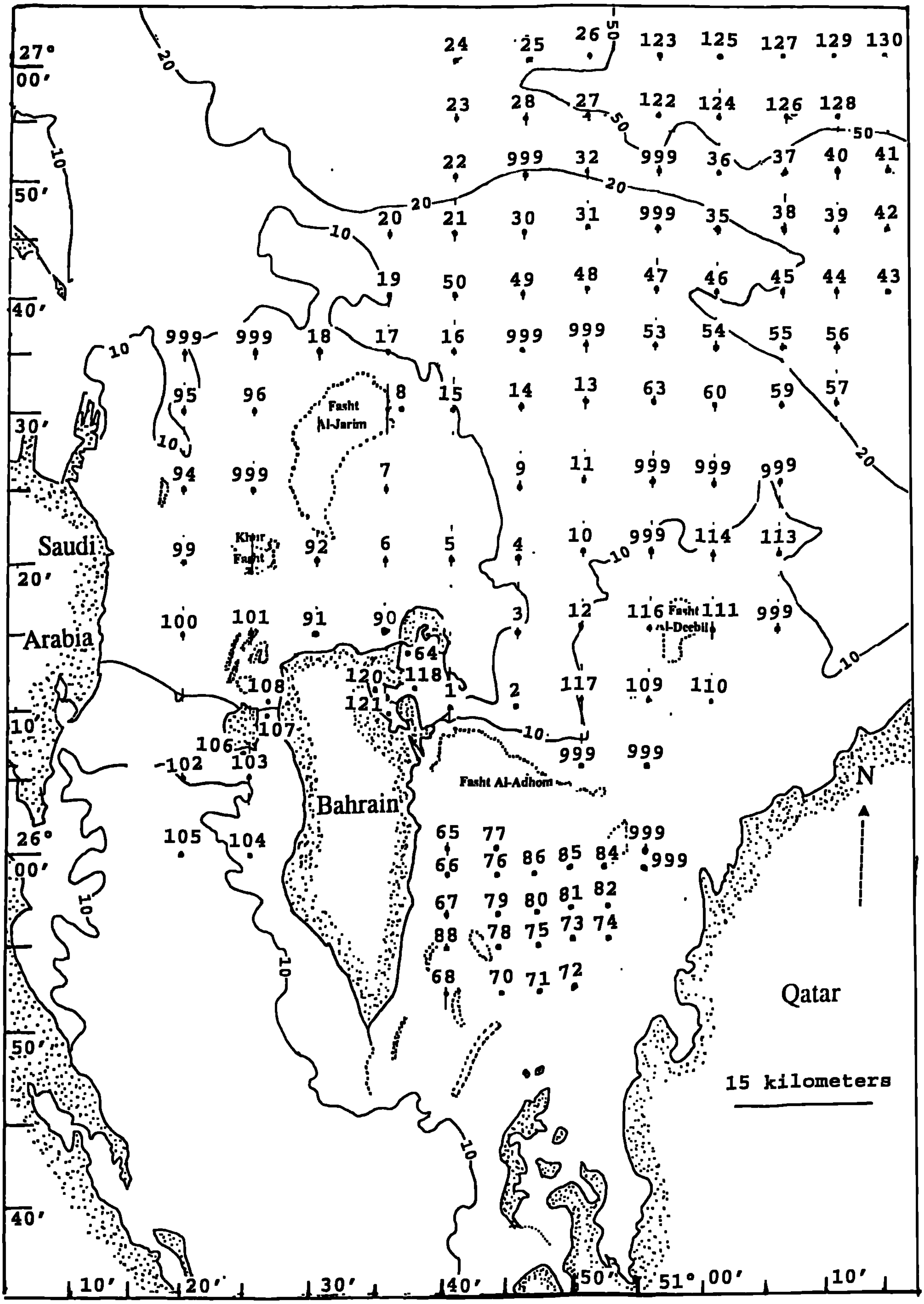

Figure 3. Limits of sediment survey. Position of the stations are noted by serial number; stations of hard bottom are coded by 999. Depth contours in meters are also shown. Coral reefs are indicated by dotted lines.

The mesh sizes of the sieves in the sieve set specified in 9 above were: 4.0 mm, 2.8 mm, 2.0 mm, 1.4 mm, 1.0 mm, 710 μ, 500 μ, 355 μ, 250 μ, 180 μ, 125 μ, 90 μ, 75 μ and 63 μ respectively.

The percentage of each grain size class (pw_i) in each sample was calculated by the following equation;

$$pw_i = (w_i / \Sigma w_i) * 100$$

where, w_i is the weight of the fraction of sediment of size class (i).

The average percentage (p_i) of two replicates samples, at each station was calculated by the following equation;

$$p_i = \Sigma pw_i / 2$$

The average particle size of the sample was usually determined from a plot of the cumulative percentage of different size classes, following Holme and McIntyre (1971). The size value which correspond to 50 percent of this cumulative curve can be taken to represent the average particle size of that sediment sample. This procedure could be adopted here since the particle size distribution usually showed unimodal normal distributions. Based also on this unimodality and normal distribution, the mean particle size (x_m) was calculated from the following equation;

$$x_m = (((50-y_1)/(y_2-y_1)) * (x_2-x_1)) + x_1$$

where, y_1 is the cumulative percent before 50 %
y_2 is the cumulative percent after 50 %
x_1 is the particle size before 50 %
x_2 is the particle size after 50 %

In practice, after preliminary use of the graphic method, the average particle size was calculated by using the above equation. This provided a good estimate of the mean and also reduced the time spent in plotting the cumulative graphs.

II.3 Meteorological data

To assess the effect of atmospheric smoke generated during the Gulf war, meterological data were obtained from the Bahrain Civil Aviation Affairs Meteorological Services. In addition sea water temperature data were obtained for the years 1990-1993 from the Sitrah Power Station located in the north of Sitrah island (Figure 2).

III.RESULTS

III.1 Physical properties of sea water

III.1.1 Open sea area

Surface sea water temperature, salinity and dissolved oxygen values at each sampling station are shown in Table 1 for June 1980 . Based on these data, temperature and salinity contour drawings were prepared (Figures 4 and 5). Slight differences in surface water temperature and salinity (≈1°C, ≈2 ppt) were found throughout the shrimping grounds, with higher values of both variables found in the south (Figures 4 and 5). Dissolved oxygen ranged from 5.1 to 6.2 mg/l (Table 1).

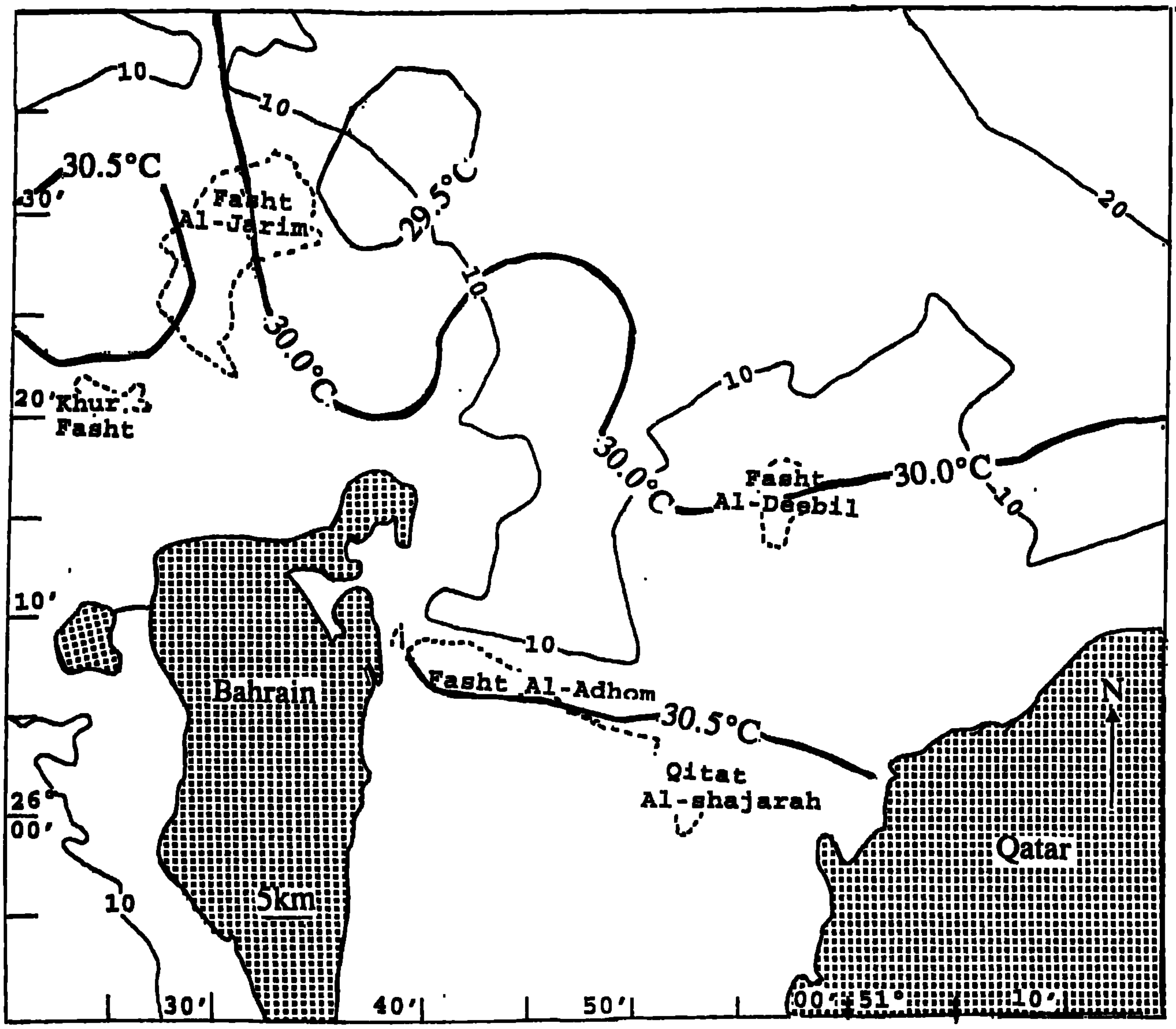

Figure 4. Contour drawing showing the temperature distribution in the shrimping grounds during June 1980 (based on Table 2). Coral reefs indicated by dotted lines

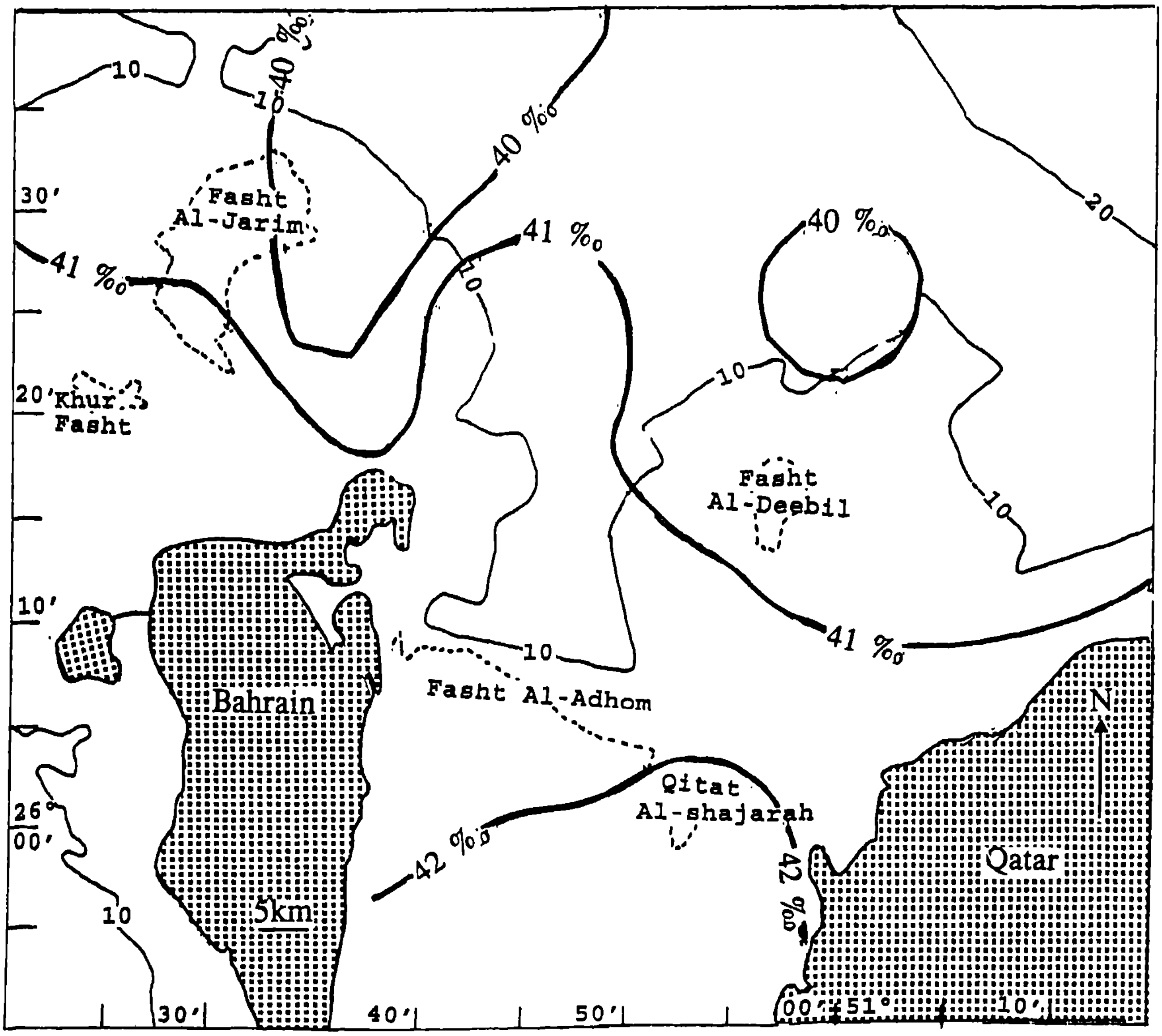

Figure 5. Contour drawing showing salinity variation in the shrimping grounds during June 1980 (based on Table 2). Coral reefs are indicated by dotted lines.

Table 1. Temperature, salinity and dissolved oxygen records at the shrimp survey stations during June 1980.

STATION NUMBER	TEMPERATURE C°	SALINITY PPT	DO mg/l
1	31.0	41.46	5.1
2	31.0	41.80	6.0
3	31.5	42.45	5.9
4	31.0	42.52	5.9
5	31.0	42.37	5.8
7	31.0	42.45	5.9
8	30.3	41.35	6.0
9	30.0	40.20	6.2
10	31.0	41.10	5.9
11	30.8	40.64	5.9
12	30.4	41.87	5.8
13	30.5	42.18	5.7
14	30.5	42.55	5.6
15	30.5	42.96	5.5
16	29.8	39.65	5.8
17	29.5	39.35	5.8
18	29.2	39.18	5.6
20	29.3	39.01	5.4
21	29.5	39.55	5.4
22	29.9	40.80	5.5
23	30.0	41.60	5.4
25	30.0	40.70	5.6

Temperature, salinity and dissolved oxygen values at 5 m interval depths at plankton stations (Figure 1) are shown in Figure 6 for October 1991. Only slight or no differences between surface and bottom temperatures were found in all stations, which indicated the absence of thermocline at the time of sampling. Surface temperature increased and salinity decreased towards the offshore, where warmer and lower salinity waters were found in station 9 (Figure 6). Dissolved oxygen values did not show any pattern, but sudden declines by 1-2 mg/l was seen near the bottom at stations 2 to 4 (Figure 6).

Surface temperature, salinity and dissolved oxygen in open sea stations 4, 7 and 8 are shown in Figure 7 for December 1991. Temperature increased and dissolved oxygen deccreased toward the offshore station (Figure 7). Generally, lower temperatures and higher dissolved oxygen values were recorded in December 1991, as compared with October 1991 (Figures 6 and 7).

During their work on pearl oysters, Nayer and Al-Rumaidh (1993) recorded the physical parameters of sea water at 5 m depths intervals in 3 offshore stations during 7 sampling days over a period from 9 July to 18 December 1990. These sampling stations were sited near the pearl banks of "Abu Amamah", "Shutayah" and "Abu Al-Jaal" (Figure 8). Temperature and salinity records at these stations are shown in Tables 2 and 3 respectively. Maximum sea water temperature occurred in September 1990, where small differences in temperature values were found between these stations (Figure 9). Small differences in temperature values were also found in October 1990, when the general decline in temperature started (Figure 9). From July to October, highest temperatures were found towards the near shore pearl bank "Shutayah", while from November to December the highest temperature were recorded toward the offshore pearl bank "Abu Amamah"(Figure 9). Throughout the period from July to December, there was no indication of a thermocline in these waters, but a sudden decline in temperature occurred during November at all stations (Figure 9). For all stations, lower salinities were found during July and August, while an increase in salinity occurred in the successive sampling intervals until it reached highest values in December (Figure 10). Throughout most of the period the highest salinity values were found around pearl bank "Shytayah" (Figure 10).

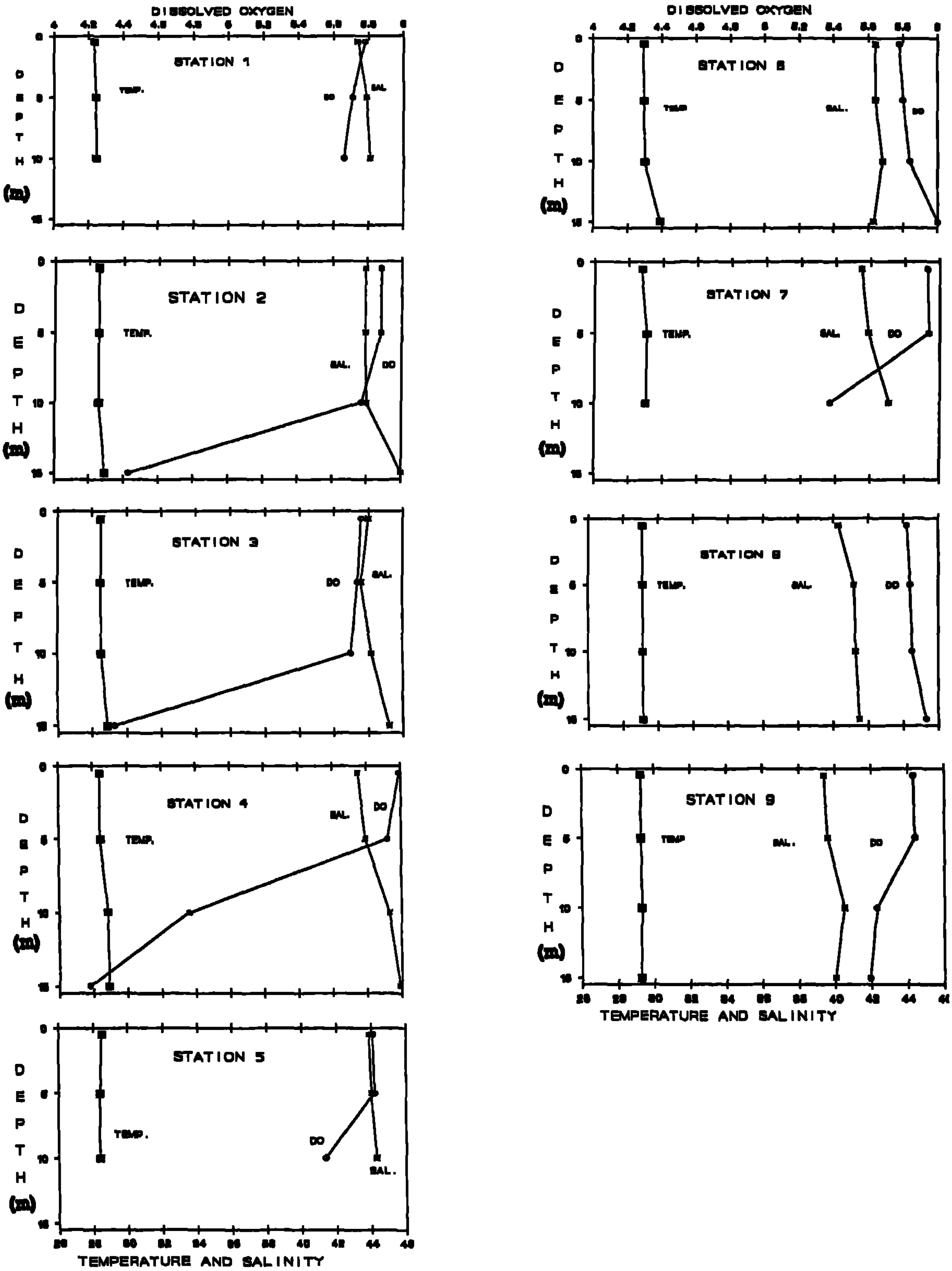

Figure 6. Temperature (°C), salinity (parts per thousand) and dissolved oxygen (mg/l) at 5 m depth interval at each plankton station in October 1991.

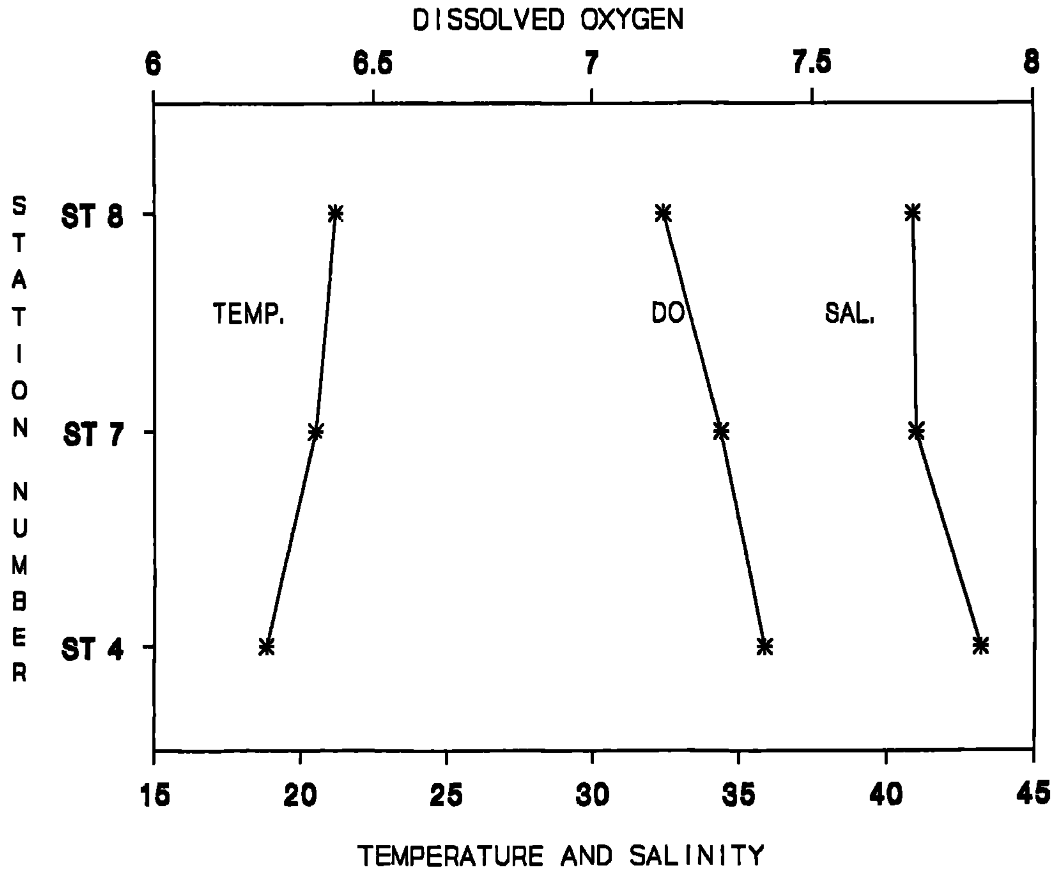

Figure 7. Temperature(°C), salinity (part per thousand) and dissolved oxygen (mg/l) of surface sea water in the open sea area in December 1991.

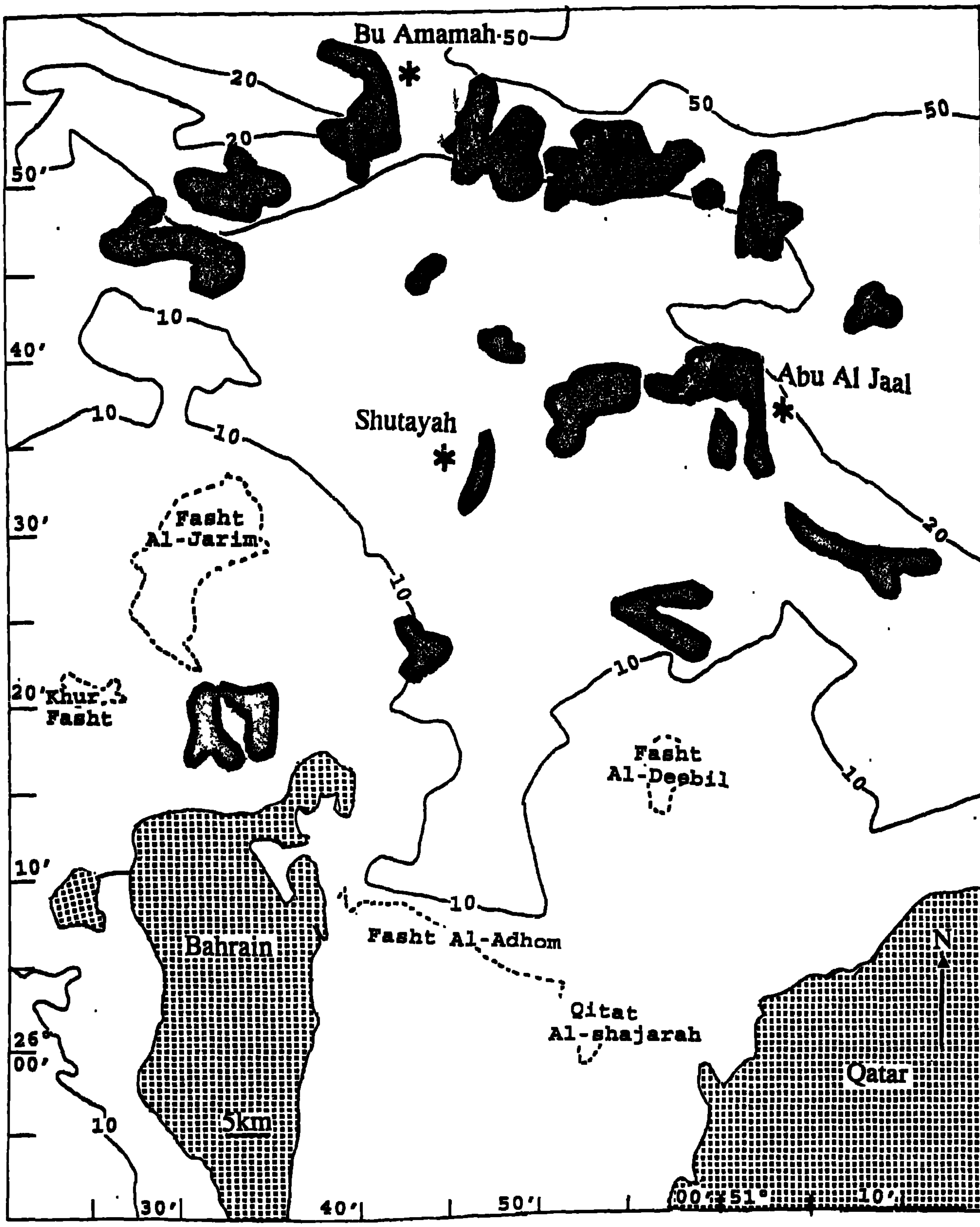

Figure 8. The important pearl banks of Bahrain (shaded), and the approximate position of the monitoring stations (*) selected by Nayar and Al-Rumaidh (1993). Land shown by dots; coral reefs by dotted lines.

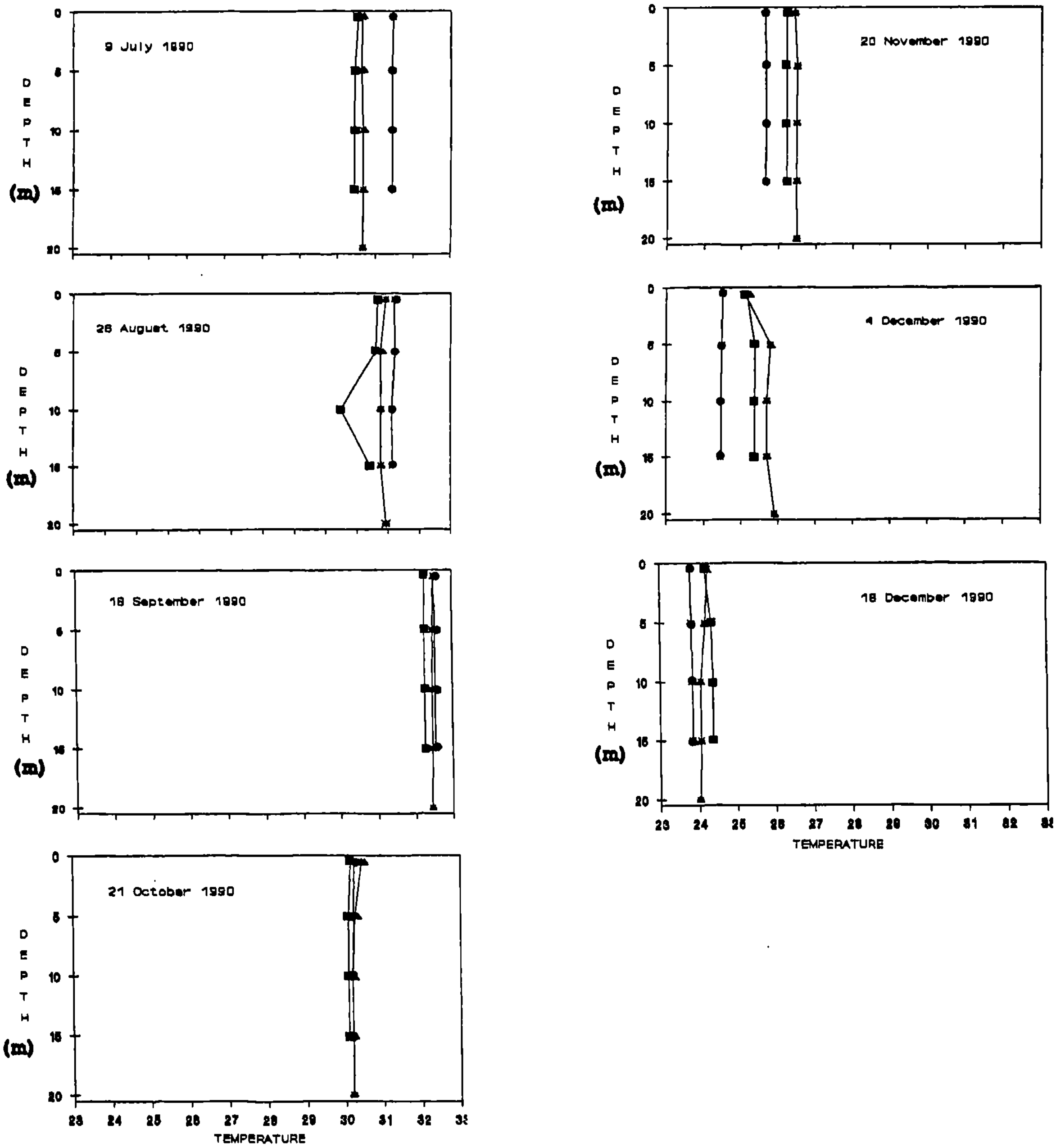

Figure 9. Temperature (°C) in selected pearl banks of Bahrain, at 5 m depth intervals on seven sampling dates for the locations; Abu Al-Jaal (triangle), Bu Amamah (square) and Shytayah (circle). The locations of these sites are shown in Figure 8 and these data are also shown in Table 2. (After Nayar and Al-Rumaidh 1993).

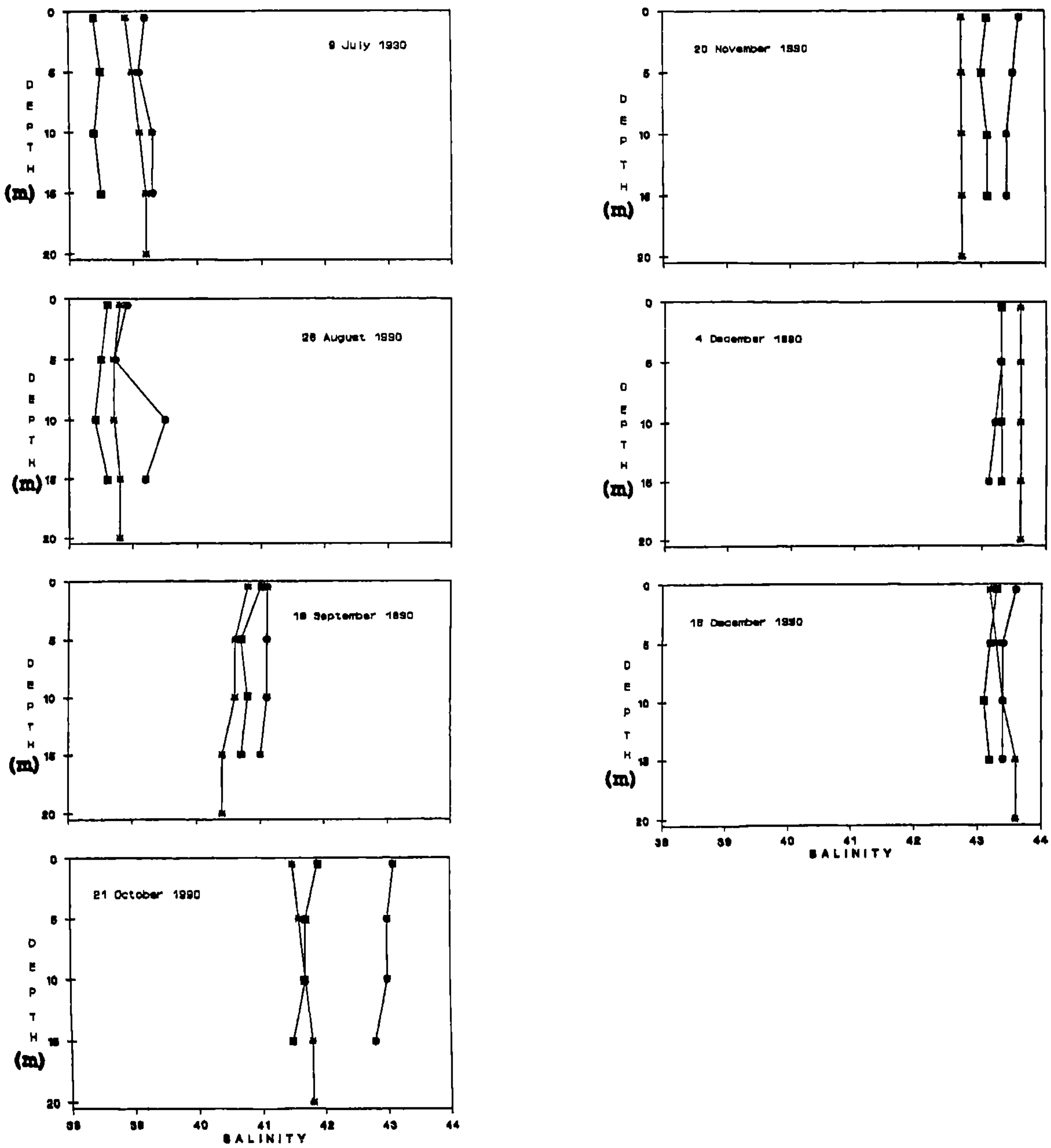

Figure 10. Salinity (ppt) records in selected pearl banks of Bahrain, at 5 m depth intervals on seven sampling dates for the locations, Abu Al-Jaal (triangle), Bu Amamah (seqaure) and Shytayah (circle). The locations of these sites are shown in Figure 8 and these data are also shown in Table 3. (After Nayar and Al-Rumaidh 1993)

Table 2. Temperature (°C) records in 5 m depth intervals at three selected pearl banks of Bahrain. These data are also shown in Figure 9. (After Nayer and Al-Rumaidh 1993)

SAMPLING DATE	DEPTH (m)	PEARL BANKS Abu Al-Jaal	Bu Amamah	Shutayah
9 July 1990	0	30.6	30.5	31.5
	5	30.6	30.4	31.4
	10	30.7	30.4	31.4
	15	30.7	30.4	
	20	30.7		
26 Aug. 1990	0	32.9	32.6	33.2
	5	32.7	32.6	33.1
	10	32.8	31.5	33.1
	15	32.8	32.4	
	20	32.9		
18 Sept. 199	0	32.5	32.3	32.5
	5	32.5	32.3	32.5
	10	32.5	32.3	32.5
	15	32.5	32.3	
	20	32.4		
21 Oct. 1990	0	30.4	30.2	30.2
	5	30.3	30.1	30.2
	10	30.2	30.1	30.2
	15	30.2	30.1	
	20	30.2		
20 Nov. 1990	0	26.4	26.2	25.6
	5	26.5	26.2	25.6
	10	26.5	26.2	25.6
	15	26.5	26.2	
	20	26.5		
4 Dec. 1990	0	25.1	25.2	24.5
	5	25.8	25.4	24.5
	10	25.7	25.4	24.5
	15	25.7	25.4	
	20	25.9		
18 Dec. 1990	0	24.3	24.2	23.8
	5	24.2	24.3	23.8
	10	24.1	24.4	23.8
	15	24.1	24.4	
	20	24.0		

Table 3. Records of salinity (ppt) in 5 m depth intervals at selected pearl banks of Bahrain. These data are also shown in Figure 10. (After Nayer and Rumaidh (1993)

SAMPLING DATE	DEPTH (m)	PEARL BANKS Abu Al-jaal	Bu Amamah	Shutayah
9 July 1990	0	38.9	38.4	39.2
	5	39.0	38.5	39.3
	10	39.1	38.4	39.3
	15	39.2	38.5	
	20	39.2		
26 Aug. 1990	0	38.8	38.6	38.9
	5	38.7	38.5	39.5
	10	38.7	38.4	39.2
	15	38.8	38.6	
	20	38.8		
18 Sept. 1990	0	40.8	41.0	41.1
	5	40.6	40.7	41.1
	10	40.6	40.8	41.0
	15	40.4	40.7	
	20	40.4		
21 Oct. 1990	0	41.5	41.9	43.1
	5	41.6	41.7	43.0
	10	41.7	41.7	42.8
	15	41.8	41.5	
	20	41.8		
20 Nov. 1990	0	42.7	43.1	43.6
	5	42.7	43.0	43.4
	10	42.7	43.1	43.4
	15	42.7	43.1	
	20	42.7		
4 Dec. 1990	0	43.6	43.3	43.3
	5	43.6	43.3	43.2
	10	43.6	43.3	43.1
	15	43.6	43.3	
	20	43.6		
18 Dec. 1990	0	43.2	43.3	43.6
	5	43.3	43.2	43.4
	10	43.4	43.1	43.4
	15	43.6	43.2	
	20	43.6		

III.1.2 Tubli Bay and Mina Sulman

In Tubli Bay and off Mina Sulman, the sea water temperature increased from May to September 1991, when the maximum temperature occurred (Figures 11 and 12). After that time temperature fell both in Tubli Bay and off Mina Sulman to minimum values in January (Figures 11 and 12). Temperatures increased again from February in both Tubli Bay and Mina Sulman (Figures 11 and 12). Salinities were relatively constant through most the sampling period but with slight maxima around May and November at each locality (Figures 11 and 12).

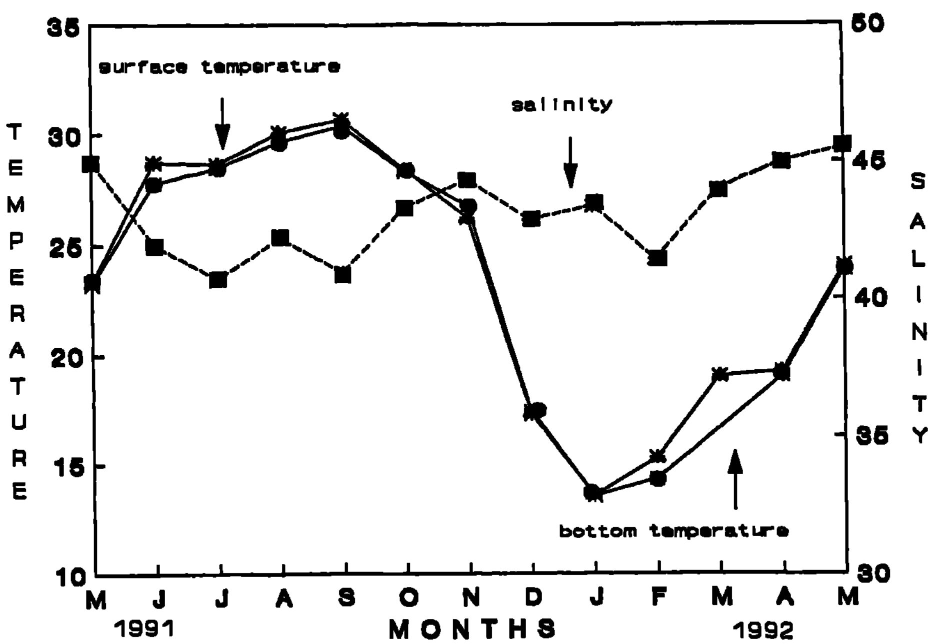

Figure 11. Surface and bottom temperature (C°) and surface salinity (parts per thousand) in Tubli Bay (S1 in Figure 2) from May 1991 to May 1992.

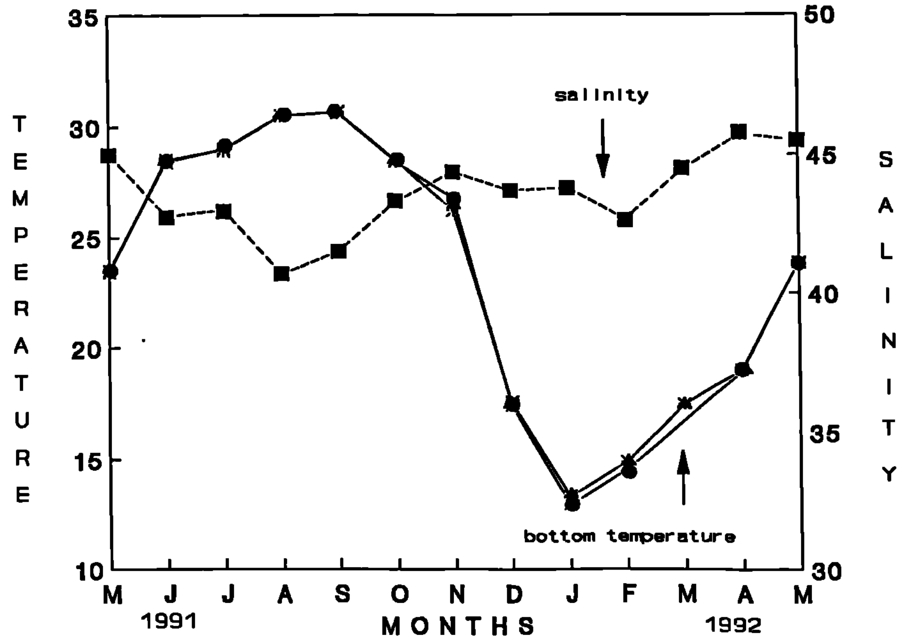

Figure 12. Surface and bottom temperature (C°) and surface salinity (parts per thousand) off Mina Sulman, averaged for S2 and S3 (Figure 2), for the period from May 1991 to May 1992.

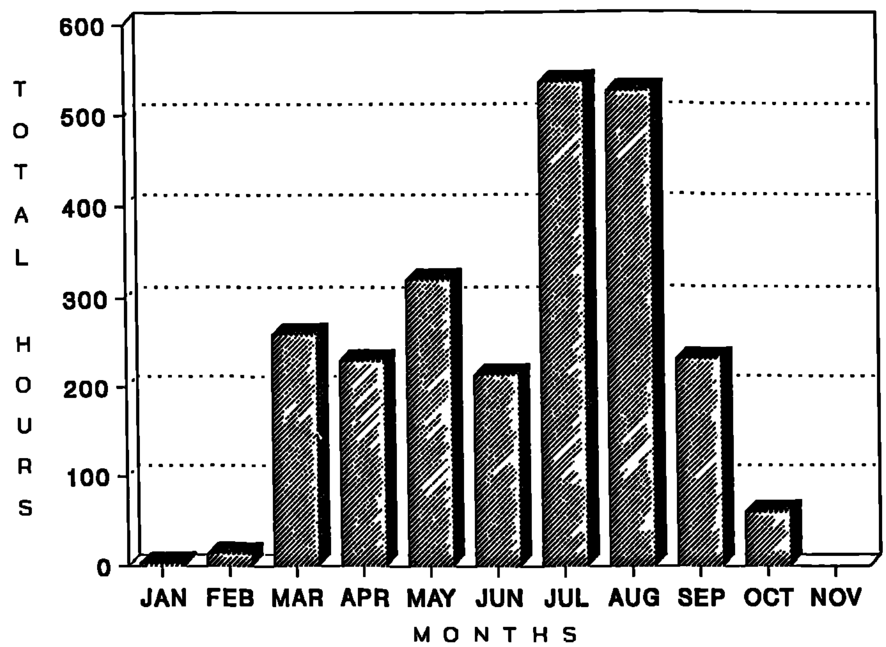

Figure 13. Total hours of smoke per month in the Bahrain atmosphere in 1991. Source: Bahrain Civil Aviation Directorate, Meteorological Service, (Shaw 1992).

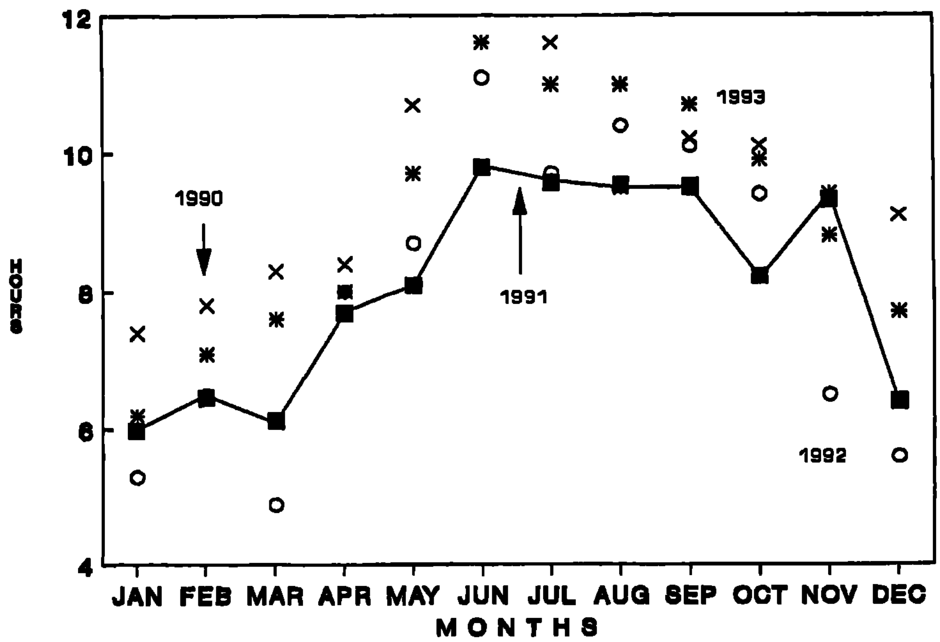

Figure 14. Daily average hours of sunshine for 1991 compared with similar data for 1990, 1992 and 1993. Source: Bahrain Civil Aviation Directorate.

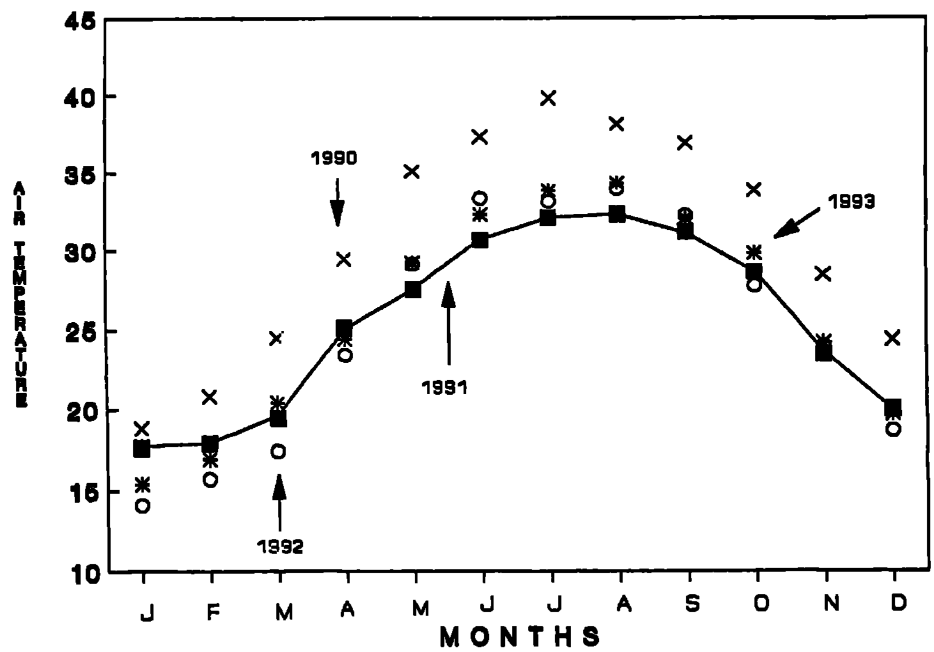

Figure 15. Average air temperature during 1991 compared with similar data for 1990, 1992 and 1993. Source: Bahrain Civil Aviation Directorate.

III.2 Gulf War effects on the sea water temperature

In the Bahrain atmosphere, smoke from Kuwait burning oil wells was most apparent from March to September 1991, but with a peak in July and August (Figure 13). Coinciding with this period, a slight reduction in the average daily sunshine hours was found from April to October 1991, compared to the same period during 1990, 1992 and 1993 (Figure 14). Similarly, slight reductions in air temperatures were clearly seen from May to September 1991 in relation to the same period in the year during 1990, 1992 and 1993 (Figure 15). Figure 16 shows water temperature during 1991 compared to the average for 1990, 1992 and 1993 at the intake of Sitrah Power Station (Figure 2). Water temperatures showed lower values from May to September 1991 than the average temperature in the same months for the years 1990, 1992 and 1993 (Figure 16).

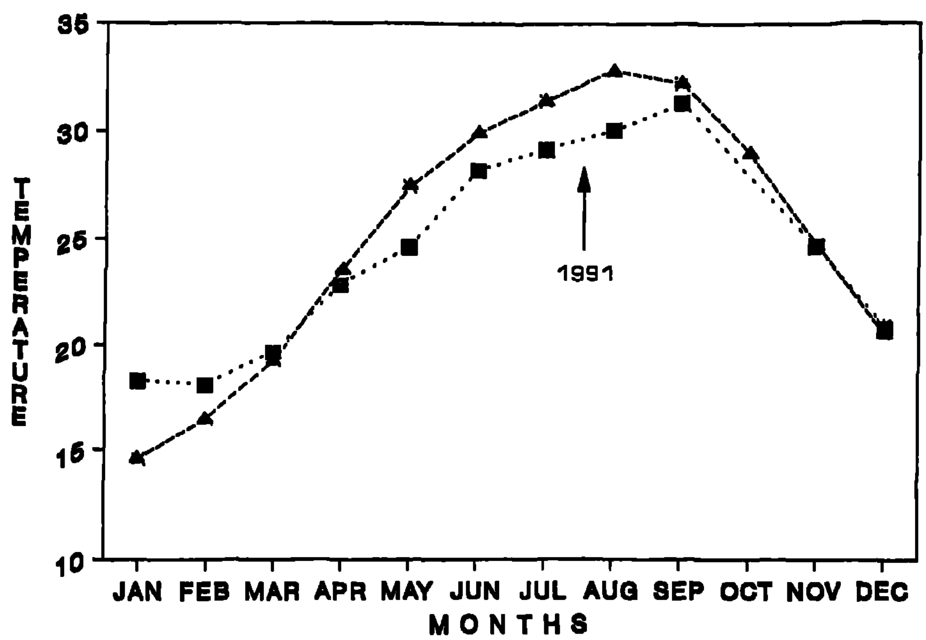

Figure 16. Monthly average seawater temperature during 1991 compared to the average of 1990, 1992 and 1993 (triangles). Measured at Sitrah power station intake (Figure 2). Source: Sitrah power station.

III.3 Sediment survey

A contour drawing for the surface sediment based on the average grain size is shown in Figure 17, and Figure 18 shows the approximate limits of the Bahrain shrimping ground. From these figures it appears that most of the known shrimping grounds are in areas to the immediate north and east of Bahrain where sediment sizes are of 400 μ or smaller in depths of around 20m or less. Fishing appears not to take place on similarly small-sized sediment grounds at greater depths to the north of Bahrain. The areas of grain sizes greater than 400 μ between the northerly and southerly regions of small grain size on Figure 17 are where most known pearl banks of Bahrain occur (Figures 8 and 17).

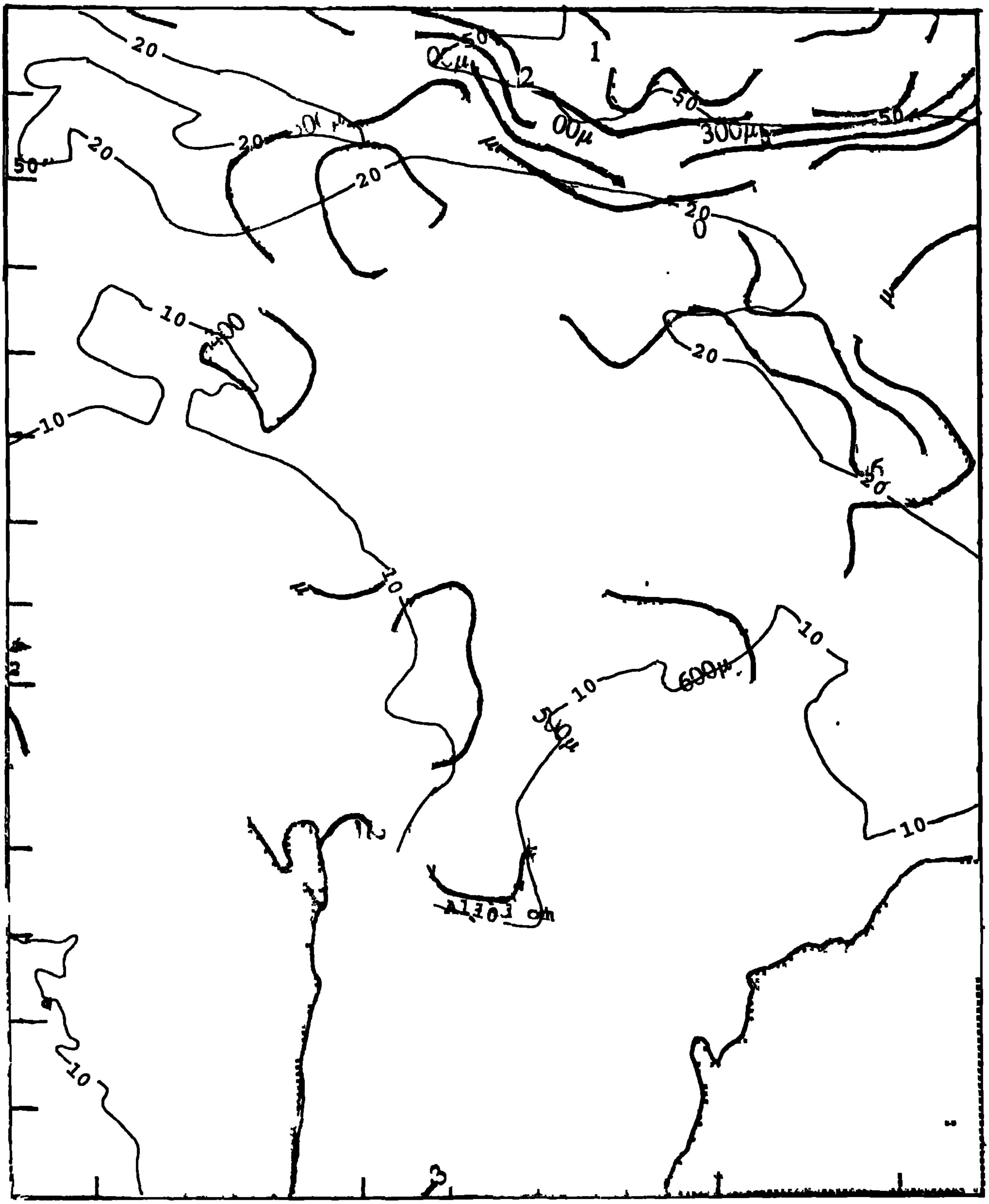

Figure 17. Contour drawing of average grain size of the surface sediment (solid lines). Coral reef areas are outlined by dotted lines, land are shown by dots. For depth contour lines see the overlay sheet.

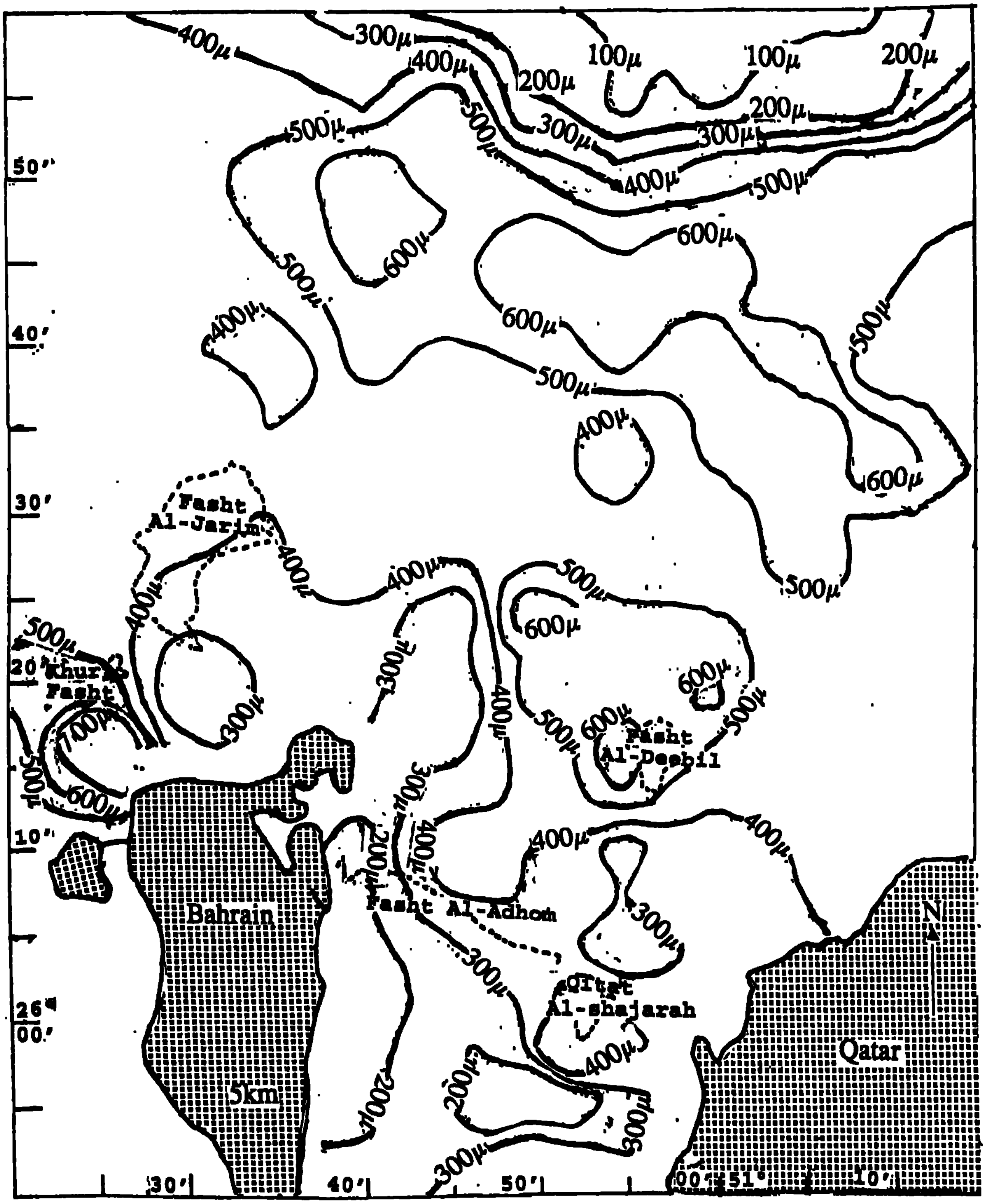

Figure 17. Contour drawing of average grain size of the surface sediment (solid lines). Coral reef areas are outlined by dotted lines, land are shown by dots. For depth contour lines see the overlay sheet.

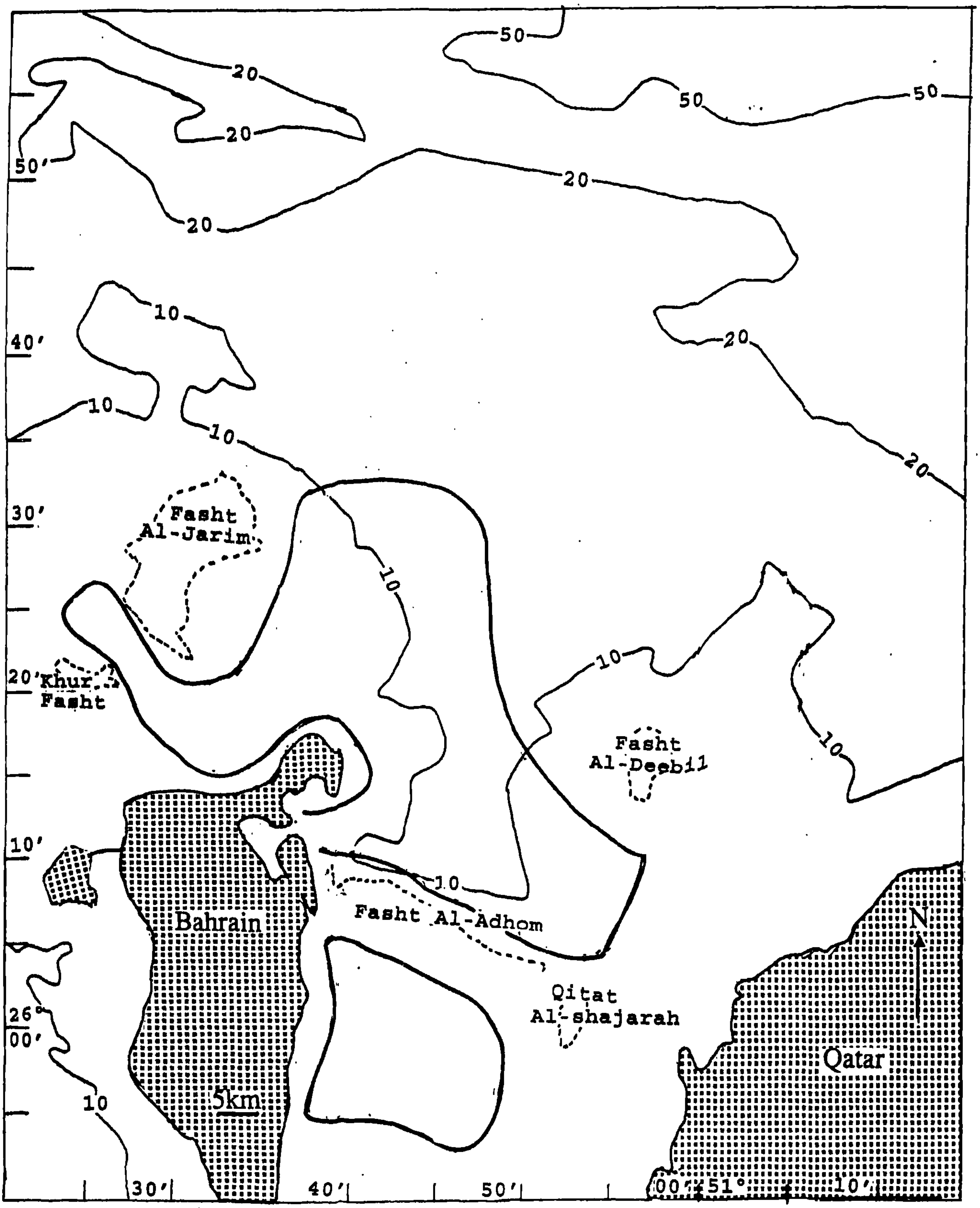

Figure 18. Shows the approximate limits of the Bahrain shrimping grounds (outlined by thick lines). Land shown by dots, coral reef outlined by dotted lines; depth contour are shown in meters.

IV. DISCUSSION

IV.1 Physical properties of sea water off Bahrain

Present work on the open sea areas was restricted to few observations. However, these data and the inshore sampling in Tubli Bay and off Mina Sulman, together with information in Nayar and Al-Rumaidh (1993), provide useful information on spatial and temporal patterns of sea water temperature and salinity in Bahrain water.

Lower salinities were usually found offshore and to the north rather than in inshore waters, perhaps due to land run off from the Iranian coast. Certainly, FAO (1981a) reported that salinity was relatively lower on the Iranian side than on the Arabian side of the Gulf. Also Raynold (1993) determined lower salinities toward the Iranian coast along the Qatari-Iranian transect.

Lower salinity found during summer in both offshore and inshore waters, indicates that a general decline occurred in the area, which was probably caused by higher land run off from the Iranian coast during summer.

Nearly constant surface and bottom temperatures found in the current work and that of Nayar and Al-Rumaidh (1993) suggested the absence of the thermoclines at least from July to December. FAO (1981a) identified thermoclines in the north east region of the Gulf in July 1978 and September 1977 at depths between 5 to 15 m and 10 to 50 m respectively.

Differences in the temperature of the offshore and inshore waters were seen in the present work and by Nayar and Al-Rumaidh (1993). Also in both offshore and inshore waters there were marked differences in temperature between summer and winter, as Raynold (1993) also showed along the Qatari-Iranian transect. In both offshore and inshore waters, temperature declined markedly from November to January, when numbers of large shrimp in the whole area declined significantly (see chapter 4). In June, temperatures were uniformly high in offshore and inshore waters, coinciding with the period when *Penaeus semisulcatus* were most abundant. The appearance of *P. semisulcatus* and *M. stebbingi* juveniles in the inshore waters (see chapter 4) coincided with rising temperatures in February, as also reported by Young (1978) and Rogers et al. (1993).

IV.2 Effect of the smoke resulting from Kuwait oil well fires

The effect of the smoke was apparent in a slight reduction of the sea water temperature, especially from May to August 1991. Even more markedly, McCain et al. (1993) determined 2.5°C lower mean temperature in 1991 compared with the means for 1986 to 1990 at Manifa pier, Saudi Arabia. The period of temperature reduction coincided with the normal timing of *P. semisulcatus* recruitment (see chapter 4), and a correlation with poor recruitment was noted. In the 1991/92 shrimping season, there was a 56.6 percent decline in shrimp landings to 646.5 tonnes compared to 1142.9 tonnes during the 1990/91 season, with only a 2.4 percent decline in fishing effort (Fisheries Statistical Services 1993). However, though temperature reduction by smoke emission was followed by low recruitment, it is not possible to conclude that such a decline in shrimp landings was due to the consequences of the Gulf War. The 1991/92 shrimping season came at the end of a sequence of several bad shrimping seasons (Fisheries Statistical Service 1993), and fishing during the 1991/92 season was restricted to certain areas and time (Fisheries Statistical Service 1992).

VI.3 Sediments of Bahrain fishing ground

The area of the present study, located within the north west part of the Arabian Gulf (Brewer et al. 1978, FAO 1981a), is characterized by low wave and tidal energy and consequent high deposition rates of the sediment (Al-Ghadban 1993). Such areas contain most of the important shrimping grounds of the Arabian Gulf (FAO 1981b). Branford (1981) found that the abundance of the *Penaeus semisulcatus* of the Red Sea increased with increasing fineness of sediment. Similarly, in Australian waters, *Penaeus semisulcatus* showed preference for sediment with a high mud content (Somers 1987 & 1994). The present study revealed that most of the shrimping ground were found in sediments of average grain size of 400 μ or less.

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CHAPTER TWO
TOPOGRAPHY AND PHYSICAL CHARACTERISTICS OF BAHRAIN SHRIMP FISHING GROUNDS

SUMMARY

Bionomics of penaeid shrimp have been found to be influenced by water temperature (Al-Attar and Ikenoue 1974, Laubier and Laubier 1979, Caubere et al. 1979, Aquacop 1975 1979, Price 1979, Penn 1980). In addition the surface sediments of the sea bottom influence the distribution of the penaeid species (Brandford 1981, Somers 1987 and 1994, Penn 1980). The aim of this chapter was to describe the environment of the Bahrain shrimping grounds and to relate it to the shrimp bionomics. A sediment survey was conducted within the area extending from 25° 50' to 27° 00' North and 50° 20' to 51° 15' East. 129 stations were sampled from 9 August to 26 October 1990, and a contour drawing of the surface sediment mean grain size for the whole Bahrain fishing ground was derived. Shrimp grounds were located in areas with average grain size of 400μ or less. From May 1991 to May 1992, a regular sampling programme was initiated to record the physical properties of sea water at fixed stations in Tubli Bay and off Mina Sulman. The physical properties of sea water were also recorded in the open sea during June 1980, October and December 1991. Information collected during the present work, together with that in Nayar and Al-Rumaidh (1993), provides useful information on spatial and temporal pattern of sea water temperature and salinity in Bahrain waters. Shrimp recruitment occurred at times of rising sea temperature. Since part of this work was conducted during the Gulf War, the effect of atmospheric smoke in the sampling area was also studied. The effect of smoke was a slight reduction of the sea water temperature, especially from May to August 1991. However, though temperature reduction by smoke emission was followed by low shrimp recruitment, it is not possible to conclude that such a decline in shrimp landings was due to the consequences of the Gulf War.

CHAPTER THREE

PLANKTONIC PHASE OF PENAEID SHRIMPS OF BAHRAIN WATERS

I- INTRODUCTION

Estimates of the spawning times of penaeid shrimp in the Gulf area have often been based upon the presence or absence of mature and maturing females in commercial catches. This method provides some indication of spawning times but considerable variation is apparent in such estimates. Thus for example some authors have suggested for the main shrimp species *Penaeus semisulcatus* that spawning is protracted (Thomas 1974, Van Zalinge 1980), while others have indicated spawning during short periods in spring and autumn (Enomoto 1971, FAO 1978 & 1982, Price and Jones 1975, Al-Attar and Ikenoue 1974, Price 1979, Mohammed et al. 1980). Such uncertainty concerning spawning times of the most important commercial penaeid shrimp clearly presents difficulties when considering management regulation issues, for example in the enforcement of protection periods for the spawning stock.

Additional and more precise information on penaeid spawning times and localities in the Gulf area has been obtained through plankton sampling (Price & Jones 1975, Price 1979 & 1982, Water Resources and Environment Division 1990, Grabe and Lees 1992, Al-Aidaroos 1993). However in Bahrain waters only limited observations are available in the literature on plankton in general and on penaeid larvae in particular (Atkins and partners 1985, IUCN n.d.) . Hence there is a clear need for more detailed studies on the planktonic stages of penaeids in the vicinity of Bahrain if penaeid spawning behaviour in that locality is to be fully understood.

Therefore, this work set out to provide details on early life histories and spawning behaviour of penaeids in that locality, based on plankton samples.

II- MATERIALS AND METHODS

Plankton collection was conducted mainly through two sampling programmes in areas predetermined from fisheries data concerning the abundance of shrimp. The first was along the open-sea shrimping grounds extending from the area of Fasht Al-Adhom northward to Al-Mayanah (Figure 1). The second was restricted to Tubli Bay (Figure 2). In the open-sea programme a speed boat (total length 10 m, with two 180 h.p. outboard Yamaha engines) was used through special arrangement with Bahrain Centre for Research and Studies. This boat could not be used in Tubli Bay because of difficulties of access. Tubli Bay plankton sampling was carried from a small boat (6 m with a single 80 hp Yamaha engine) belonging to the Directorate of Fisheries. The same sampling gear was used from each boat and collections were compared by expressing catches as a density index (individuals m^{-3}).

All sampling was conducted using horizontal tows at night since zooplankton in general are often more abundant in the upper layers at night (Raymont 1963).

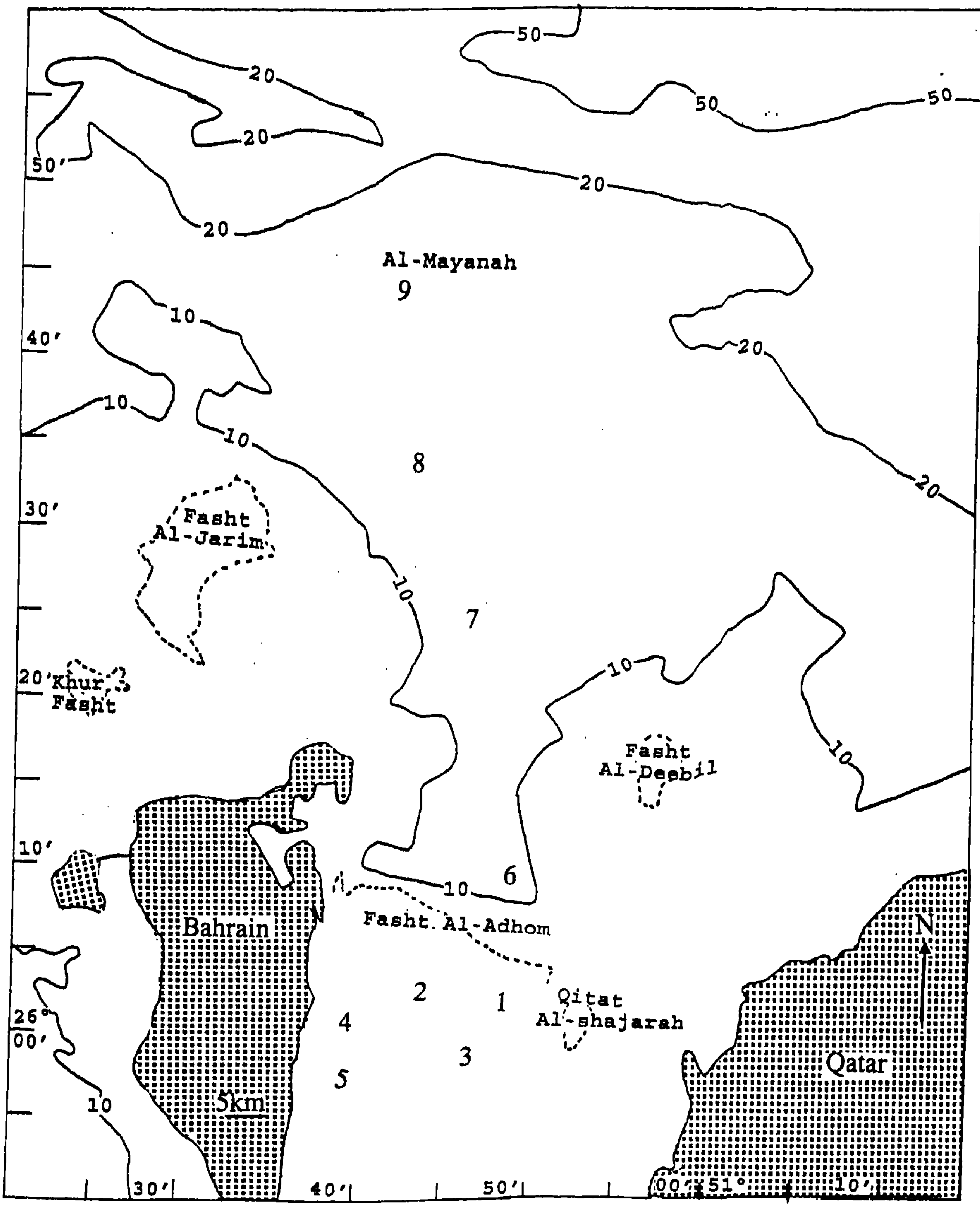

Figure 1. Open sea plankton sampling stations 1 to 9 in the Bahrain shrimping grounds. Depth contours (in meters) and important coral reefs (outlined by dotted lines) are also shown.

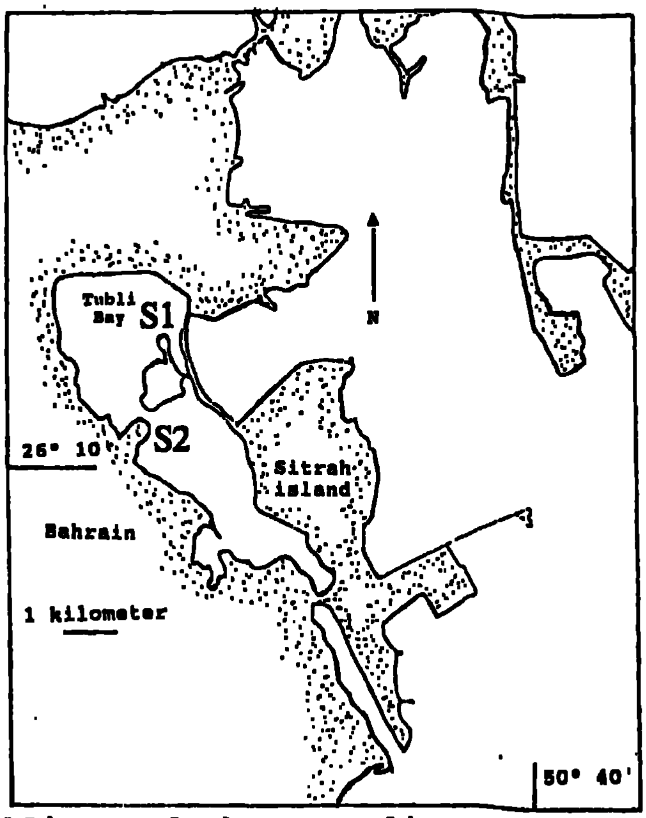

Figure 2. Tubli Bay plankton sampling stations S1 and S2. S1 S2

II.1 Open-sea samples

Stations were located to cover the full depth range of the shrimping ground (Figure 1). Stations 1 to 5 were located to the south of coral reef Fasht Al-Adhom, and station 6 to 9 were located on a line extending northward towards middle of the Gulf. The coordinates and mean depths of these stations are as follows:

St. Number	Coordinates		Mean Depth(m)
1	25 58 75 N	50 48 81 E	11.9
2	25 56 20 N	50 43 80 E	14.8
3	25 55 55 N	50 46 95 E	14.5
4	25 58 80 N	50 38 20 E	14.2
5	25 55 80 N	50 38 80 E	11.0
6	26 08 00 N	50 47 60 E	16.8
7	26 23 00 N	50 46 00 E	10.5
8	26 34 50 N	50 42 10 E	14.4
9	26 45 00 N	50 42 00 E	16.3

The open-sea sampling programme was conducted from September 1991 to January 1992, excluding November 1991 (Figure 3). This period covered the presumed spawning time for *Penaeus semisulcatus* (see chapter 4).

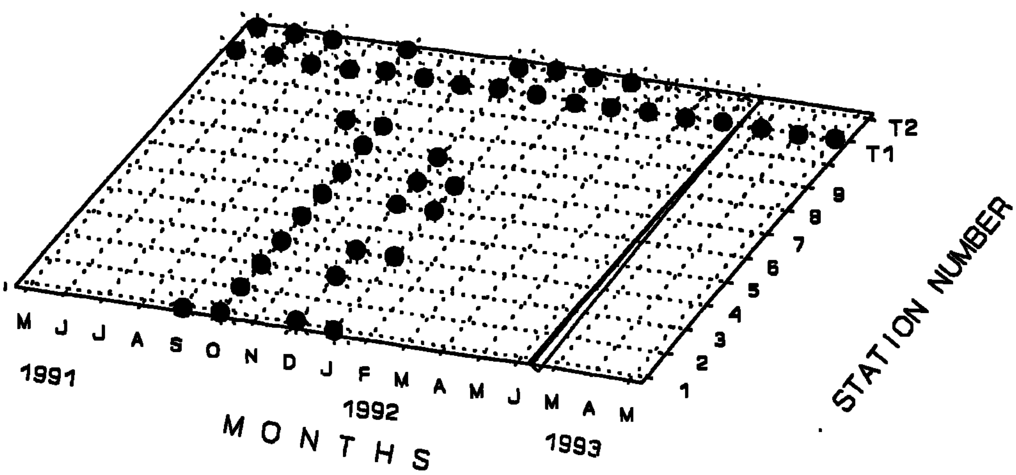

Figure 3. Months when plankton samples were obtained in Tubli Bay (T1 and T2) and in the open sea (station 1-9) during the period May 1991 to May 1993, with a gap from July 1992 to February 1993.

II.2 Tubli Bay

Two stations were sampled within Tubli Bay (Figure 2), Station 1 in the deepest area (about 11 m) to the north and Station 2 over a maximum depth of 2 m in the southern portion of the Bay. At station 1, samples were obtained during new and full moon, over periods from May 1991 to June 1992 inclusive and from March to May 1993 inclusive (Figure 3). Station 2 was sampled from May 1991 to June 1992, with gaps in August, October and December 1991 (Figure 3).

II.3 Sampling Procedure

For most samples a standard 0.5 m diameter plankton net (Kahlsico cat. no. 008WA202, mesh size 390 micron) was used after modification by the addition of netting material (about 1 mm mesh size) at the front of the net. The modification increased the diameter of net to 0.97 m, thus increasing the sample volume. An unmodified version of the net was used at the shallow station 2 in Tubli Bay and occasionally elsewhere when the larger net was damaged.

On each sampling occasion a pre-calibrated pygmy type flowmeter (Khalsico model no. 005WB138) was placed at the centre of the net mouth. The net was towed for a standard 10 minutes period on each sampling occasion. At the end of each plankton collection, the resulting (≈300 ml) sample was transferred to a plastic container. Then, depending on plankton density, 40% Borax Formaldehyde solution was added to the sample to make 2 to 4% Formaldehyde solution for preservation. The Borax Formaldehyde solution was prepared following Omari & Ikeda (1984), except that because of handling restrictions (Ministry of Health), Borax was substituted by Sodium tetraborate-10-hydrate.

After preservation of the plankton sample, label details were written on the bottle and also on thick paper placed inside the plastic bottle. Sample numbers were formatted as follows:-

```
 1   2    3      4  5 6
AAA\AA\DD-MM-YY\NN\N\N
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where, 1 is the sampling area, TUB in case of Tubli Bay samples & ASK for station outside Tubli

2 is the sampling gear used, which is PK for plankton

3 sampling date
4 sample number
5 replicate number
6 bottle number

In most cases two replicate tows were made per station, except for station 2 inside Tubli Bay where only one sample was collected.

II.4 Processing of plankton samples

From each sample, two 66 ml sub-samples (v) were taken randomly after stirring. All individuals in predetermined taxa or developmental stages were counted (n_i) in one sub-sample, including penaeid eggs, larvae and post-larvae. In the second sub-sample only penaeid eggs, larvae and post-larvae were counted. All penaeid larvae counted from each sub-sample were preserved in 4% Borax formaldehyde solution as well the original sample. In addition to the penaeid material in the plankton samples the Copepoda and total zooplankton abundance were recorded.

II-5 Calculation of plankton density

Total filtered volume (V_f) of seawater was calculated from the following equation;

$$V_f = \frac{1}{2} d r^2 ¶$$

where d is the distance (m) travelled by net which equal to (R2-R1)/rpm, where R1 & R2 are flowmeter readings before and after each tow, and rpm is the revolutions per meter obtained from flowmeter calibration

r is the net radius, which equal to 0.485 m.

¶ is equal to 3.1429

Total number (N_i) of ith-group in the whole sample was obtained by ratio estimation from the following equation;

$$N_i = (V/v) * n_i$$

where V sample total volume
v sub-sample volume (=66 ml)
n_i number of ith-group in sub-sample

Accordingly the density (number per cubic meter) of the ith-group for a sample was obtained from the following

$$N_i \;/\; V_f$$

Densities of the ith-group in a station were obtained from direct averaging of four sub-samples results in the case of penaeid plankton. The averages of two sub-samples were calculated for Copepoda and total zooplankton density. Monthly estimates were calculated by direct averaging of the fortnightly densities.

II.6 Identification of penaeid eggs, larvae and post-larvae

Penaeid larvae were identified by the general characters outlined by Cook (1966) and to genus or species level following Davarajan et al (1978), Muthu et al. (1978), Shokita (1984), Jackson et al. (1989), Chong (1991) and Al-Attar (n.d.).

II.6.1 Eggs

Since egg diameter and perivitelline space are the most important characters used in the identification of penaeid eggs (Muthu et al. 1978), egg and yolk diameters (Figure 4) were measured for most of the penaeid eggs found in the collection.

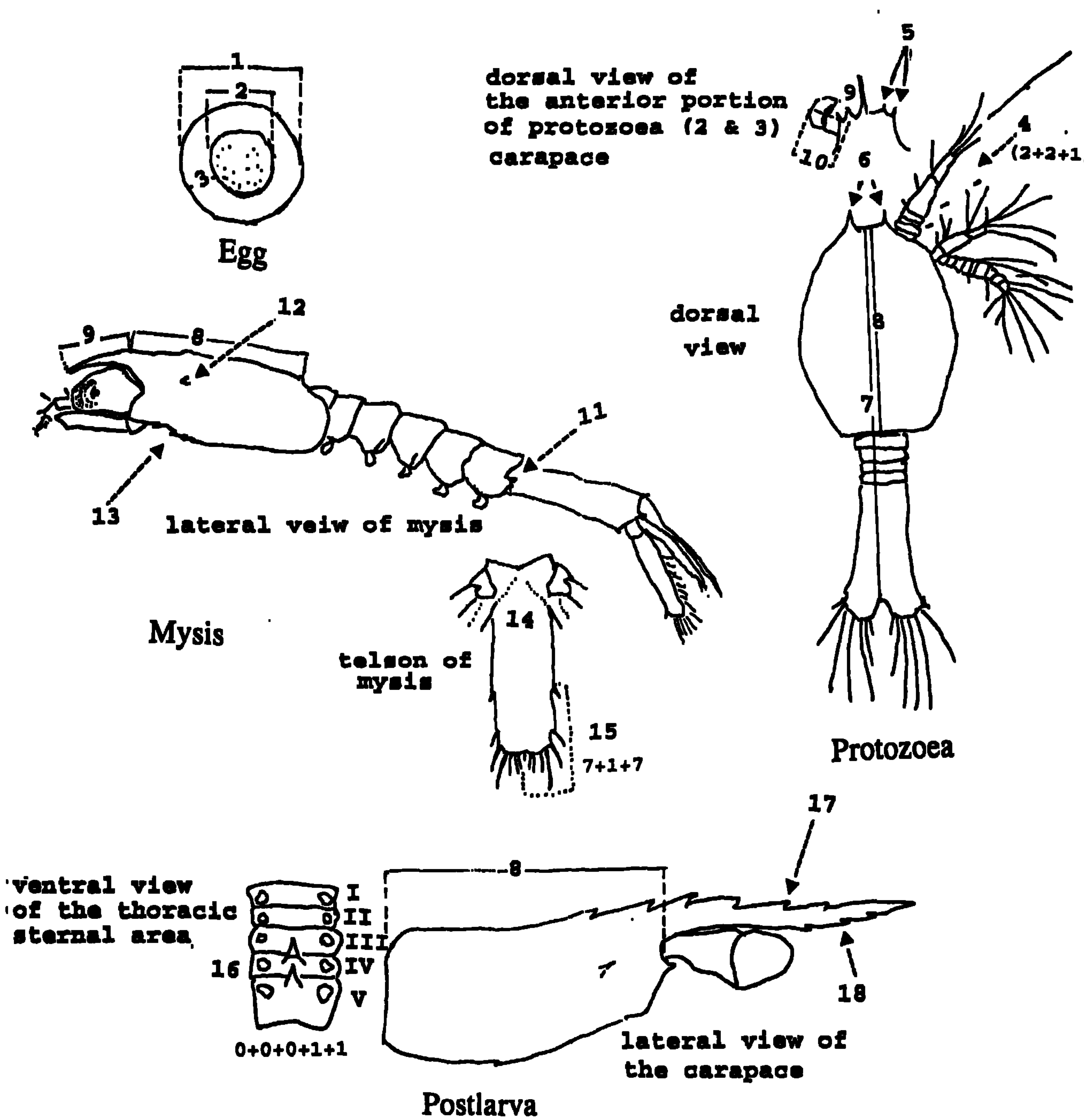
Based on their shape, locality of origin and time of collection, five types of penaeid egg were provisionally identified. Egg type 1 is medium sized with wide perivitelline space; it was found only in the open sea collections. Egg types 2 and 5 were found in Tubli Bay collection only during the months March to June; egg type 2 is of medium size with a wide perivitelline space, and egg type 5 is smaller with narrower perivitelline space. Egg Type 3 is a typical *Penaeus* egg of small size with narrow perivitelline space; it was found in the open sea collection. Egg Type 4 is large with a very wide perivitelline space; it was found only in the open sea area.

The validity of this egg grouping was confirmed by Discriminant Analysis (Chatfield and Collins 1980) applied to egg and yolk diameters for similar numbers of observations randomly selected from each egg type. The significance of differences of the average sizes of all egg types was tested by t-test.

For comparison, eggs of *Penaeus semisulcatus* and *Metapenaeus stebbingi* were obtained from the National Mariculture Centre (NAMAC) and Bahrain Centre for Studies and Research (BCSR) respectively. Gravid females of *M. stebbingi* spawned in BCSR were collected from Tubli Bay during the adult sampling programme (see chapter 4).

II.6.2 Protozoeae

The most important characters in protozoea identification (Muthu et al. 1978, Jackson et al. 1989) are numbers of setae on the inner margin of the endopodite of the second thoracic appendages (A2 formula), numbers of supraorbital spine pairs and the presence of the frontal spines (Figure 4). These characters, together with measurements of the total, carapace and rostrum length, and eye stalk length were noted (Figure 4).



1 egg diameter	10 eye stalk length
2 yolk diameter	11 posterio-lateral spine
3 perivitelline space	12 hepatic spine
4 A2 spine formula	13 carapace antero-ventral serration
5 Supra-orbital spines	14 telson
6 Frontal spine	15 telson formula
7 total length	16 thoracic sternal spine formula
8 carapace length	17 dorsal rostral teeth
9 rostrum length	18 ventral rostral teeth
I to V thoracic segments	

Figure 4. Distinctive characters used for identification of penaeid egg, larvae and postlarvae.

II.6.3 Mysis

The main characters used to identify the penaeid mysis (Muthu et al. 1978, Jackson et al. 1989, Al-Attar n.d.) are rostrum length in-relation to eye length, presence of posterio-lateral spines on the fifth abdominal segment, presence of the hepatic spine and telson spines formula (Figure 4). The presence of serration on the anterior ventral margin of the carapace is also an important feature in identification of the mysis of the genus *Metapenaeopsis* (Jackson et al. 1989). In addition to these characters, carapace length (Figure 4) measurement for each specimen was recorded.

II.6.4 Post-larvae

The main characters used for penaeid post-larvae identification (Muthu et al. 1978, Jackson et al. 1989) are rostrum length in relation to the eye, presence of the rostrum ventral spines, telson spines formula and the spine formula of the thoracic sterna (Figure 4). In addition to these characters, records of carapace length for each specimen were kept.

III RESULTS

III.1 Identification of penaeid eggs, larvae & post-larvae

III.1.1 Eggs

Scatter plots of egg diameter against yolk diameter for the five provisionally defined egg types (see Materials and Methods), together with similar plots for confirmed *P. semisulcatus* and *M. stebbingi* eggs, are shown in Figure 5. All five egg types show different plot locations which are broadly confirmed by Discriminant Analysis (Figure 6). Egg diameter and perivitelline space means for the five egg types, together with the means for *P. semisulcatus* and *M. stebbingi* are shown in Table 1. Student t-tests on the difference in mean egg diameters between pairs of these five egg types and the eggs collected from *P. semisulcatus* and *M. stebbingi* are presented in Table 1. All pairs of egg types showed significant differences, except for egg type 3 and *P. semisulcatus* eggs (Table 1). It is reasonable to accept egg type 3 as *Penaeus semisulcatus* on this evidence. Also it is logical to accept type 2 as *Metapenaeus stebbingi* and type 5 as *Metapenaeus kutchensis* from the presence of the gravid females of both species in Tubli Bay during same periods (see chapter 4). However, because it is difficult to determine the species, egg type 3 was identified as *Penaeus* egg only.

Based on the above, the five egg types found in the plankton collection are identified accordingly as follows; (1) egg type 1, (2) *Metapenaeus stebbingi* eggs, (3) *Penaeus semisulcatus* eggs, (4) egg type 4 and (5) *Metapenaeus kutchensis* eggs.

III.1.2 Protozoea

Protozoeal stages were the most abundant larvae in the present penaeid plankton collections. Five types were identified during provisional identification, namely; *Penaeus*, *Trachypenaeus*, *Metapenaeopsis*, *Metapenaeus* 1 and *Metapenaeus* 2 protozoae. Scatter plots of total length against carapace length for all protozoeal types at various development stages are illustrated in Figure 7.

Penaeus protozoae and their sub-stages could be identified by the A2 formula (2+1+1) of the endopodite of the second thoracic appendage (Table 2). It was not possible to distinguish between *P. semisulcatus* and *P. latisulcatus* protozoae.

Trachypenaeus protozoae and their sub-stages were identified by the A2 formula which reads as 2+2+0. Protozoea 2 and 3 of this species were also characterised by the absence of a supraorbital spine (Table 2) (see Figure 4).

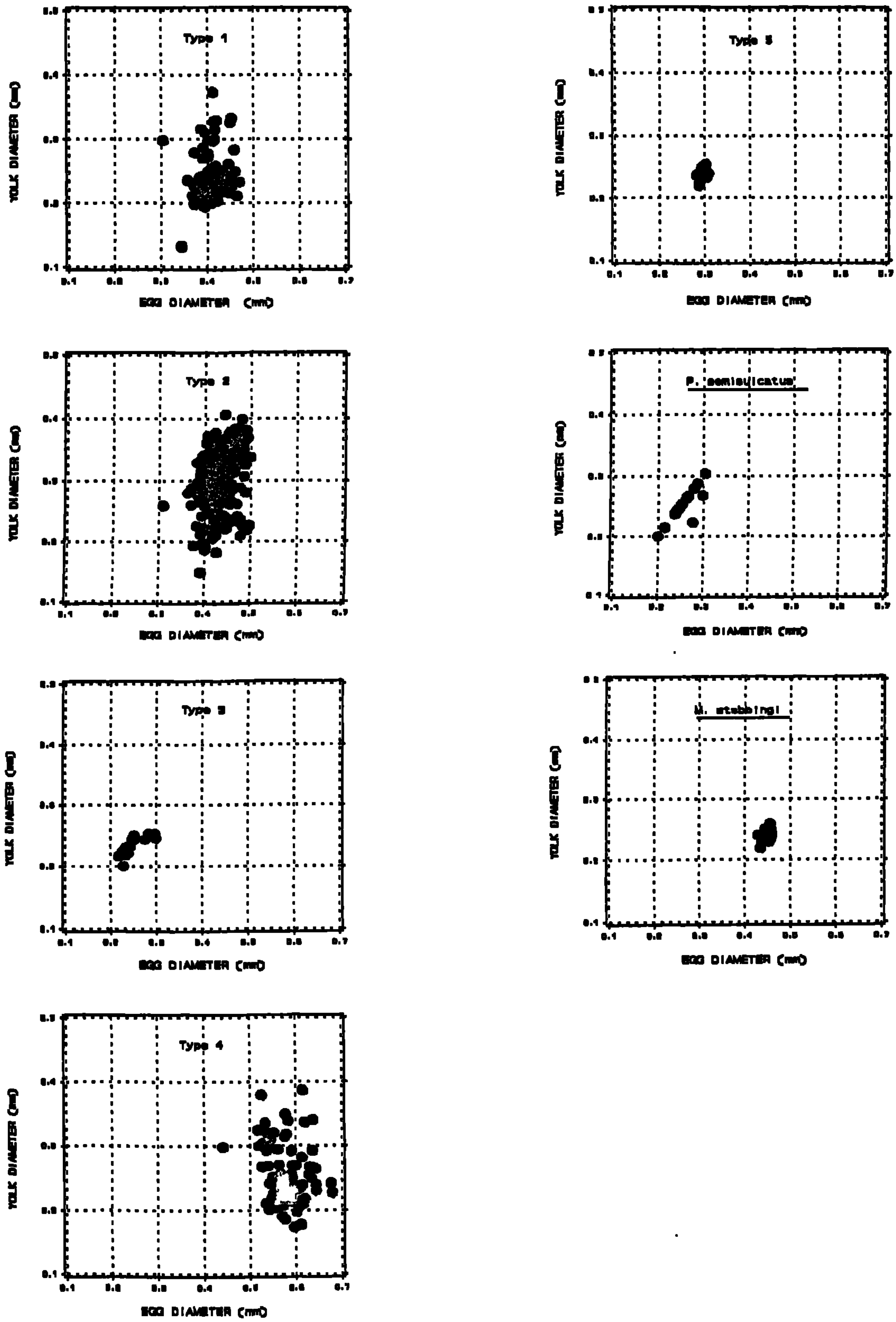


Figure 5. Scatter plots of egg diameter versus yolk diameter for all egg types found in the plankton collection and for confirmed samples of both *P. semisulcatus* and *M. stebbingi* eggs.

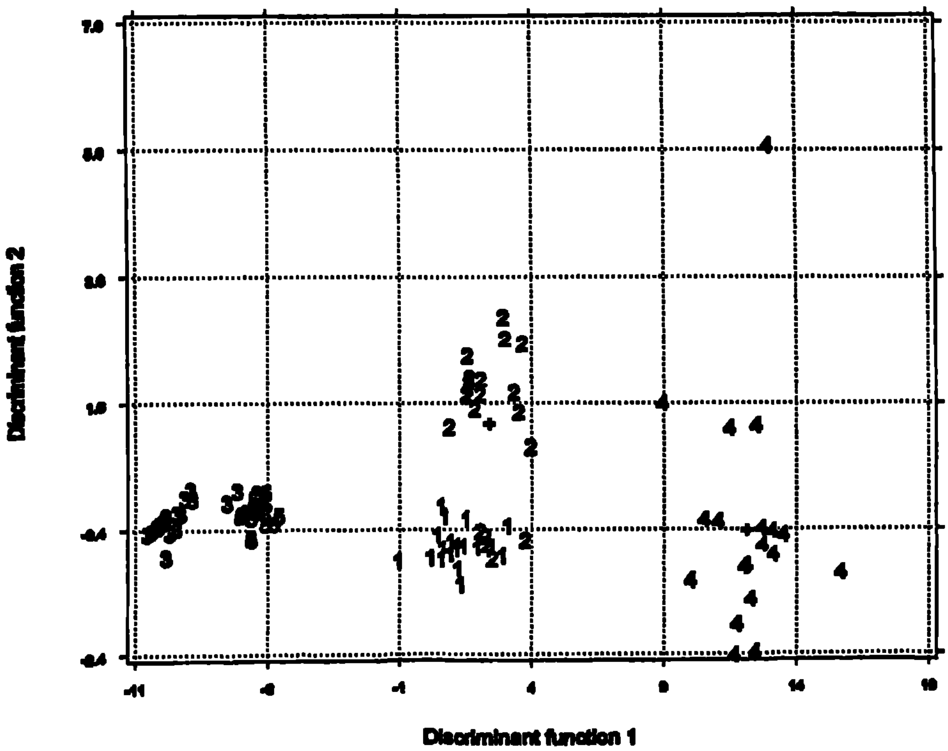


Figure 6. Five egg groups determined by Discriminant Analysis method.

Table 1 Egg diameter mean (x in microns) and standard deviation (sd), number of observation (n) and average perivitelline space (in microns) for five unknown egg types and those of *P. semisulcatus* (PS) and *M. stebbingi* (MS) in present samples.

		EGG TYPES 1	2	3	4	5	PS	MS
egg	x	0.404	0.426	0.244	0.578	0.294	0.259	0.45
diameter	sd	0.026	0.029	0.024	0.035	0.007	0.024	0.008
	n	128	347	21	123	22	24	24
	*	a	b	c	d	e	c	f
periv. space		0.168	0.126	0.014	0.328	0.056	0.004	0.211

* pairs with different letters are all significantly different from each others.
Please refer to Figure 4 for measurement dimensions.

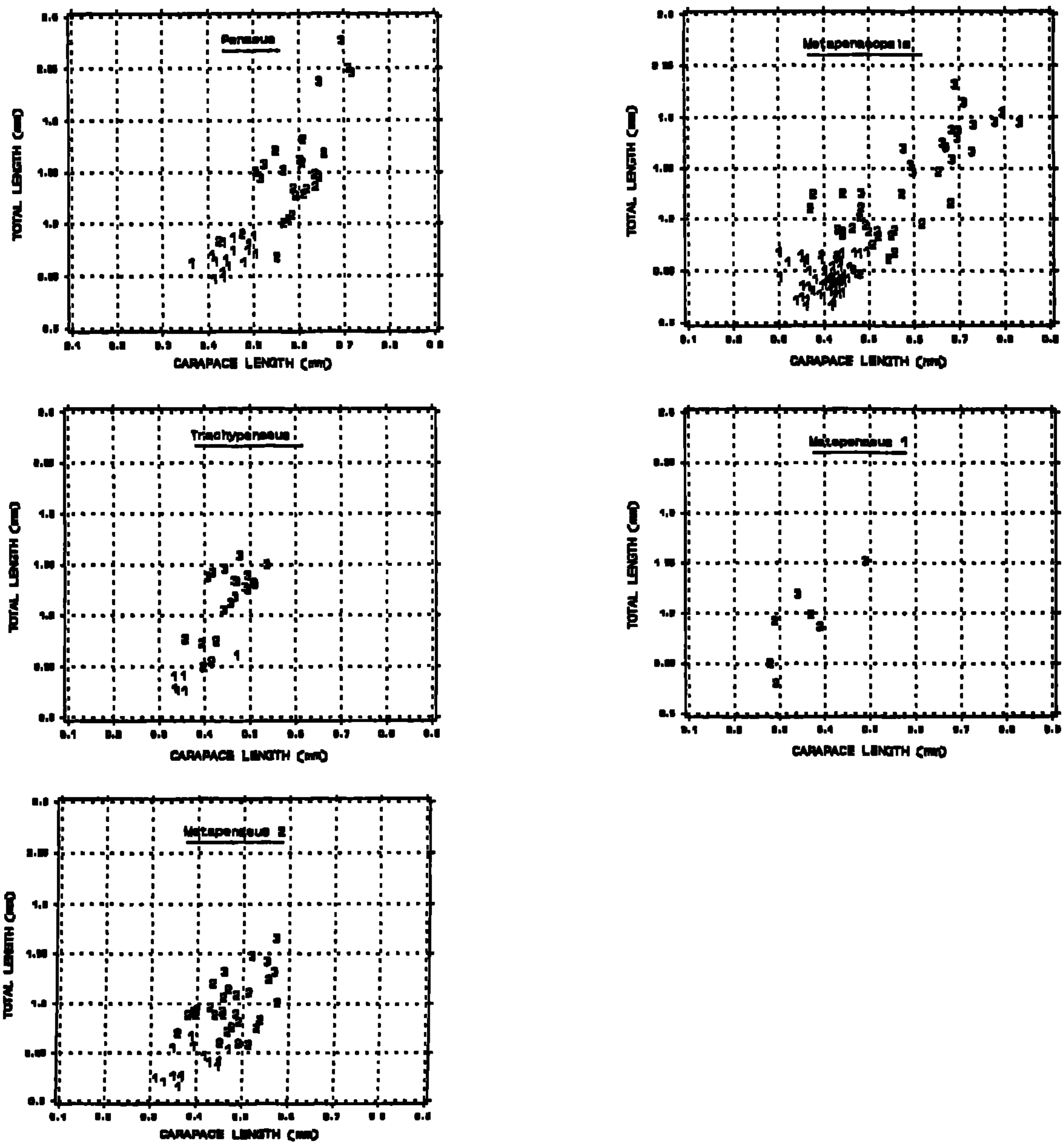


Figure 7. Scatter plots of total length against carapace length for the five identified types of penaeid protozoea of each substage (1 to 3).

Table 2 Measurements of selected parts and characters of five identified protozoeal groups in the plankton collections.

Species	Stage		Carapace length (mm)	Rostrum length (mm)	Eye length (mm)	Total length (mm)	A1 length (mm)	Supraorbital spine	Number of spines on the inner margin of second appendage endopodite (A2 formula)
Penaeus	ZI	mean	0.446	-	-	0.978	0.359	-	2+1+1
		sd	0.04	-	-	0.09	0.05		
		n	18	-	-	16	18		
	ZII	mean	0.586	0.183	0.193	1.422	0.367	1	2+1+1
		sd	0.05	0.06	0.03	0.22	0.05		
		n	22	18	21	19	22		
	ZIII	mean	0.627	0.196	0.228	1.96	0.395	1	2+1+1
		sd	0.10	0.09	0.05	0.39	0.11		
		n	11	10	11	7	11		
Meta-	ZI	mean	0.385	-	-	0.761	0.247	Nil	2+2+1
-penaeus 2		sd	0.05	-	-	0.11	0.07		
		n	15	-	-	15	15		
	ZII	mean	0.47	0.102	0.149	1.124	0.249	2L	2+2+1
		sd	0.05	0.04	0.02	0.13	0.03		
		n	32	19	30	25	30		
	ZIII	mean	0.529	0.095	0.175	1.503	0.288	1	2+2+1
		sd	0.05	0.03	0.03	0.10	0.04		
		n	13	10	13	5	12		
Trachy-	ZI	mean	0.376	-	-	0.759	0.312	0	2+2+0
-penaeus		sd	0.06	-	-	0.09	0.05		
		n	7	-	-	6	7		
	ZII	mean	0.399	0.073	0.135	0.959	0.32	0	2+2+0
		sd	0.02	0.02	0.01	0.09	0.04		
		n	6	5	6	5	6		
	ZIII	mean	0.467	0.083	0.188	1.43	0.351	0	2+2+0
		sd	0.04	0.02	0.02	0.04	0.04		
		n	21	18	21	15	21		
Meta-	ZI	mean	0.412	-	-	0.797	0.235	-	2+2+1
-penaeopsis		sd	0.04	-	-	0.09	0.03		
		n	88		-	75	88		
	ZII	mean	0.449	0.153	0.162	1.152	0.278	2S	2+2+1
		sd	0.08	0.07	0.03	0.16	0.05		
		n	34	21	33	25	34		
	ZIII	mean	0.683	0.188	0.22	1.754	0.336	2L	2+2+1
		sd	0.07	0.07	0.04	0.18	0.05		
		n	24	18	23	17	24		
Meta-	ZII	mean	0.355	0.201	0.133	0.999	0.221	1	2+2+1
		sd	0.05	0.24	0.02	0.21	0.02		
-penaeus 1		n	12	7	12	5	11		
	ZIII	mean	0.444	0.1	0.161	1.446	0.258	1	2+2+1
		sd	0.05	0.02	0.02	0.16	0.02		
		n	9	4	7	2	6		

Refer to Figure 4 for various structure locations and measurement dimensions.
S= similar height, L= inner pair is less than outer pair, ZI, ZII and ZIII = protozoea stage 1, 2 and 3.

The remaining protozoeal types all possess the same A2 formula, namely 2+2+1 (Table 2). However they could be separated on the basis of the presence of a frontal spine (in the case of protozoea 1), number of supraorbital spine pairs (protozoea 2 and 3) and carapace to total length relationship. *Metapenaeopsis* protozoea 1 possesses a pair of sharp and long frontal spines. Protozoea 2 of this form possesses two pairs of similar length supraorbital spines, while the inner pair is shorter than the outer pair in protozoea 3 (Table 2).

In *Metapenaeus* 2, the protozoea 1 lack the frontal spine and protozoea 2 possesses two pairs of supraorbital spines where the inner pair is shorter than the outer. Protozoea 3 possesses a pair of supraorbital spines (Table 2). *Metapenaeus* 1 is distinguishable from *Metapenaeus* 2 by its short total and carapace length (Table 2). Also protozoea 2 possesses a pair of supraorbital spines.

III.1.3 Mysis

Three types of penaeid mysis were identified in the collections, namely; *Penaeus*, *Metapenaeopsis* and *Trachypenaeus*. Mysis stages of *Penaeus* are characterised by a rostrum extending beyond the eye, the presence of a hepatic spine and the posterio-lateral spine on the fifth abdominal segment (Figure 4) (see Table 3). *Metapenaeopsis* mysis 2 were identified by the serration on the anterior ventral margin of the carapace, the telson formula and the relatively large carapace (Table 3). *Trachypenaeus* mysis larvae possess a short rostrum and lack both posterio-lateral and hepatic spines (Table 3).

III.1.4 Post-larvae

Four types of penaeid post-larvae were identified in the present collections, namely; *Penaeus semisulcatus*, *Penaeus latisulcatus*, *Metapenaeus* and *Metapenaeopsis*. The thoracic sternal spine formula (Figure 4) is diagnostic for *Penaeus* post-larvae; it reads 0+0+0+1+1 counting in an anterio-posterior direction (Table 4). In *P. semisulcatus* post-larvae, the rostrum extends beyond the eye, but does not do so in *P. latisulcatus* (Table 4). Presence or absence of spinules on the dorsal side of the sixth abdominal segment and of an antennal spine are additional characters used to identify the post-larvae of these two *Penaeus* species (Muthu M. S. 1993, personal communications); such spines are present in *Penaeus latisulcatus* and absent in *P. semisulcatus* post-larva.

Table 3 Carapace length and some distinctive characters of penaeid mysis stages in plankton collection.

SPECIES	STAGE		Carapace length (mm)	Rostrum extends beyond the eye	Posterior lateral spine on fifth abdominal segment	Telson formula	Anterior ventral margin of carapace serrated	Hepatic spine present
Penaeus	MI	x	0.82	yes	yes	8+8	no	yes
		sd	0.02					
		n	2					
	MII	x	0.90	yes	yes	8+8	no	yes
		sd	0.03					
		n	2					
	MIII	x	0.94	yes	yes	8+8	no	yes
		sd	0.01					
		n	2					
Metapen--aeopsis	MII	x	1.031	yes	yes	7+1+7	yes	?
		n	1					
Trachy--penaeus	MI	x	0.859	no	no	8+8	no	no
		n	1					

x= mean, sd= standard deviation, n= number of observation.

Please refer to Figure 4 for various structure locations and measurement dimensions.

Metapenaeus post-larvae are characterized by a short rostrum and a ventral thoracic area which is relatively broader than other post-larval types. *Metapenaeus* types are identified further by the thoracic sternal spine formula which reads as 0+0+0+1+0 and by telson spine formula which reads as 7+7 (Figure 4 and Table 4). *Metapenaeopsis* post-larvae exhibit a telson spine formula which reads as 7+1+7 (Table 4).

III.2 Zooplankton densities

The extent of the plankton sampling in Tubli Bay and in the open sea area is presented in Figure 3, which should be referred to in relation to the figures on abundance presented in this section. Due to its consistance pattern with other works in the area (Michel et al. 1986), the complete seasonal data (from May 1991 to May 1992) obtained for station 1 of Tubli Bay are here taken as a reasonable representation of the general seasonal trend of the zooplankton in Bahrain waters.

Table 4 Carapace and rostral length, and important characters used in the identification of post-larval penaeids.

SPECIES	Number of rostral teeths Dorsal	Ventral		Carapace length (mm)	Rostrum length (mm)	Rostrum extending beyond the eye	Thoracic sternal spine formula	Telson formula
P. semi-sulcatus	3	0	x	1.045	0.402	yes	0+0+0+1+1	8+8
			sd	0.042	0.031			
			n	2	2			
	4	0	x	1.695	0.768	yes	0+0+0+1+1	9+9
			sd	0.146	0.074			
			n	4	4			
	4	1	x	1.861	0.837	yes	0+0+0+1+1	9+9
			sd					
			n	1	1			
	5	0	x	1.592	0.739	yes	0+0+0+1+1	9+9
			sd	0.077	0.058			
			n	3	3			
	5	1	x	2.023	0.917	yes	0+0+0+1+1	9+9
			sd	0.062	0.070			
			n	2	2			
P. lati-sulcatus	4	0	x	1.614	0.361	no	0+0+0+1+1	8+8
			sd	0.177	0.031			
			n	4	3			
	5	0	x	1.748	0.376	no	0+0+0+1+1	8+8
			sd	0.193	0.042			
			n	7	7			
Metap-enaeus	1	0	x	0.686	0.146	no	0+0+0+1+0	7+7
			sd					
			n	1	1			
	2	0	x	0.823	0.084	no	0+0+0+1+0	7+7
			sd	0.129	0.010			
			n	2	2			
	3	0	x	0.864	0.041	no	0+0+0+1+0	7+7
			sd	0.016	0.005			
			n	2	2			
	4	0	x	0.843	0.082	no	0+0+0+1+0	7+7
			sd	0.033	0.002			
			n	2	2			
Metap-enaeopsis	5	0	x	0.83	0.343	no	?	7+1+7
			sd					
			n	1	1			

x= mean, sd= standard deviation, n= number of observations
Please refer to Figure 4 for various part locations and measurement dimensions.

III.2.1 Tubli Bay

In the Tubli Bay samples of 1991/92, lowest total plankton abundance occurred from January to April (Figure 8). Particularly high values in May 1992 were due to the presence of newly spawned fish eggs (Figure 8). Copepod abundance broadly followed the general pattern, except for a low value in July 1991 (Figure 9). Highest abundances of total plankton and of copepods occurred during the period of rising temperatures and abundance fell as temperatures declined during the winter period (Figures 8 and 9).

III.2.2 Open sea area

In the open sea total plankton and copepod abundances were low in January and high in October, consistent with the data for Tubli Bay (Figures 8 to 10).

III.3 Penaeid plankton

Figure 11 shows the seasonal variation in penaeid plankton and temperature at station 1 in Tubli Bay. High penaeid abundance values in April and May, when large numbers of eggs were present, coincided with the seasonal rise of sea temperature (Figure 11). Penaeid eggs and larvae were absent from Tubli Bay plankton during the periods of maximum and minimum temperature (Figure 11).

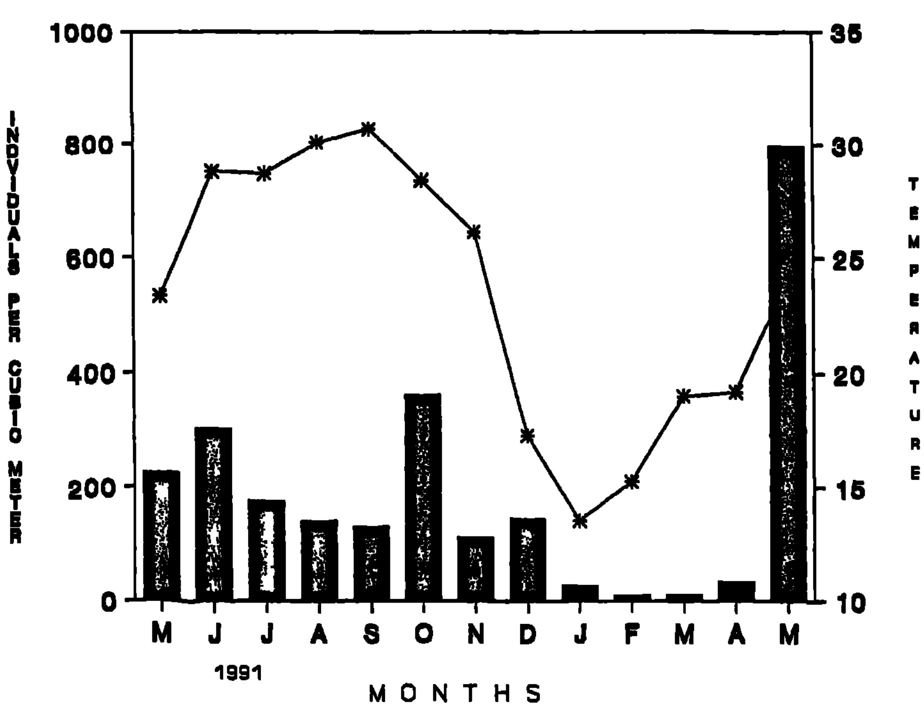


Figure 8. Monthly changes in total zooplankton abundance (vertical bars) and sea water temperature (stars) at station 1 of Tubli Bay for the period from May 1991 to May 1992.

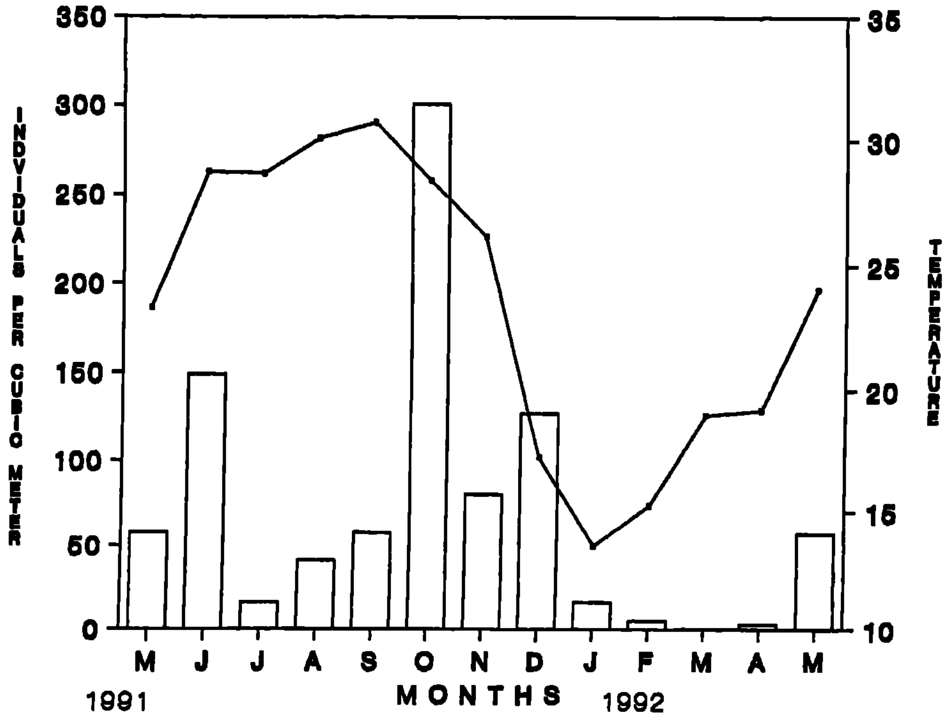


Figure 9. Monthly changes in Copepoda abundance (histograms) and sea water temperature (dots) in station 1 of Tubli Bay, from May 1991 to May 1992.

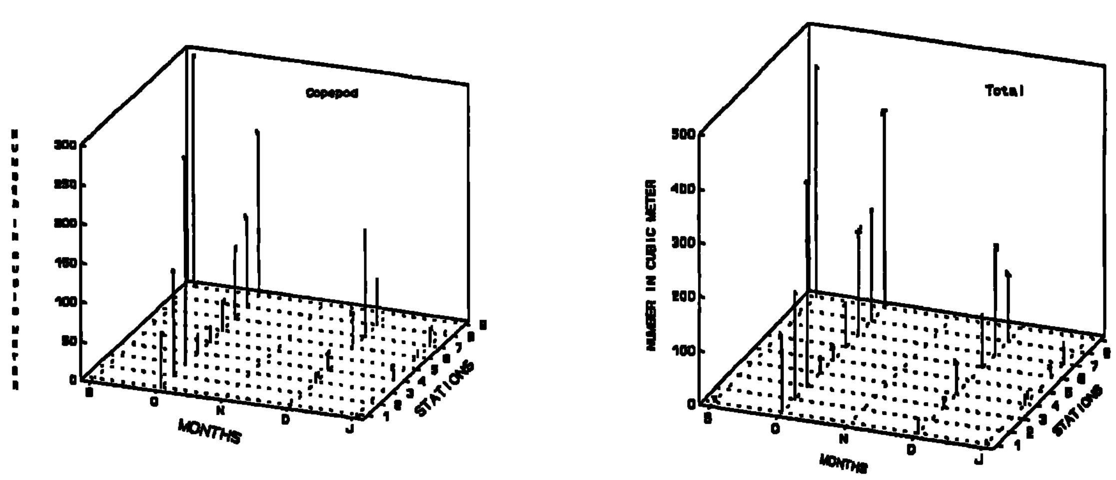


Figure 10. Monthly changes in total zooplankton and Copepoda abundances in open sea station 1 to 9 for the period from September 1991 to January 1992, with a gap in November 1991.

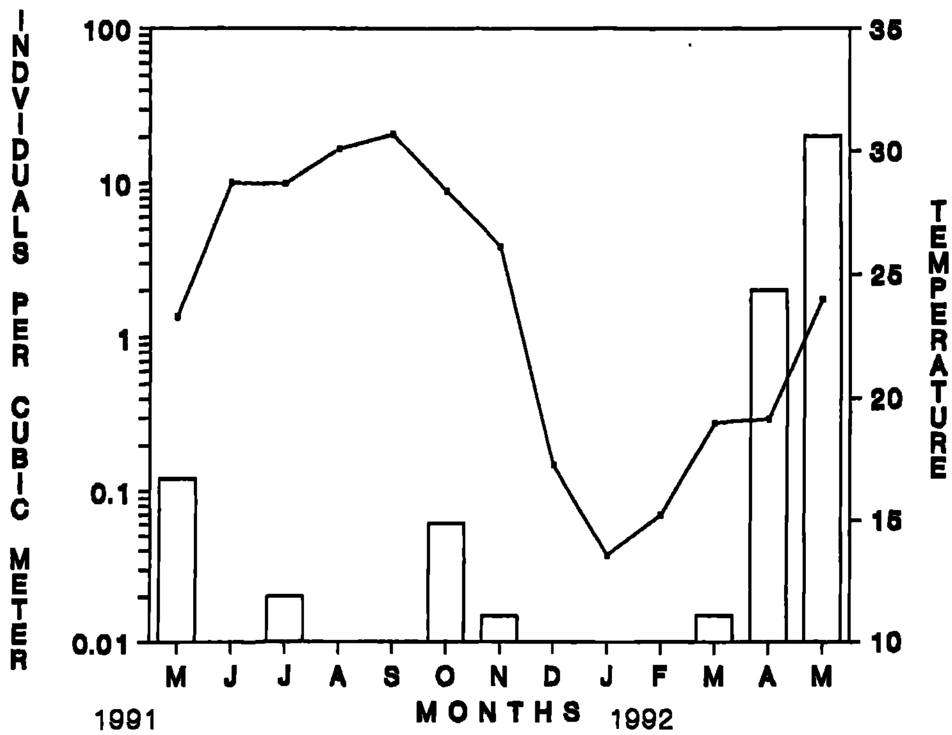


Figure 11. Monthly changes in total penaeid plankton abundance (histograms) and sea water temperature (squares) in station 1 of Tubli Bay, for the period from May 1991 to May 1992.

III.3.1 Eggs

M. stebbingi eggs were collected in station 1 of Tubli Bay in March to June 1992 and April and May 1993, when the average water temperature ranged from 19.0° to 23.9°C (Figure 8 and 12). Similarly, *M. kutchensis* eggs occurred in low numbers in May 1992, and April and May 1993 at the same station (Figure 12). At the shallow water station 2 in Tubli Bay only *M. stebbingi* eggs occurred, and in the months of April, May and June 1992 (Figure 13).

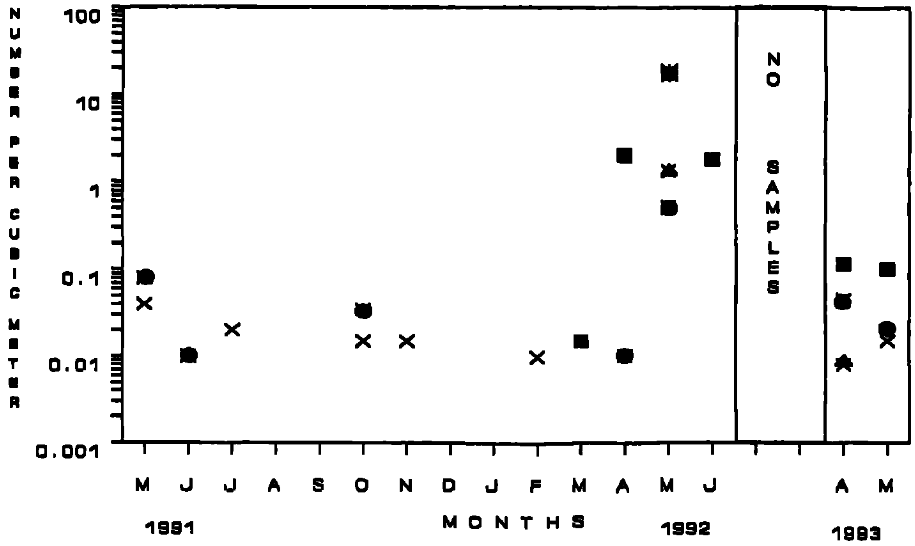


Figure 12 Monthly abundance of *M. stebbingi* eggs (square), *M. kutchensis* eggs (close triangle), total protozoea (circle), and total postlarvae (X) at station 1 of Tubli Bay for the period from May 1991 to June 1992 and April to May 1993.

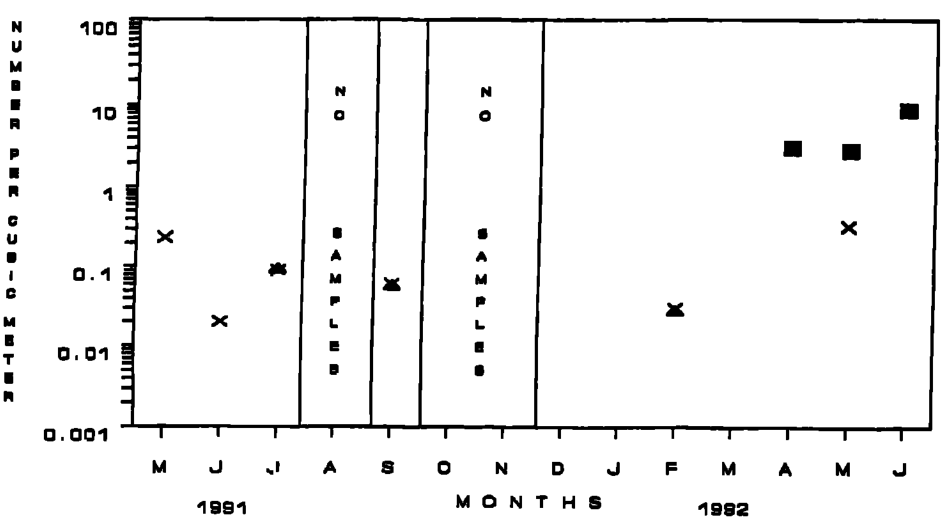


Figure 13. Monthly abundance of *M. stebbingi* eggs (square), total protozoeae (X) and total postlarvae (closed triangle) at station 2 of Tubli Bay for the period from May 1991 to June 1992.

Penaeus eggs were collected only in October where they occurred at open sea stations 3 to 7 (Figure 1 and 14, Table 5). Egg type 4 occurred at stations 5 to 9 in October and December 1991. Egg type 1 occurred in the open sea area in the stations 1 to 7 during September, October and December 1992 (Figures 1 and 14, Table 5).

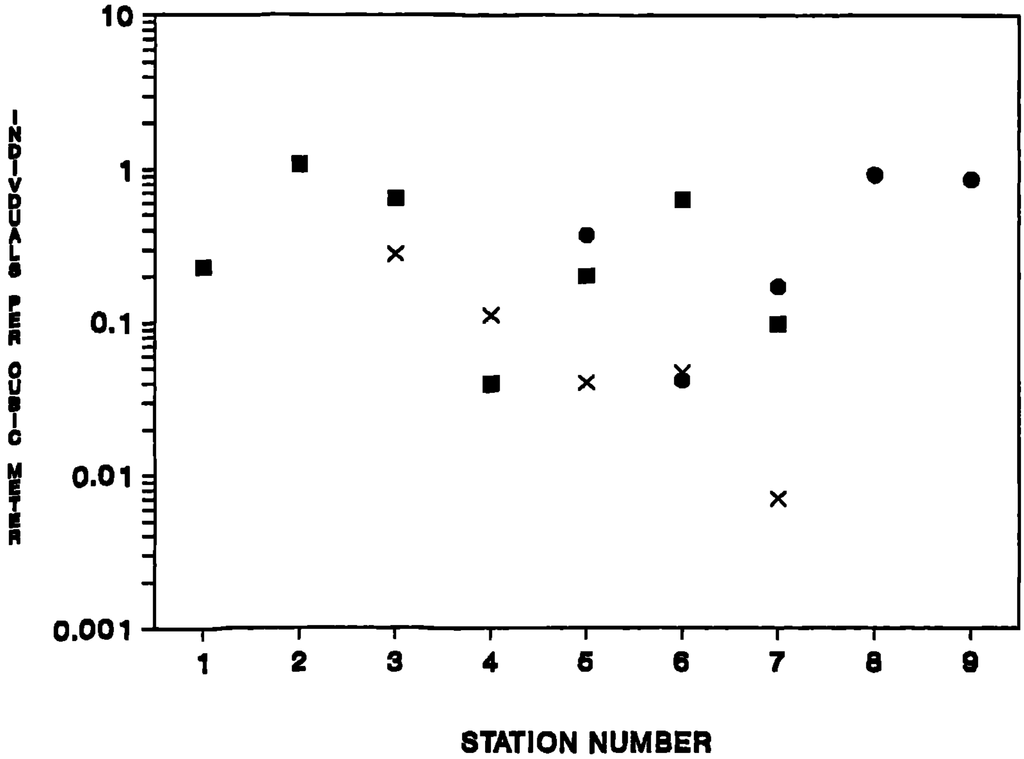


Figure 14. Occurrence of Type 1 (square), *Penaeus* (X) and Type 4 (hexagon) eggs at the nine open sea stations, using pooled data for September, October and December 1991 and January 1992.

No penaeid eggs were found in Tubli Bay and in the open sea station in January 1992, when minimum average temperature occurred (Figures 12 to 14, Table 5). At that time in Tubli Bay sea temperature had fallen to its lowest average value of 13.4°C (Figure 8).

III.3.2 Nauplii

Nauplius larvae were the least common stages found in the present plankton collection. Only six individuals were collected; four specimens were collected in the open sea at stations 1 and 7 in October 91 (Table 5) and two in Tubli Bay in May 1991.

III.3.3 Protozoea

Protozoeae occurred in Tubli Bay stations 1 and 2; they were found at station 1 in May and June 1991, October 1991, and April and May of 1992 and 1993 (Figure 12 and 13). In the open sea, *Penaeus* protozoeae were collected from stations 6 to 9 and during most of the sampling period from September 1991 to January 1992 (Figure 15). *Metapenaeus 2* protozoeae occurred at stations 1 to 3 and 5 to 7; *Trachypenaeus* protozoae occurred at stations 1 and 4, and 6 to 9; *Metapenaeopsis* protozoea occurred in all stations except station 4 (Figures 1 and 15, Table 5).

Table 5 Presence (+) of penaeid eggs and larval stages of various taxonomic groups in the plankton samples collected in open sea area, for the months September, October, and December 1991, and January 1992.

DEVELOPMENT STAGES	TAXONOMIC GROUPS	MONTHS Sept 91	Oct 91	Dec 91	Jan 92
eggs	*Penaeus*		+		
	Type 1	+	+	+	
	Type 4		+	+	
Nauplii			+		
Protozoea	*Penaeus*	+	+	+	+
	Metapenaeopsis	+	+	+	+
	Metapenaeus 2		+		
	Trachypenaeus		+	+	
Mysis	*Penaeus*		+	+	
	Metapenaeopsis			+	
	Trachypenaeus		+	+	
Post-larvae	*P. semisulcatus*		+	+	
	P. latisulcatus	+	+	+	+
	Metapenaeopsis			+	
	Trachypenaeus			+	

III.3.4 Mysis

Generally, penaeid mysis stages occurred in low abundance in the present plankton collections. *Penaeus* mysis occurred only at the open sea stations 6 to 8. *Trachypenaeus* mysis were collected from the open sea stations 6 and 7 and *Metapenaeopsis* mysis from the open sea station 7 and Tubli Bay.

III.3.5 Post-larvae

P. semisulcatus post-larvae occurred in the open sea samples only during October and December 1991 at station 7 (Table 5). *P. latisulcatus* post-larvae occurred more abundantly, being found in the open sea throughout the sampling period (Table 5); it occurred at stations 1, 6 to 8, and in Tubli Bay. *Metapenaeus* post-larvae were mainly found in Tubli Bay from May to December 1991, and *Metapenaeopsis* post-larvae occurred at the open sea station 7.

The average carapace length ranged from 1.05 to 2.02 mm for *P. semisulcatus* post-larvae found in the plankton, and from 1.61 to 1.75 mm for *P. latisulcatus* (Table 4).

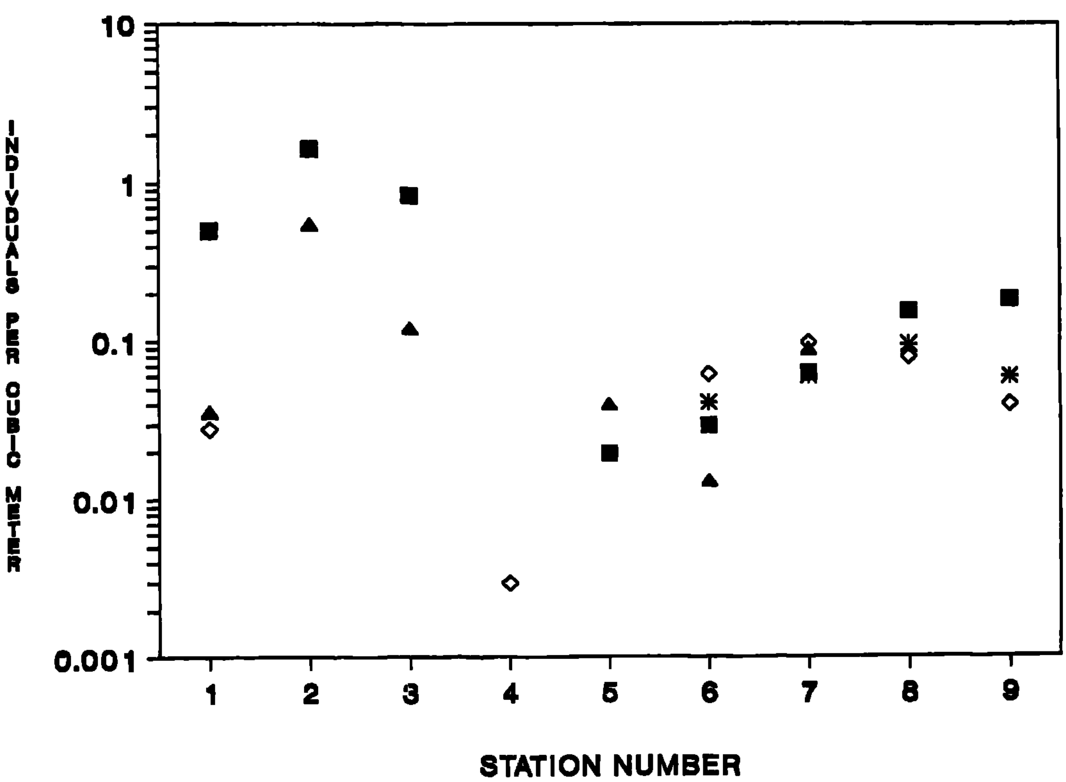


Figure 15. Station-wise abundance of *Penaeus* (star), *Metapenaeopsis* (square), *Trachypenaeus* (diamond) and *Metapenaeus* 2 (triangle) protozoeae in the open sea area, using pooled data for September, October and December 1991 and January 1992.

IV DISCUSSION

IV.1 Spawning of *Penaeus* spp. in Bahrain waters

At present it is difficult to determine the species responsible for the *Penaeus* eggs found in the plankton collection. However, since in Bahrain water *Penaeus semisulcatus* usually occurs in higher numbers than any other penaeid, including *P. latisulcatus* (see chapter 4), it seems likely that *P. semisulcatus*, for which large number of mature females occurred in the samples (see chapter 4), produces most of the *Penaeus* eggs found in the plankton. Nevertheless, since *P. semisulcatus* and *P. latisulcatus* have similar spawning seasons and areas in Australian waters (Rothlisberg et al. 1987), and may do so in Bahrain waters, it is likely that the latter species will contribute to *Penaeid* egg occurrence but in low numbers.

The absence of the *Penaeus* eggs and mature females (see chapter 4) from Tubli Bay confirms that Tubli Bay is not a spawning ground for either *Penaeus semisulcatus* or *P. latisulcatus*. Further, the occurrence of the *Penaeus* eggs in the open sea confirms the offshore spawning behaviour of each of these two *Penaeus* species. Certainly, offshore spawning behaviour for *P. semisulcatus* has been reported by a number of authors (Price 1979, Manisseri 1986, Crocos 1987, Rothlisberg et al. 1987 and Grabe and Lees 1992), and similarity of spawning seasons and areas between *P. semisulcatus* and *P. latisulcatus* (Rothlisberg et al. 1987) has already been referred to.

The presence of *Penaeus* eggs in October and protozoea in most of the sampling period suggests that spawning of *P. semisulcatus* and *P. latisulcatus* occurred from September to at least December. More extensive sampling was not undertaken in the present study but Muthu M. S. (personal communication, 1993) carried out plankton sampling in

Bahrain open sea areas from August 1992 to March 1993 in the same locations as current plankton stations 3, 7 and 8 (Figure 1). His results showed that *Penaeus* eggs were present in the plankton for the most of the sampling period. In addition, Price (1979) showed that *Penaeus* eggs were present off Ras Tanura (Saudi Arabia) in all months from September 1975 to September 1976, and Manisseri (1986) indicated that the breeding of *P. semisulcatus* took place in most of the year in Indian waters. Furthermore, the 1980/81 shrimp survey reported in the present study (Chapter 4) revealed the presence of significant numbers of *P. semisulcatus* mature females from August 1980 to April 1981 (see chapter 4). Hence, *P. semisulcatus* is probably able to spawn throughout the year, but based on the 1980/81 shrimp survey (see chapter 4), spawning peaks occur in September and December.

Certainly, the absence of penaeid eggs of all types in the current plankton collections during January 1992 suggested a decline in penaeid spawning activities at that time, coincident with low sea water temperatures which averaged 13.4°C at that time (see Chapter 2). Muthu M. S. (1993, personal communication) was able to collect *Penaeus* eggs from plankton in January 1993, but at that time water temperature was 17°C, suggesting that year to year differences in spawning behaviour may be temperature related. The effect of temperature on spawning activities of penaeids has also been noted by number of authors (Al-Attar and Ikenoue 1974, Laubier and Laubier 1979, Caubere et al. 1979, Aquacop 1975 & 1979, Penn 1980). Al-Attar and Ikenoue (1974) found that *P. semisulcatus* spawning activity increases when bottom water temperature ranged from 18° to 19.5°C, and Penn (1980) noted latitude-related differences in the spawning season of *P. latisulcatus*. Price (1979) found that *Penaeus* eggs were most abundant in plankton samples at temperatures range from 18° to 26°C and Courtney and Dredge (1988) found low proportions of *P. latisulcatus* mature females at a maximum water temperature of 28.5°C. Experimentally, *P. semisulcatus* females developed mature ovaries in temperatures ranging between 25° to 29°C (Aquacop 1975). Hence, year to year differences in water temperatures may cause variation in spawning timing for *P. semisulcatus*, leading to its description as protracted (Thomas 1974, Van Zalinge 1980, Manisseri 1986), or seasonal (Enomoto 1971, FAO 1978 & 1982, Price & Jones 1975, Al-Attar & Ikenoue 1974, Price 1979, Mohammed et al. 1980).

Devarajan et al. (1978) reared *P. semisulcatus* at a temperature of 31.0°C and salinity 35.2 part per thousand from egg to 1.5 mm carapace length post-larvae in about 13 days. In one rearing experiment carried out in the National Mariculture Centre (Bahrain) it was shown that *P. semisulcatus* attained carapace length 3.45 mm (sd = 0.56, n = 31) after 45 days from hatching in temperature ranged from 18.2 to 25°C, and in 45 part per thousand sea water. From the present investigations it was found that *P. semisulcatus* of up to 2.02 mm carapace length were still found in the plankton, and the minimum average size of benthic *P. semisulcatus* found in Tubli Bay was 2.14 mm carapace length (see chapter 4). Hence, it seems likely that the *P. semisulcatus* planktonic phase extends for between 13 and 45 days.

IV.2 Spawning of *Metapenaeus stebbingi* and *M. kutchensis* in Bahrain waters

The appearance of mature females (see chapter 4) and eggs of *M. stebbingi* and *M. kutchensis* in Tubli Bay in 1992 and 1993 confirms the shallow water spawning behaviour of these species. This period extended from March to June for *M. stebbingi*, and from April to May for *M. kutchensis*. The appearance of *M. stebbingi* mature females in the open sea from March to July (see chapter 4) indicates general spawning of *M. stebbingi* in the shallow waters of Tubli Bay and the open sea during spring and early summer. Habib-Ul-Hassan (1992) found that *M. stebbingi* spawned in spring and early summer, while it was found over the period from April to October in the Suez Canal region (Gab-Alla et al. 1990). Spawning of *M. kutchensis* in Tubli Bay was determined to occur in April and May, and the appearance of mature females of this species in open sea in June and July, and in December (see chapter 4), indicates its spawning in the open sea areas.

Plankton sampling inside Kuwait Bay (Grabe and Lees 1992), revealed the presence of unspecified penaeid eggs from April to August 1982. Bishop and Khan (1991) found that both *M. affinis* (*kutchensis*) and *M. stebbingi* are common species in that locations.

In Tarut Bay (Saudi Arabia) penaeid eggs were found to be most abundant in May (in 1985) and March (in 1986) (Water Resources & Environment Division 1990), presumed to be related to the spawning of *P. semisulcatus* and *M. affinis* in the area. The present work confirms that *P. semisulcatus* did not spawn in the shallow water. Thus, it is most likely that both common species *M. stebbingi* and *M.kutchensis* (*affinis*) spawned in the Bay.

IV.3 Spawning of other penaeids in Bahrain waters

The presence of egg types 1 and 4 (Figures 13 and 17) indicated spawning of two or more penaeid species in the open sea areas. The remaining penaeid species found in Bahrain water (see chapter 4); *Metapenaeopsis stradulans*, *M. mogiensis* and *Trachypenaeus curvirostris* are the candidate spawners for these eggs. These species were found only in the open sea shrimping grounds (see chapter 4).

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CHAPTER THREE
PLANKTONIC PHASE OF PENAEID SHRIMPS OF BAHRAIN WATERS

SUMMARY

This chapter set out to provide details on early life histories and spawning behaviour of penaeid shrimps in Bahrain waters. Plankton collection was conducted mainly through two sampling programmes. The first was conducted in the open sea shrimping ground from September 1991 to January 1992 (excluding November 1991). The second programme was restricted to Tubli Bay where samples were obtained during the new and full moon from May 1991 to June 1992 inclusive and from March to May 1993. All samples were collected at night using horizontal tows. The presence of five eggs types in the plankton collection was confirmed by Discriminant Analysis. These egg types were identified as follows; (1) egg type 1, (2) *Metapenaeus stebbingi* eggs, (3) *Penaeus* eggs, (4) egg type 4, and (5) *Metapenaeus kutchensis* eggs. Different types of protozoea, mysis, and post-larvae were identified and detailed measurements of these were recorded. The occurrence of *Penaeus* eggs in the open sea confirms the offshore spawning behaviour for *Penaeus semisulcatus* and *P. latisulcatus*. The presence of *M. stebbingi* and *M. kutchensis* eggs in Tubli Bay plankton collection confirmed the spawning of these two species in the Bay during spring to early summer.

CHAPTER FOUR

BIONOMICS OF PENAEID SHRIMPS OF BAHRAIN

I. INTRODUCTION

The biological requirements of penaeid shrimps change throughout their life cycles. These changes influence the fishery of these species, resulting in seasonal variations in catches. This chapter aims to highlight biological aspects of penaeid shrimps of the Bahrain fishery.

In the Gulf, commercial exploitation of shrimp resources commenced in 1959 (Boerema 1969). They were quickly recognised as an important fishery, for which concerns were soon raised about the status of the stocks. For stock assessment, two types of data are usually collected. The first of these are fishery statistics which describe the distribution and abundance of the species. The second type requires measurements of the biological parameters of shrimp populations in order to make assessment of growth and mortality rates. At an early stage of the fishery, both types of information were obtained from the records of fishing companies (Boerema 1969, FAO 1973, Van Zallinge 1980).

The requirement for more precise biological information initiated a number of direct sampling programmes based on shrimp commercial landings (Enomoto 1971, Price and Jones 1975, FAO 1978, Van Zalinge et al. 1981, Mohammed et al. 1981, Mathews 1985, Al-Shoushani 1985). However, those samples were not always representative.

Shrimps are short lived and rapidly moving crustaceans (Garcia and Le Reste 1981). Different size groups may occur in the same general area at the same time, but at different depths. This raises the possibility of sampling error, particularly when samples are based on shrimp landings.

Furthermore, these types of sampling programmes do not provide consistent spatial and temporal coverage. Fishing fleets usually change their operation areas according to the available catch.

Fishing surveys provide more precise data on fish stocks. Partial surveys were carried out on Gulf shrimp population by a number of workers (Al-Attar and Ikenoue 1974, Al-Attar 1982, Jones and Al-Attar 1982, Department of Fisheries 1984, Bishop 1989, Water Resources and Environment Division 1990). However, until the present study no extensive surveys of shrimp populations either regionally within the Gulf or within country boundaries had been carried out. In view of the importance of this resource, the present study was initiated to survey adult and juvenile shrimp population in Bahrain waters.

II. MATERIALS AND METHODS

Two major benthic surveys were completed. The first was conducted from June 1980 to June 1981 using an industrial trawler, covering the whole shrimping ground except Tubli Bay. This survey was carried on shrimp populations in the open sea areas. A second survey was conducted with a 6 m small boat powered by an 85 HP outboard engine. This was undertaken on shrimp populations in Tubli Bay from May 1991 to June 1993 in three time periods, from May 1991 to June 1992, in November 1992 and from April to June 1993. The time difference between the two surveys was thought to be acceptable for comparison since the general pattern of shrimp movements between shallow and deep waters is considered to remain broadly unchanged over a long period of time (Young 1978, Robertson et al. 1985, Wenner and Beatty 1993, Rogers et al. 1993).

II.1 Open sea survey

In preparation for the 1980/81 survey experienced shrimp fishermen were interviewed to determine the extent of Bahrain's shrimping grounds. Based on these interviews 28 sampling stations were designated (Figure 1). Stations were spaced almost at equal intervals within these grounds. Most of these stations were trawled for 45 minutes once a month from June 1980 to June 1981. Sampling was conducted from the industrial trawler "Al Sulman". A single trawl of the Gulf of Mexico type with an approximately 18 m head rope was used, rather than a conventional double trawl rig. Total numbers and weight of penaeid shrimps in each trawl were recorded. A representative sample or the whole catch (if less than 5 kg) was retained for further examination.

In the laboratory, shrimp samples were sorted by species and sex. For each specimen sex, carapace length (the distance between the post-orbital margin and the medial posterior border of the carapace) and maturity stage of the ovary (females only) were recorded as length-frequency data. Ovary maturity staging as outlined by Motoh (1981) was adopted in this work. Total wet weight by species and sex were recorded for each sample.

The penaeid species recorded were identified following taxonomic keys (Hall 1962, George 1969, Tirmizi 1972). With experience all seven species recorded could be identified immediately on collection by their body coloration and external appearance. The species recorded were *Penaeus semisulcatus* De Haan, 1844, *P. latisulcatus* Kishinouye, 1896, *Metapenaeus stebbingi* Nobili, 1904, *M. kutchensis* George, George, and Rao, 1963, *Trachypenaeus curvirostris* Stimpson, 1860, *Metapenaeopsis stridulans* Alcock, 1905 and *M. mogiensis* Rathbun, 1902.

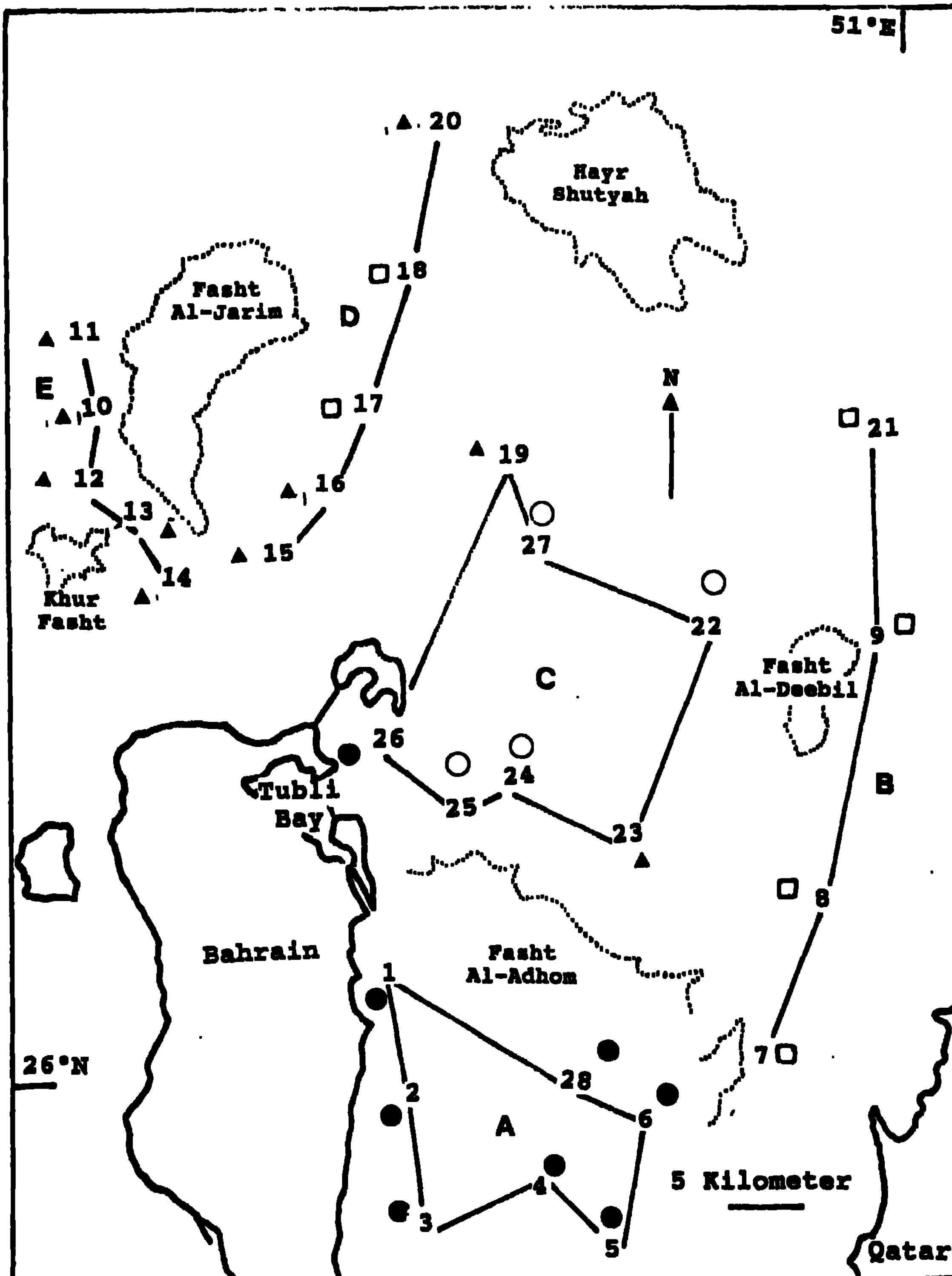

Figure 1 Penaeid shrimp survey sampling sites (1-28) geographically grouped into five areas A to E. A grouping based on the Indicator Species Analysis method/(●, □, ○, ▲) is also shown (see text for procedure). Coral reef boundaries are defined by dotted lines.

In addition to shrimp samples, bycatch were also collected on a monthly basis for each station. Bycatch data were analyzed using multivariate clustering and ordination techniques. These methods allowed rational grouping of the stations, based on ecological evidence (Abdulqader 1986). Figure 1 shows the clustering of the sites into four groups based on the Indicator Species Analysis Method (Hill et al. 1975), which agree in most cases with the geographical distribution of these stations. By splitting the stations found on the east and west of Fasht Al-Jarim into two groups, the sampling stations were grouped into five geographical areas (Figure 1), as follows: A (stations 1 to 6 & 28), B (stations 7 to 9 & 21), C (stations 22 to 27 & 19), D (stations 15 to 18 & 20) and E (stations 10 to 14). These were then arbitrarily designated as: south of Fasht Al-Adhom, eastern ground, northern ground, east and west to Fasht Al-Jarim.

For all occasions where sub-samples were collected, the number per size class (N_i) in the catch was estimated for the sample. The percentage of each size class (p_i) was calculated from the following equation;

$$p_i = (n_i / \Sigma n_i) \times 100$$

where, n_i is the number of shrimp per size class.

From total numbers of shrimp in the catch (N) and percent of each size class in the sample (p_i), number of shrimps per size class in the catch (N_i) was calculated as follows;

$$N_i = p_i \times (N/100)$$

The average length frequency (f) for each open sea area was then calculated by the following equation;

$$f = \Sigma N_{ij} / n_j$$

where, N_{ij} is number of shrimp in size class (i) for (j) stations sampled within the area.

n_j number of stations sampled of this area.

II.2 Tubli Bay surveys

Tubli Bay (Figure 1) is semi-enclosed inshore shallow locality linked to the open sea through northern and southern channels (Figure 2). The main shrimping grounds were found in the southern portion of the bay, where the depth is about 2 m at low tide. In this survey a 1.8 m beam trawl was used in shallow water and a 3.7 m (head rope) otter trawl in deeper waters.

In each month sampled two trips were conducted, during successive spring tide periods when water movement was most extensive. Such samples were obtained from May 1991 to June 1992 inclusive, in November 1992, and then from March to June 1993 inclusive. In addition to the trawl samples, on each occasion 'drifter net' (see below) sampling was carried out to catch shrimp which were swimming near the surface. Except for 'drifter net', all shrimp sampling was carried out during day time, preliminary studies having established that there were no differences between day and night catches. Water turbidity was high at all times (Raveendran et al. 1994), causing low visibility as measured by Secchi disk by 0.5 m at the southern part of the Bay.

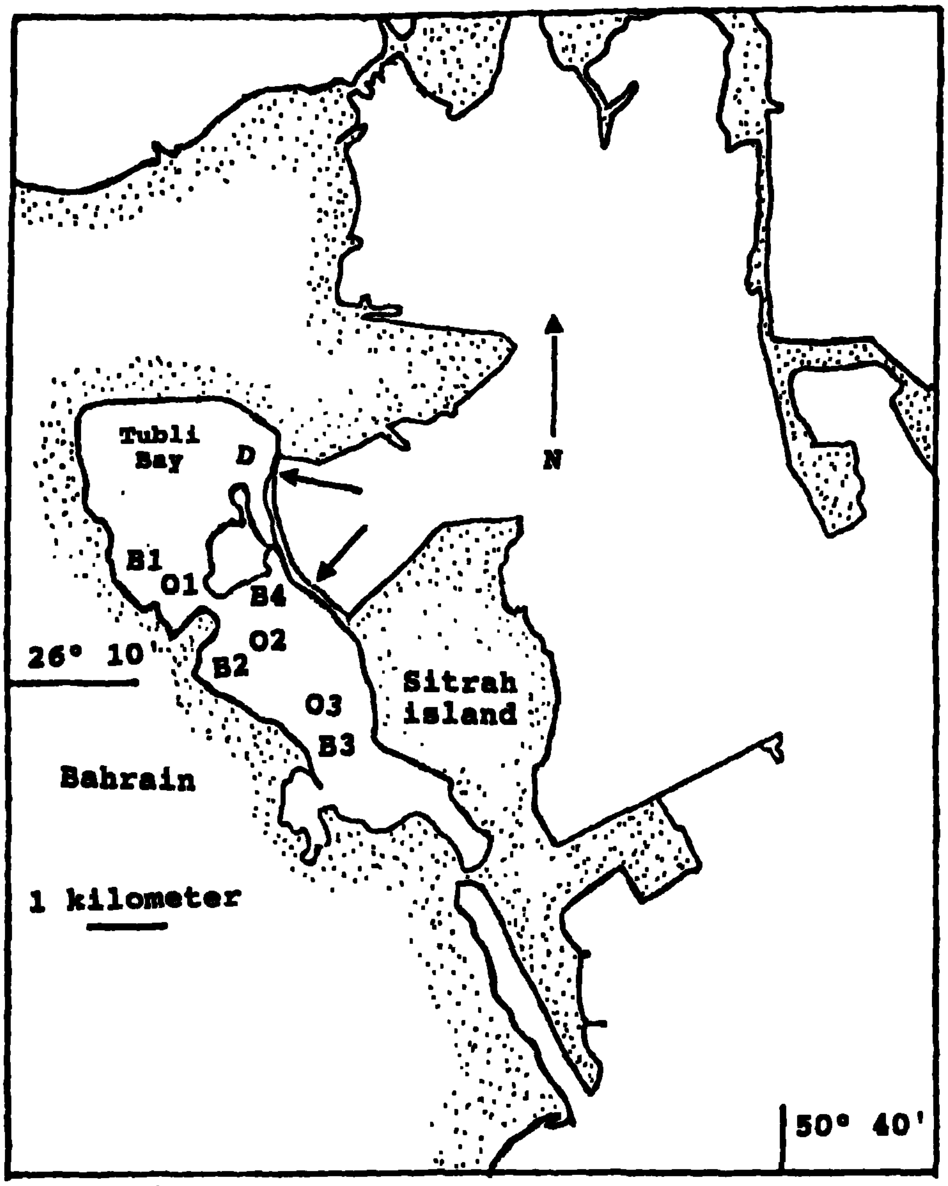

Figure 2. Tubli Bay, illustrating the sample sites for the drifter (D), beam trawl (B1-4) and otter trawl (O1-3). Arrows indicate the sites of water exchange with the open sea.

II.2.1 Drifter net sampling

The 'drifter net' was designed and made locally (Figure 3) to sample penaeid shrimp entering Tubli Bay during high water. This was constructed of 0.7 cm mesh nylon material in a conical shape, with a circular mouth of 0.97 m diameter. A lift buoy (0.4 x 0.3 x 0.6 m polystyrene) attached in front of the net acts to raise the net upward. A 1 m length of the rope between the lift buoy and the net determined the depth of net operation, keeping the net just below the water surface. A small buoy was used to raise and mark the end of the net. A third buoy was used to mark the position of the anchor which held the drifter at a desired position. The drifter was left free against the water current throughout most (3 to 4 hours) of each high water period of sampling in the deep channel below the northernmost bridge of the Bay (D, Figure 2). This area is characterized by strong tidal currents (Watson Hawksley 1984).

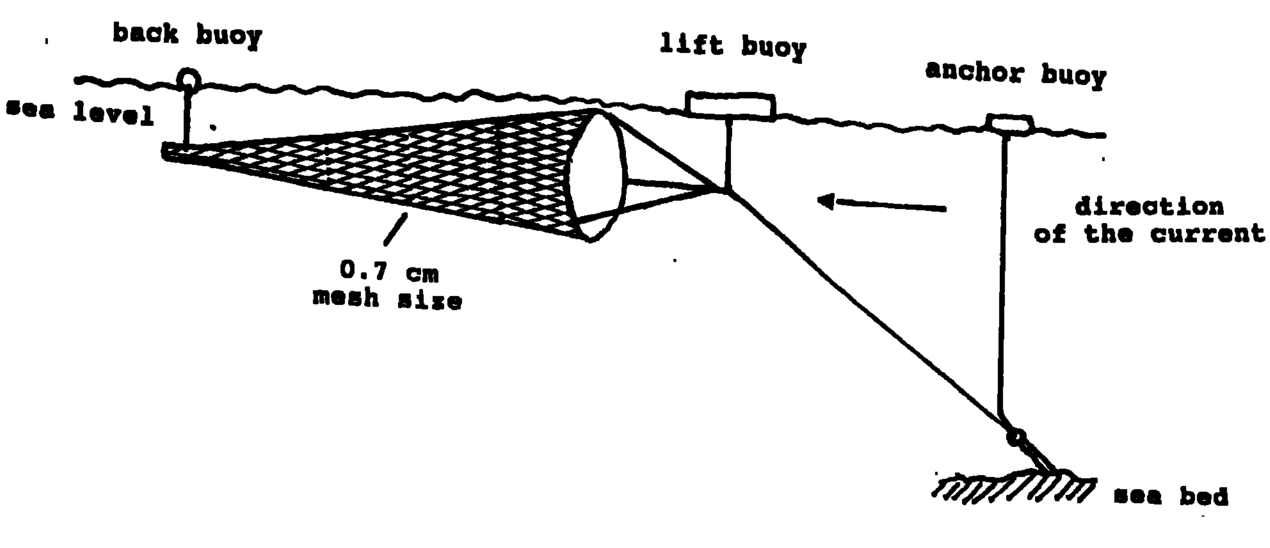

Figure 3. The drifter (see text for procedure).

The catch was collected and preserved in labelled plastic container in 4 percent buffered formaldehyde solution. Times of placement and retrieval of the net were recorded for each sampling period. In the laboratory penaeid shrimps were sorted according to species and sex. Carapace length, maturity stages, number, and weight of shrimp were recorded.

Drifter net sampling started in June 1991 and continued at two-week intervals until May 1992. Twenty two sampling intervals were completed.

II.2.2 Beam trawl sampling

A 1.8 m beam trawl of 1 mm mesh size, as used by Renfro (1963 in Garcia and Le Reste 1981), was used in sampling the shallow waters of Tubli Bay where juvenile penaeids were known to occur. The net was towed by boat for about 10 minutes at all four stations (B1-4, Figure 2) on each sampling occasion. These Samples were obtained mainly at low tide in day time at depths of about 0.7 m. The samples were collected every two weeks from May 1991 to June 1992.

Each haul usually contained large quantities of algae; these were first washed over a sieve which retained penaeid shrimp and other animals such as mysids and amphipods. The catch was then transferred to plastic containers and fixed in 4 percent buffered formaldehyde solution.

Specimens were kept in separate containers labelled both outside and inside. Sample labelling following a procedure similar to that adopted for labelling plankton samples (see chapter 3).

The penaeid samples were later sorted based on species and sex. Individual carapace length was measured either by calipers (for bigger individuals) or through a microscope (for smaller individuals). Detailed measurements of carapace length, length of the eye and rostrum, and counts of dorsal and ventral rostral teeth were made for selected numbers of each species. All collections were stored for future reference.

II.2.3 Otter trawl sampling

The Tubli Bay main shrimping ground is in the southern portion of the Bay. It was sampled at three stations (O1-3, Figure 2) using a small otter trawl (3.7 m head rope) made locally. On each sampling occasion the net was towed once for 30 minutes.

Two layers of netting material were used in the cod end of the otter trawl, the outer of 11 mm mesh size and the inner of 21 mm. The double layer permitted the capture of the smaller size in the catch. After each trawl, all penaeid shrimps were sorted, isolated in plastic bags, and stored in ice.

In the laboratory, samples were sorted according to species and sex. Carapace length, sex, and maturity stages (females only) were recorded for each specimen. Most penaeid samples collected during this programme were fully worked up without the necessity to sub-sample. The exceptions were samples on 17 May and 7 June 1992, when only a portion of the samples was measured.

The first otter trawl samples were obtained on 13 May 1991, and they continued every two weeks until June 1992, covering twenty seven sampling days. There were two more sampling days in November 1992, and five further sampling days from April to June 1993.

For each species on each sampling date, the average size frequency, abundance, maturity, and sex ratio were determined by direct averaging of the pooled individual records of that sampling date.

III. RESULTS

III.1 *Penaeus semisulcatus*

Monthly length frequency values for average 45 minutes hauls pooled for all open sea areas are shown in figure 4. Generally, unimodal population structure is seen throughout the year, with recruitment apparently occurring from April to July. A clear modal progression started in September 1980 and continued to January 1981 (Figures 4). Population mean carapace lengths increased from August 1980 to February 1981 for both sexes, while females show higher mean sizes throughout the period (Figure 5). Lowest abundance of this species was found from February to April 1981, while peaks of abundance were found in September, December 1980 and May 1981 (Figure 5). Mature females were found throughout the sampling period, but they appeared in higher abundance from August 1980 to March 1981 (Figure 5). Higher numbers of mature females were found in the open sea area C (Table 1) which is an important spawning ground. Sex ratio showed a clear dominance of males in January (Figure 5), coincident with a sharp decline in female numbers (Figure 4). Male dominance in the population was most frequently seen in areas A and E, and less frequently in area C (Table 2).

The bionomics of *P. semisulcatus* in the shallow waters of Tubli Bay are shown in Figure 6, based on otter trawl sampling. Mature females of this species were found intermittently throughout the sampling period (Figure 6). Two abundance periods were determined, the first extending from February to June with major abundance occurring from April to May (Figure 6). The second period occurred from October to December 1992, when bigger individuals appeared

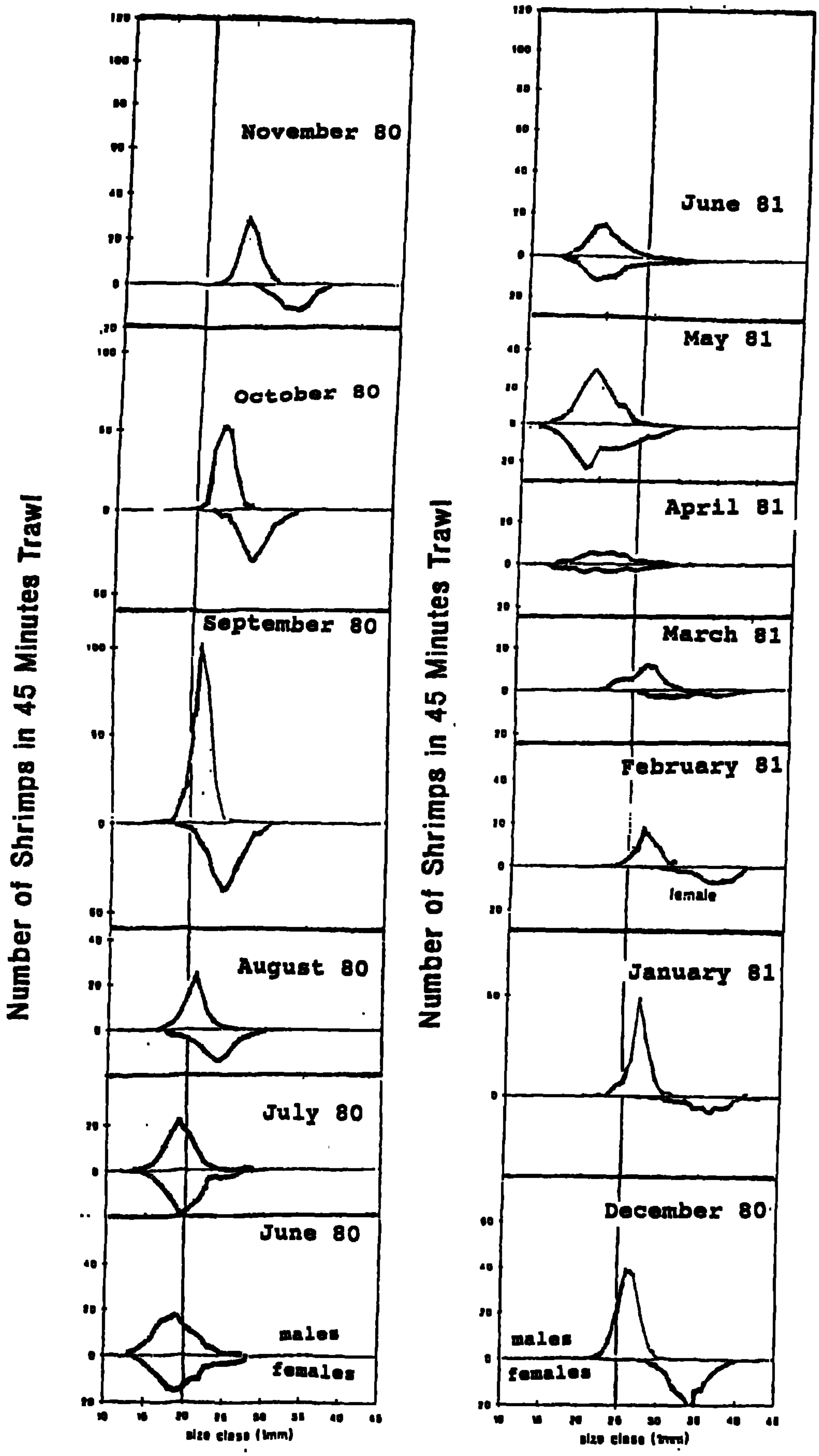

Figure 4. Monthly length frequency values for average 45 minutes haul, based on *P. semisulcatus* data pooled for the open sea samples.

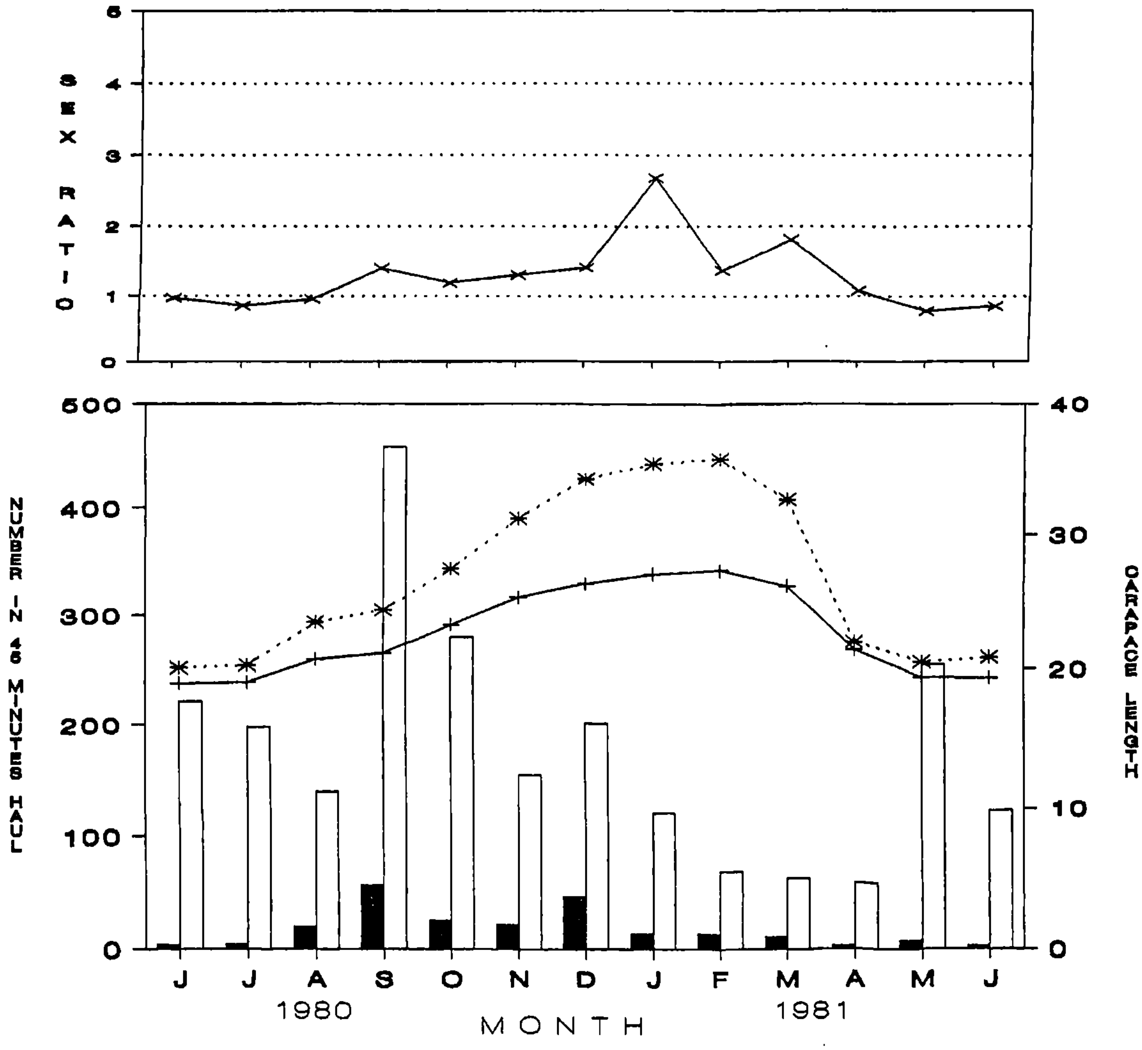

Figure 5. *P. semisulcatus* : total number per 45 minutes haul (open histograms), male (+) and female (*) monthly mean carapace length, number of mature females in 45 minutes haul (closed histograms) and sex ratio (number of males/number of females) in open sea area, based on otter trawl sampling.

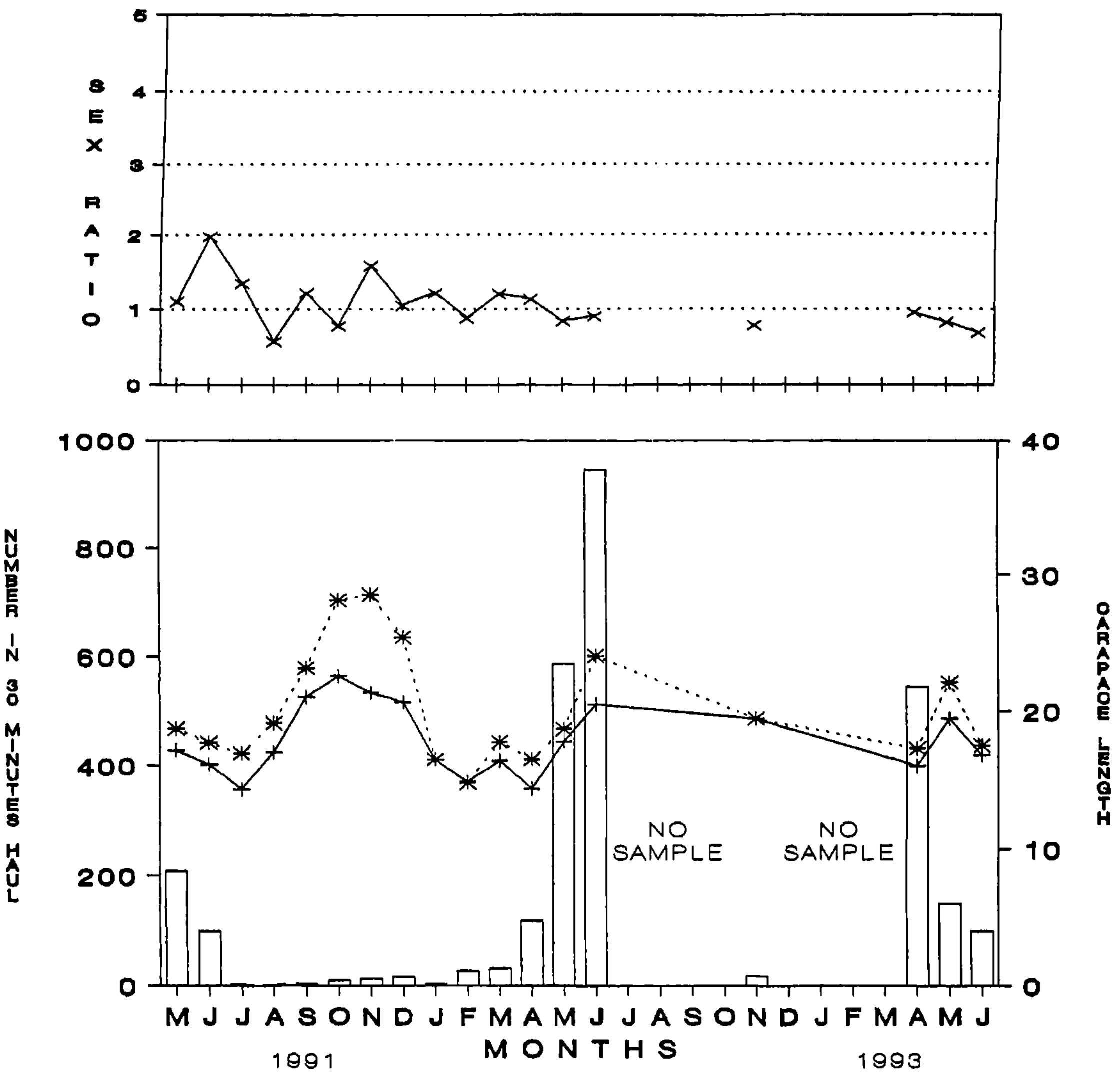

Figure 6. *P. semisulcatus* : total number per 30 minutes haul (histograms), male (+) and female (*) monthly mean carapace length and sex ratio (number of males/number of females) in Tubli Bay, based on otter trawl samples.

Table 1. Number of *P. semisulcatus* mature females in average 45 minutes haul in the open sea area, shown on a monthly basis for the period from June 1980 to June 1981.

MONTHS	OPEN SEA AREAS A	B	C	D	E
June 1980	0.60	0.00	15.26	1.80	0.00
July	0.02	0.72	16.14	0.70	1.29
August	7.01	29.67	57.19	2.00	0.97
September	65.80	48.65	75.74	94.10	1.51
October	29.01	5.01	80.16	1.03	10.71
November	11.60	25.03	53.82	10.02	8.51
December	43.82	38.98	117.82	28.23	2.50
January 1981	23.18	3.33	33.78	8.01	0.00
February	11.60	3.33	43.66	8.00	0.00
March	10.00	2.67	32.67	9.67	0.00
April	2.63	0.22	7.00	4.50	1.00
May	3.34	0.68	31.85	0.75	0.33
June	0.38	0.99	10.66	0.67	0.34

Table 2. *P. semisulcatus* monthly sex ratio (number of males/number of females) in the open sea area for the period from June 1980 to June 1981.

MONTH	OPEN SEA AREAS A	B	C	D	E
June 1980	0.67	1.16	0.92	0.78	0.82
July	0.79	0.75	0.84	1.05	0.82
August	1.12	0.77	0.99	0.82	0.83
September	1.02	1.19	1.25	1.83	2.12
October	1.29	0.76	1.20	1.24	1.15
November	1.12	0.98	1.33	1.19	2.38
December	2.52	1.16	0.99	0.77	4.07
January 1981	3.19	1.39	2.18	3.01	2.50
February	2.84	2.27	0.98	1.18	4.00
March	2.94	1.20	1.37	1.69	1.00
April	0.83	0.50	1.63	1.02	2.00
May	0.78	0.59	0.83	0.89	0.62
June	0.80	1.03	0.87	0.90	0.64

causing a sudden increase in mean carapace lengths of the population, which was particularly seen in females (Figure 6). Neither sex of *P. semisulcatus* dominated in shallow water throughout the sampling period (Figure 6).

Numbers of *P. semisulcatus* per unit of sampling for the three gears used in sampling the shrimp population of Tubli Bay are shown in Table 3. Numbers increased from February to May 1992 whatever the sampling gear used (Table 3). In the shallow water of Tubli Bay, beam trawl samples contained smaller sizes of *P. semisulcatus* at all times, but this species was most abundant from February to May 1992 (Table 4).

Table 3 Number of *P. semisulcatus* per sampling unit : in the drifter (numbers per 1 hour), beam trawl (numbers per 10 minutes) and otter trawl (number per 30 minutes) in sampling the inshore waters of Tubli bay, during the period from May 1991 to May 1992.

	SAMPLING GEARS		
MONTH	Drifter	Beam Trawl	Otter Trawl
May 1991	NS	16.4	209.0
June	7.0	1.2	99.5
July	4.5	1.1	2.3
August	3.5	0.8	1.8
September	0.5	0.2	3.7
October	0	NS	10.3
November	0	0.9	12.8
December	0	2.0	15.7
January 1992	2.0	NS	3.7
February	0.5	10.4	27.2
March	1.0	15.6	31.3
April	5.0	48.8	119.2
May	43.5	52.2	587.0

NS: No Sample

Based on their rostral spine configuration, mean carapace lengths of *P. semisulcatus* juveniles collected from Tubli Bay are shown in Table 5. These sizes were compared to the sizes found in the plankton collection (Table 4, see chapter 3). The smallest average size of benthic *P. semisulcatus* found in Tubli Bay was 2.14 mm carapace length, while the maximum average size found in the plankton was 2.02 mm (Table 5).

Table 4. Mean carapace length of combined sexes of *P. semisulcatus* and number per 10 minutes haul in beam trawl samples collected during the period from May 1991 to June 1992 in Tubli Bay.

MONTH		CARAPACE LENGTH	NUMBER IN 10 MINUTES HAUL
May 91	mean	14.3	16.4
	sd	3.39	
	n	131	
June	mean	12.96	0.9
	sd	6.47	
	n	7	
July	mean	9.4	1.1
	sd	4.46	
	n	7	
August	mean	13.81	0.9
	sd	4.92	
	n	7	
September	mean	15.93	0.3
	sd	4.08	
	n	2	
October	mean		0
	sd		
	n		
November	mean	13.34	0.9
	sd	4.98	
	n	7	
December	mean	8.27	2
	sd	2.86	
	n	2	
January 92	mean		0
	sd		
	n		
February	mean	7.39	13.8
	sd	3.62	
	n	83	
March	mean	5.92	15.5
	sd	3.96	
	n	124	
April	mean	8.74	48.8
	sd	3.09	
	n	390	
May	mean	12.58	52.1
	sd	3.28	
	n	417	
June	mean		0
	sd		
	n		

Table 5. Sizes of P. semisulcatus post-larvae and juveniles based on their dorsal and ventral rostral spines in the plankton and beam trawl collections.

LIFE PHASE		CARAPACE LENGTH	NUMBER OF ROSTRAL TEETH VENTRAL	DORSAL
PLANKTONIC	mean	1.05	0	3
	st. dev.	0.04		
	n	2		
	mean	1.70	0	4
	st. dev.	0.15		
	n	4		
	mean	1.86	1	4
	st. dev.			
	n	1		
	mean	1.59	0	5
	st. dev.	0.08		
	n	3		
	mean	2.02	1	5
	st. dev.	0.06		
	n	2		
BENTHIC	mean	2.14	1	5
	st. dev.	0.28		
	n	2		
	mean	2.49	2	6
	st. dev.	0.29		
	n	26		
	mean	3.09	2	7
	st. dev.	0.66		
	n	10		
	mean	3.90	3	6
	st. dev.	1.67		
	n	9		
	* mean	4.95	3	7
	st. dev.	1.65		
	n	144		
	* mean	5.59	3	8
	st. dev.	1.11		
	n	11		
	* mean	5.38	4	7
	st. dev.	1.45		
	n	6		
	* mean	5.63	4	8
	st. dev.	1.19		
	n	3		

* same rostral configuration also found in bigger individuals

III.2 *P. latisulcatus*

P. latisulcatus is the second most abundant *Penaeus* species found in Bahrain waters; it was most abundant in areas B and D less abundant in area C, and sporadic in areas A, E (Table 6). Also sporadic numbers of this species were found in beam trawl collections in Tubli Bay during March and April.

The mean carapace lengths increased from September 1980 to a maximum in January 1981 in both sexes, with females being larger than males throughout the period (Figure 7). *P. latisulcatus* abundance is about 90 percent lower than *P. semisulcatus*, but both showed similar abundance peaks in September and December 1980 (Figures 5 and 7). Low numbers of mature females of *P. latisulcatus* were found from July 1980 to January 1981, with a gap in August and peak in December 1980 (Figure 7). Except for December 1980, when males outnumbered females, the sex ratio was around 1:1 over the whole sampling period (Figure 7).

Table 6. Number of *P. latisulcatus* in 45 minutes hauls in each open sea area for the period from July 1980 to June 1981.

	OPEN	SEA	AREAS		
MONTH	A	B	C	D	E
July 80	0	19.0	0.2	64.0	0
August	0	73.7	0	15.7	0
September	0	48.7	38.3	167.0	0
October	0	11.7	21.4	72.0	2.5
November	0	60.5	43.0	35.5	0
December	0	179.3	19.7	62.8	0
January 81	0	16.7	16.6	135.7	0
February	0.4	67.0	34.3	70.0	0
March	0.3	25.7	16.0	42.3	0
April	0.8	0	0.3	99.3	0
May	0.1	4.7	42.8	17.0	0
June	0.1	0	8.3	35.3	0

III.3 *Metapenaeus stebbingi*

M. stebbingi was most abundant in the open sea areas A and B, least abundant in C and D, and it was found sporadically in E (Table 7). The appearance of this species was seasonal, it was found in the first half of the year, with similar timing in both open sea and inshore waters of Tubli Bay (Figures 8 and 9).

The mean carapace length of both sexes declined from February/March to June, in the open sea and in inshore (Tubli Bay) waters (Figures 8 and 9). Mature females were found in Tubli Bay in April and May, and in the open sea from March to May 1981 and in July 1980 (Figure 8 and 9). Mature females were most abundant in open areas A and B (Table 8) indicating the importance of these areas as spawning grounds. Sex ratios indicated the dominance of females throughout the period in both open sea areas and in Tubli Bay (Figures 8 and 9). *M. stebbingi* juveniles appeared in beam trawl samples carried out in the shallow waters of Tubli Bay (Table 9). These juveniles appeared most abundantly from February to May 1992, with sporadic numbers in July, August, November and December 1991 (Table 9).

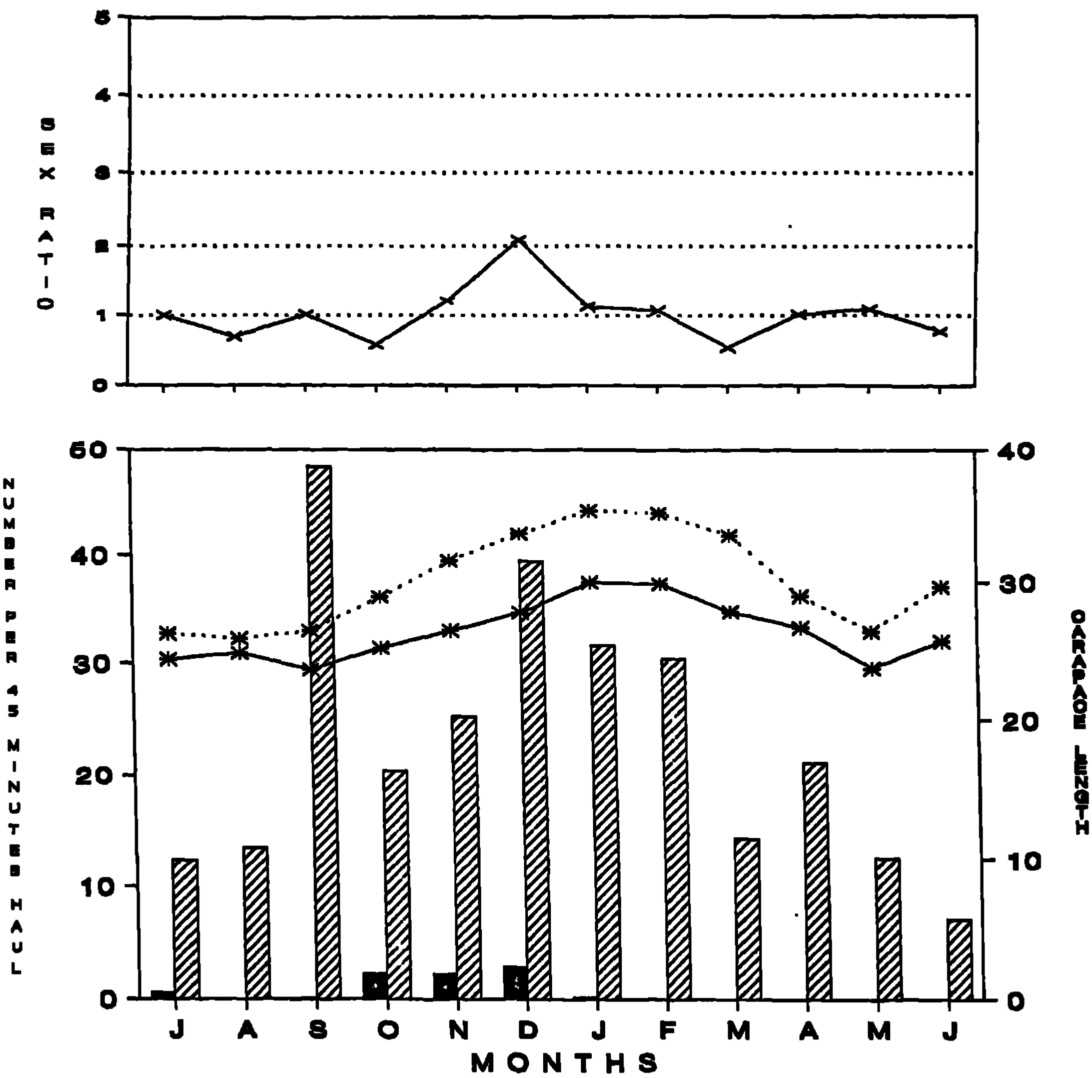

Figure 7. *P. latisulcatus* total number per 45 minutes haul (striped histogram), male (solid line) and female (dotted line) mean carapace length (mm), number of mature females in 45 minutes hauls (close histogram) and sex ratio (number of males/number of females) in the open sea, based on otter trawl samples.

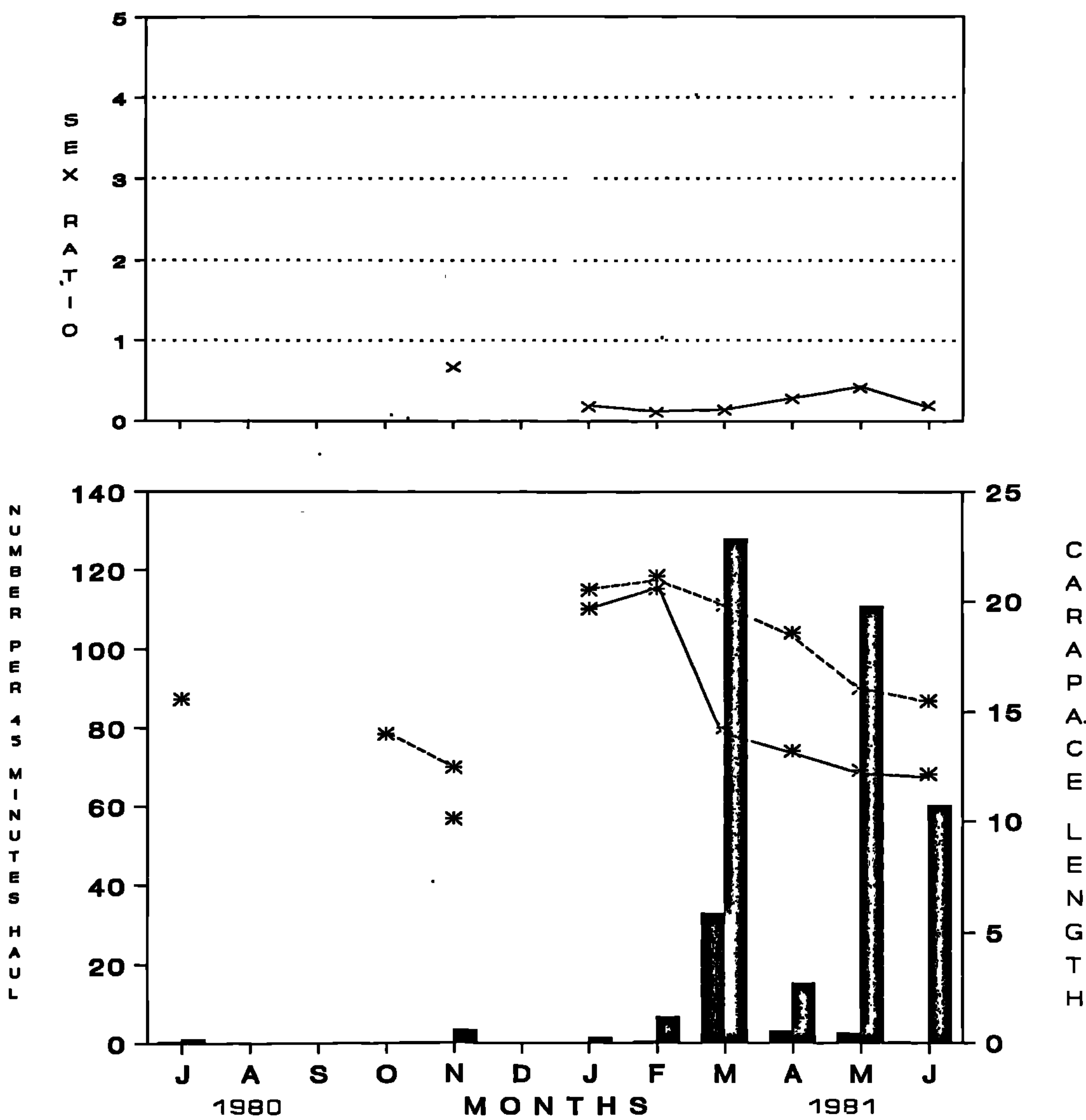

Figure 8. *M. stebbingi* total numbers per 45 minutes haul (light shaded histogram), male (solid line) and female (dotted line) carapace length, number of mature females in 45 minutes hauls (dark shaded histogram) and sex ratio (number of males\number of females) in the open sea area, based on otter trawl samples. (No shrimps found in August, September and December samples. Sex ratio is not shown when only one sex appeared in the sample)

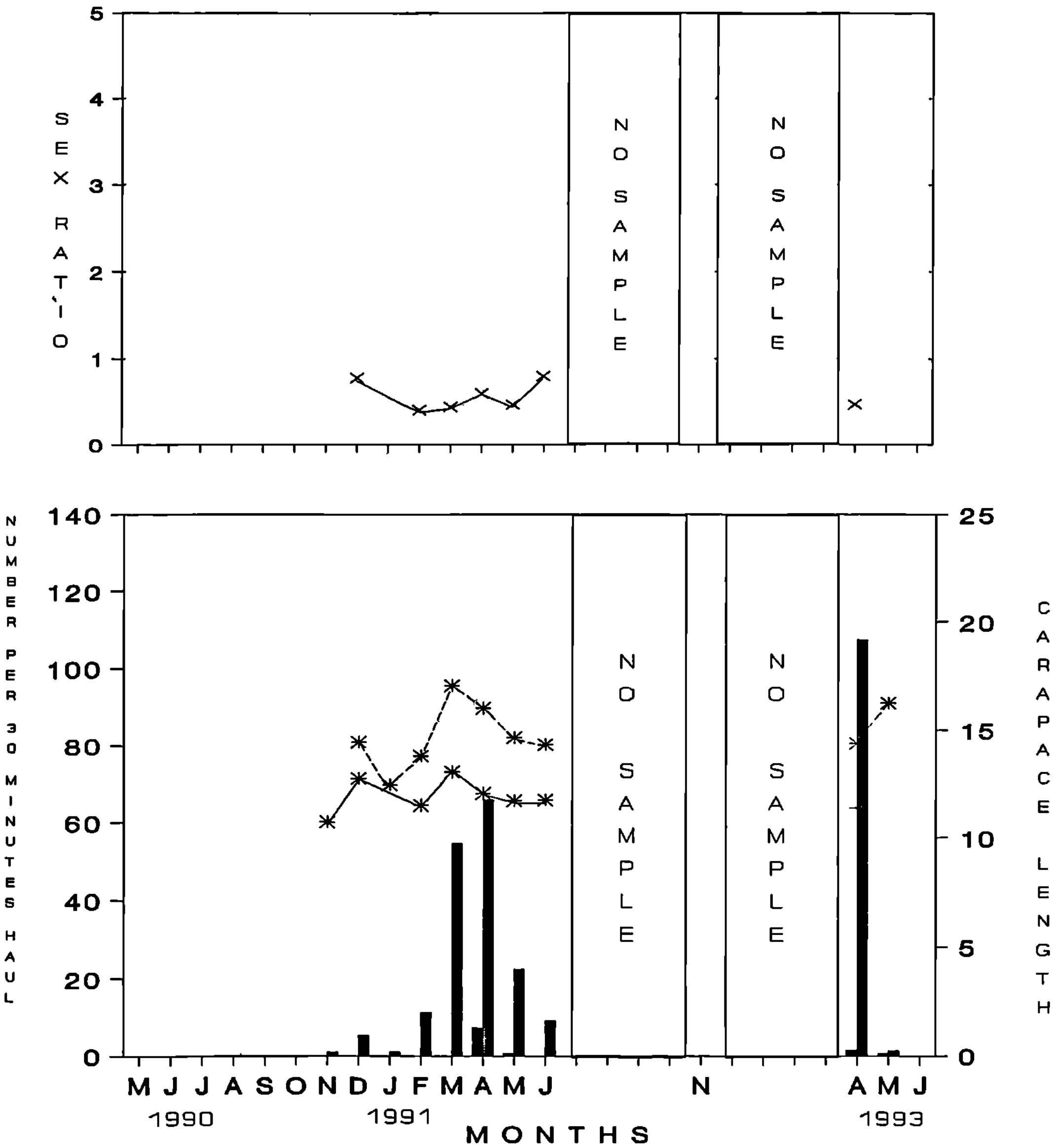

Figure 9. *M. stebbingi* total number per 30 minutes haul (light shaded histogram), male (solid line) and female (dotted line) mean carapace length, number of mature female per 30 minutes haul (dark shaded histogram) and sex ratio (number of males/number of females) in Tubli Bay, based on otter trawl samples. (No shrimps found samples collected in March to October 1990, November 1991, and June 1993)

Table 7. *M. stebbingi* **numbers in 45 minute hauls in the open sea area during the period from July 1980 to June 1981.**

MONTH	OPEN SEA AREAS A	B	C	D	E
July 80	0.2	0.6	0	4.3	0.3
August	0	0	0	0	0
September	0	0	0	0	0
October	0.3	0	0	0	0
November	0	9.6	0	0	0
December	0	0	0	0	0
January 81	4.0	0	0	0	0
February	8.4	8.3	4.5	0	0
March	130.8	368.7	54.3	28.3	0
April	20.0	0.3	3.0	38.8	1.0
May	304.1	16.7	5.7	0	0.3
June	145.7	26.0	6.5	0	0.3

Table 8. On a monthly basis, the numbers of ***M. stebbingi*** **mature females in 45 minutes hauls in the open sea area shown for the period from July 1980 to June 1981.**

MONTHS	OPEN SEA AREAS A	B	C	D	E
July 80	0	0	0	2.0	0
August	0	0	0	0	0
September	0	0	0	0	0
October	0	0	0	0	0
November	0	0	0	0	0
December	0	0	0	0	0
January 81	0	0	0	0	0
February	0	0	0.7	0	0
March	24.6	131.3	10.0	7.0	0
April	5.4	0	0	4.3	0
May	4.7	4.3	0.7	0	0
June	0	4.7	0	0	0

Table 9. Mean carapace length and number per 10 minutes haul in beam trawl samples in Tubli Bay for *M. stebbingi* for the period from May 1991 to June 1992.

MONTH		CARAPACE LENGTH MALES	FEMALES	NUMBER IN 10 MINUTES HAUL
May 91	mean	0	0	0
	sd			
	n			
June	mean	0	0	0
	sd			
	n			
July	mean	0	6.1	0.1
	sd			
	n		1	
August	mean	6.37	0	0.1
	sd			
	n	1		
September	mean	0	0	0
	sd			
	n			
October	mean	0	0	0
	sd			
	n			
November	mean	10.26	0	0.1
	sd			
	n	1		
December	mean	4.37	5.5	0.8
	sd	2.8		
	n	5	1	
January 92	mean	0	0	0
	sd			
	n			
February	mean	5.93	6.92	47.7
	sd	2.39	3.26	
	n	174	112	
March	mean	7.72	8.22	91.9
	sd	2.98	3.95	
	n	403	332	
April	mean	7.5	8.58	53.38
	sd	2.04	2.89	
	n	197	230	
May	mean	9.68	11.3	20.88
	sd	1.02	1.92	
	n	83	84	
June	mean	0	0	0
	sd			
	n			

III.4 *M. kutchensis*

M. kutchensis was found most abundantly in open sea area A; it was less abundant in C and absent from B, D and E (Table 10). This species is seasonal; it appeared from March to June in the open sea and in Tubli Bay, and in the open sea it appeared in sporadic numbers in most of the remaining period (Figures 10 and 11).

Table 10. *M. kutchensis* numbers per 45 minutes haul in the open sea area for the period from July 1980 to June 1981.

	OPEN		SEA	AREAS	
MONTH	A	B	C	D	E
July 80	1.0	0	0.8	0	0
August	2.6	0	0	0	0
September	0.2	0	0	0	0
October	0	0	0	0	0
November	0	0	0.2	0	0
December	2.5	0	0	0	0
January 81	0	0	0	0	0
February	0	0	0	0	0
March	2.0	0	0.2	0	0
April	6.4	0	1.0	0	0
May	16.4	0	33.8	0	0
June	157.4	0	4.5	0	0

Slight increases in the mean carapace length are seen from March to June for both sexes in the open sea and Tubli Bay (Figures 10 and 11). Mature females of this species were found during April and May in Tubli Bay, probably indicating spawning in these waters at those times. Sporadic number of mature females were found during July 1980 and June 1981 in the open sea area. Sex ratio showed a dominance of females in most of the samples (Figures 10 and 11). In Tubli Bay, this species appeared only in otter trawl samples, while in case of *P. semisulcatus* and *M. stebbingi* they appeared in otter and beam trawl samples.

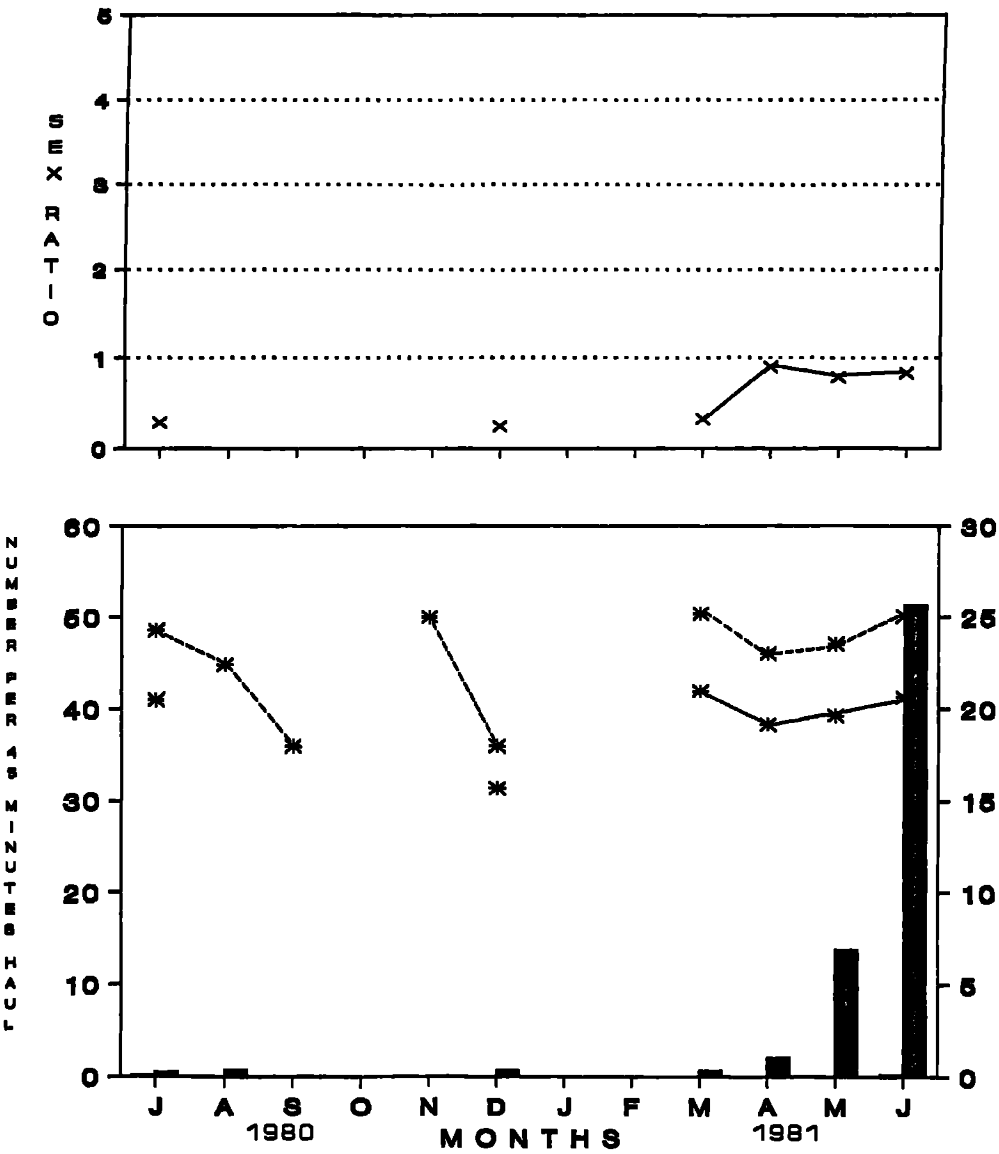

Figure 10. *M. kutchensis* total number per 45 minutes haul (light shaded histogram), male (solid line) and female (dotted line) mean carapace length, number of mature females per 45 minutes haul (dark shaded histogram) and sex ratio (number of males/number of females) in open sea, based on otter trawl samples. (No shrimps found in October, January and February samples)

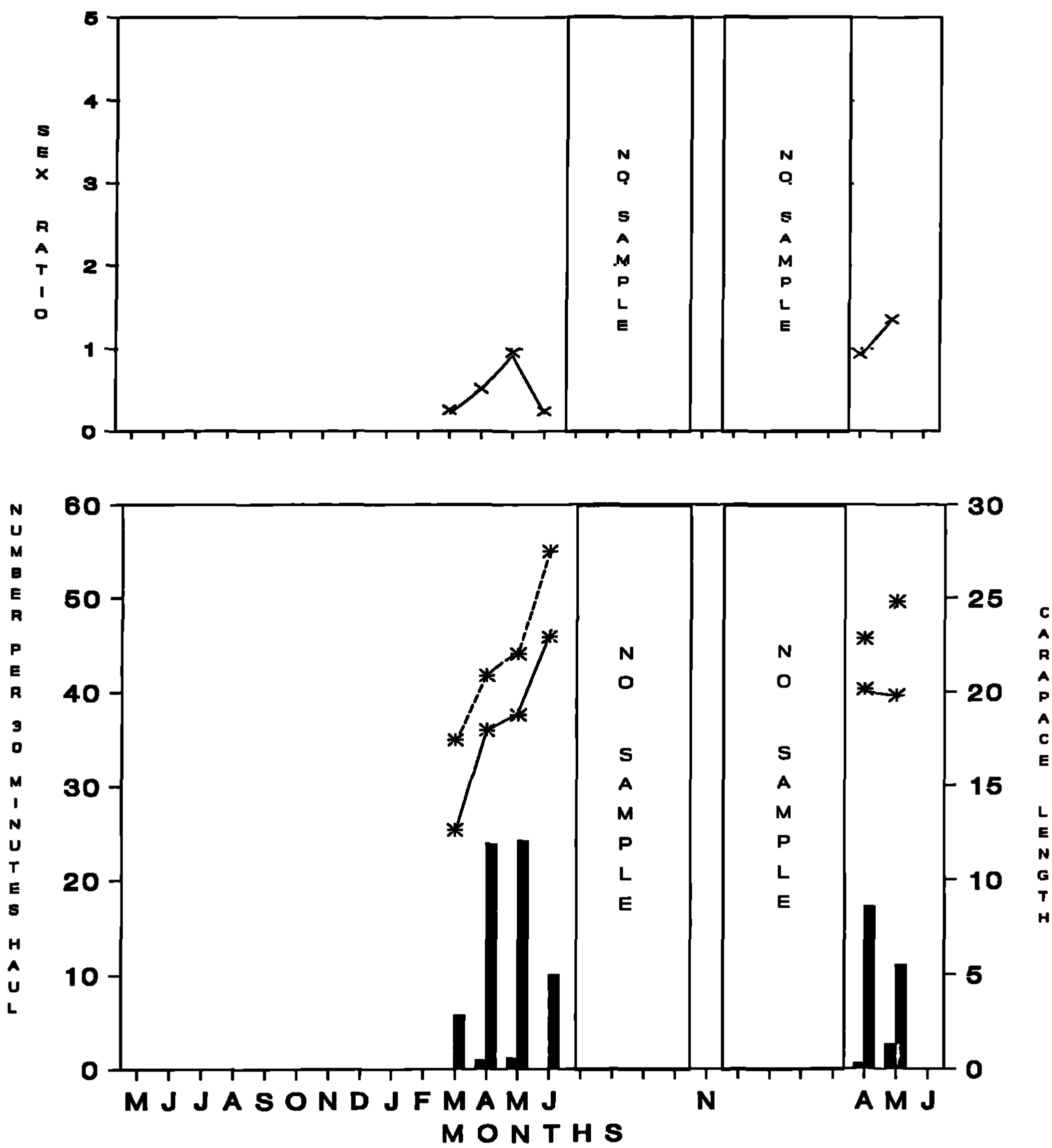

Figure 11. *M. kutchensis* total number per 30 minutes haul (light shaded histogram), male (solid line) and female (dotted line) carapace length, number of mature females per 30 minutes haul (dark shaded histogram) and sex ratio (number of males/number of females) in Tubli Bay, based on otter trawl samples. (No shrimps found in the samples collected in May 1991 to February 1992, in November 1992 and in June 1993)

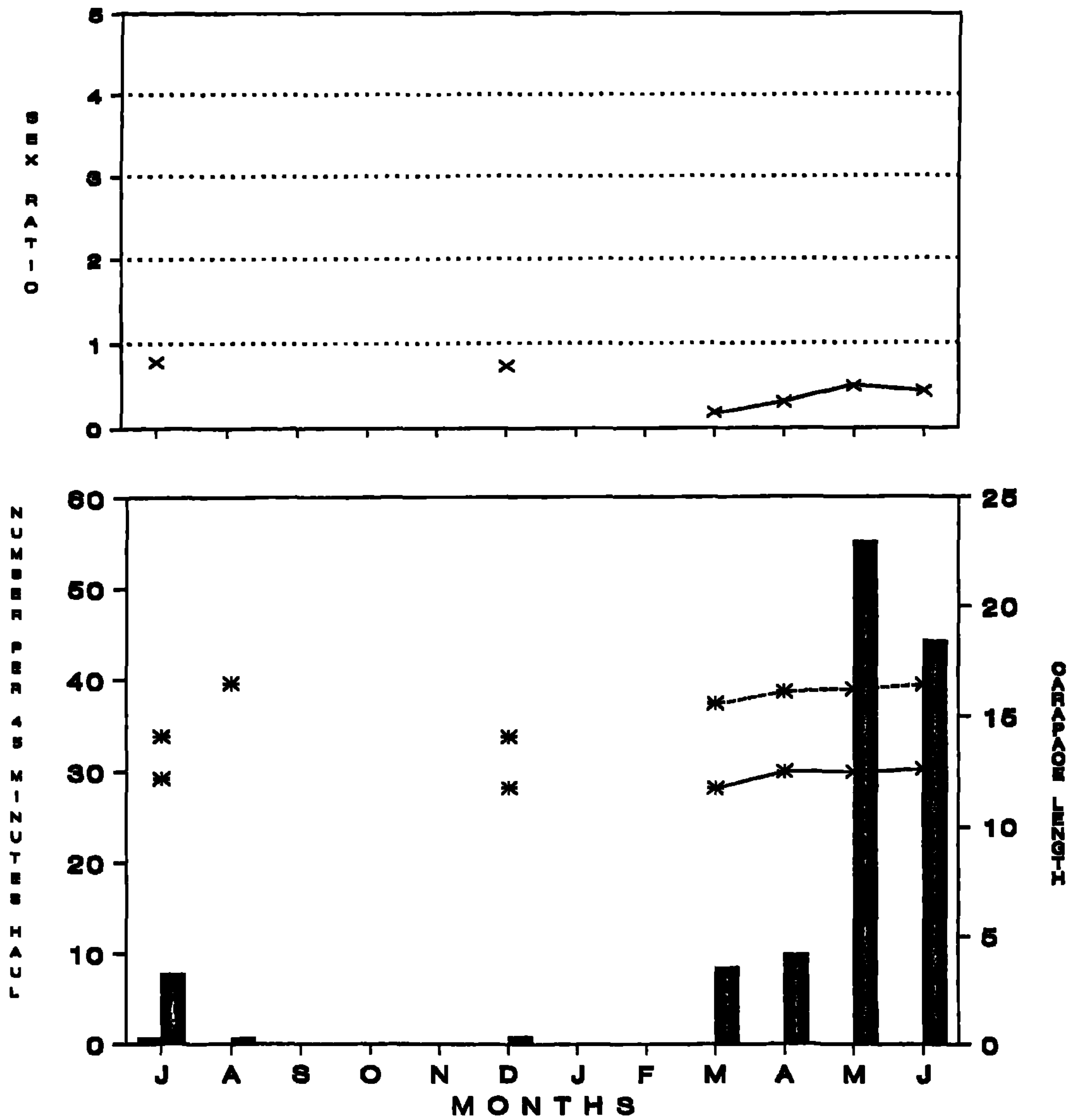

Figure 12. *T. curvirostris* total number per 45 minutes haul (light shaded histogram), male (solid line) and female (dotted line) carapace length, number of mature females in 45 minutes haul (dark shaded histogram) and sex ratio (number of males/number of females) in open sea, based on otter trawl samples. (No shrimps found in samples collected in September to November 1980, January and February 1981.

Table 11. Monthly *T. curvirostris* numbers per 45 minutes haul in the open sea area for the period from July 1980 to June 1981.

MONTH	OPEN A	SEA B	AREAS C	D	E
July 80	0	0	28.6	0	0
August	0	0	2.4	0	0
September	0	0	0	0	0
October	0	0	0	0	0
November	0	0	0	0	0
December	8.0	5.0	6.0	0	0
January 81	0	0	0	0	0
February	0	0	0	0	0
March	4.5	3.3	20.5	5.0	0
April	18.0	0	10.3	9.5	0
May	95.9	24.0	97.3	0.8	0
June	10.0	3.3	138.5	0	0

III.5 *Trachypenaeus curvirostris*

T. curvirostris was found more abundantly in open sea areas A and C; it was less abundant in B and D and absent from E (Table 11). This species was not found in Tubli Bay.

This species is seasonal; it appeared most abundantly from March and probably up to August with a peak in May 1981 (Figure 12). This species also appeared during December in lower numbers (Figure 12). Females dominated throughout the sampling period, and a few mature females were found in July 1980 (Figure 12).

III.6 *Metapenaeopsis stridulans*

M. stridulans was found most abundantly in area A; it was less abundant in C and B, and absent from D and E and Tubli Bay (Table 12). This species appeared in the open sea from February to June, with a gap in April and highest numbers in May 1981 (Figure 13). Mature females of this species were not found in the open sea areas (Figure 13).

Table 12. *M. stridulans* numbers per 45 minutes haul in the open sea area for the period from July 1980 to June 1981.

	OPEN		SEA	AREAS	
MONTH	A	B	C	D	E
July 80	0	0	0.8	0	0
August	0	0	0	0	0
September	0	0	0	0	0
October	0	0	0	0	0
November	0	0	0	0	0
December	0	0	0	0	0
January 81	0	0	0	0	0
February	2.2	0	1.7	0	0
March	8.8	1.0	1.8	0	0
April	0	0	0	0	0
May	289.3	1.0	29.7	0	0
June	213.1	10.3	3.7	0	0

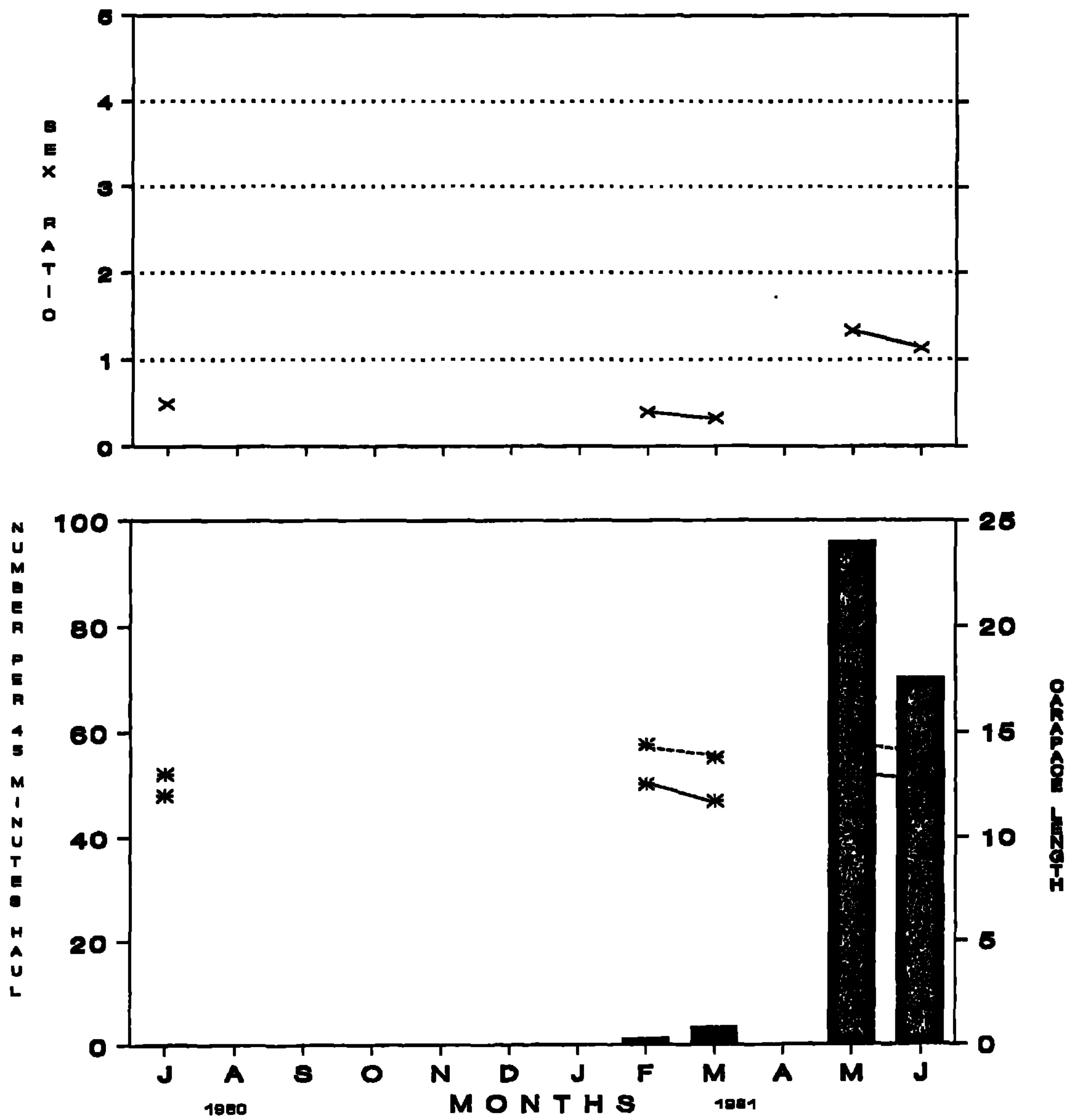

Figure 13. *M. stridulans* total numbers per 45 minutes haul (histogram), male (solid line) and female (dotted line) carapace length (mm) and sex ratio (number of males/number of females) in the open sea area, based on otter trawl samples. (Shrimps not found in samples collected in August 1980 to January 1981 and April 1981).

III.7 *M. mogiensis*

M. mogiensis is the least abundant penaeid species in Bahrain waters; it was found most abundantly in areas A and C, sporadically in B and D, and was absent from E and Tubli Bay (Table 12). *M. mogiensis* is seasonal species; it appeared from April and probably up to July (Figure 14), and a few mature females were found in June 1981 (Figure 14).

Table 13. *M. mogiensis* numbers per 45 minutes haul in the open sea area for the period from July 1980 to June 1981.

	OPEN		SEA	AREAS	
MONTH	A	B	C	D	E
July 80	0	0	0	0.6	0
August	0	0	0	0	0
September	0	0	0	0	0
October	0	0	0	0	0
November	0	0	0	0	0
December	0	0	0	0	0
January 81	0	0	0	0	0
February	0	0	0	0	0
March	0	0	0	0	0
April	11.2	0	0	1.0	0
May	0	0.3	4.0	0.3	0
June	9.6	0.3	14.5	0.3	0

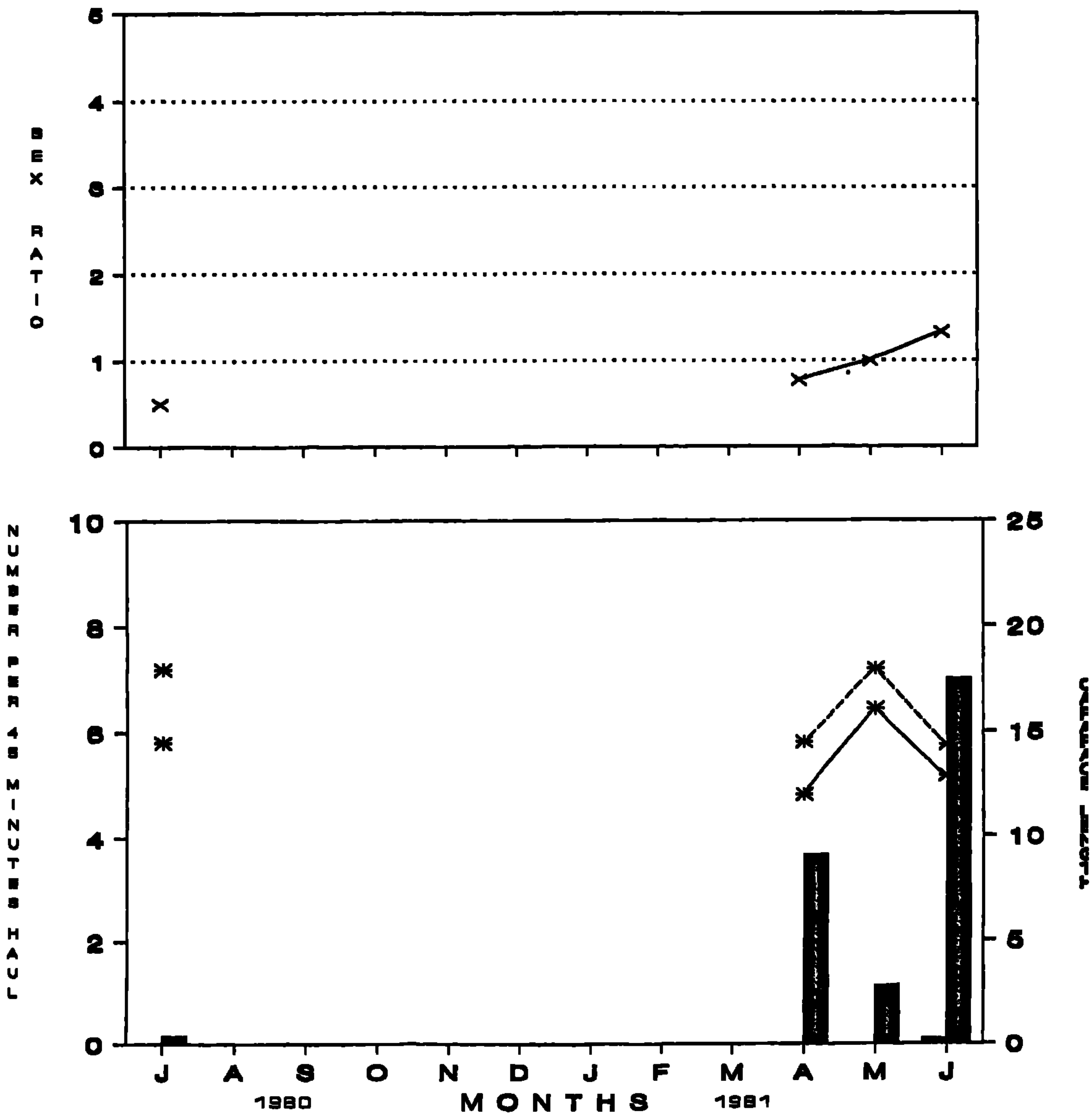

Figure 14. *M. mogiensis* total number per 45 minutes haul (light shaded histogram), male (solid line) and female (dotted line) carapace length (mm), number of mature females in 45 minutes haul (dark shaded histogram) and sex ratio (number of males/number of females) in open sea area, based on otter trawl samples. (No shrimps found in the samples collected in August 1980 to March 1981).

IV. DISCUSSION

IV.1 *P. semisulcatus*

P. semisulcatus was found in wide range of habitats from shallow inshore (Tubli Bay) to offshore open sea waters, throughout most of the year. It occurs on a wide range of substrates from fine sediment to coarse sand substratum (Moller and Jones 1975), but it shows a preference for mud or sandy muddy substrate (Somers 1994). The species is dominant in the Arabian Gulf (Boerema 1969, FAO 1978, Van Zalinge 1980, Water Resources and Environment Division 1990).

IV.1.1 Nurseries and recruitment

The occurrence of *P. semisulcatus* juveniles in Tubli Bay suggests the importance of the bay as a nursery ground for this species. FAO (1978) also suggested that Tubli Bay is a nursery ground for *P. semisulcatus*, but due to its relatively small size the Bay was thought not to support the entire *P. semisulcatus* stock. Certainly IUCN (n.d.) identified the shallow areas within the open area A as an additional nursery ground for *P. semisulcatus*. Area A contains vast sea-grass beds (Atkins and partners 1985) which are the natural habitat of *P. semisulcatus* nurseries (Price 1976, Department of Fisheries 1984, Coles et al. 1987).

The coincident increase in *P. semisulcatus* numbers in the drifter and otter trawl samples during the summer period suggests that substantial movement of shrimp into the Tubli Bay occurred at that time. It seems likely that juveniles and adults moved into the Bay with the assistance of the tidal current, which is directed into the Bay during low tide (Survey Directorate 1988).

The main recruitment period for *P. semisulcatus* is determined from April to July, while it was determined to be from May/June to September in Kuwaiti waters (Van Zalinge 1980).

IV.1.2 Spawning behaviour

The occurrence in the samples of *P. semisulcatus* mature females throughout most of the year, particularly from August to April, indicates prolonged spawning behaviour for this species, as also suggested by Thomas (1974). Other workers have variously reported *P. semisulcatus* spawning period to be from December to March in Bahrain waters (FAO 1978), from October to April (Price and Jones 1975) and from December to May (Price 1979) in Saudi waters, from January to May (Enomoto 1971), March to April (Al-Attar and Ikenoue 1974), and from January to April (Mohammed et al. 1981) in Kuwaiti waters, and from August to September, and in February in Australian waters (Crocos 1987a). In the present study greater numbers of mature females were found during September to December (Figure 5) suggesting that in Bahrain waters the autumn spawning is more important than the spring spawning.

The absence of *P. semisulcatus* mature females from Tubli Bay confirms that this species did not spawn in shallow water and plankton collections for the same period provide further evidence for that conclusion (see chapter 3). Crocos (1987b) also reported *P. semisulcatus* did not spawn in inshore areas. Su and Liao (1987) found that ovaries of all *P. semisulcatus* females sampled from August 1984 to April 1987 in Dapping Bay (Taiwan) were undeveloped. Further, offshore spawning behaviour for *P. semisulcatus* was reported by a number of authors (Price 1979, Rothlisberg et al. 1987, Crocos 1987a, Grabe and Lees 1992).

Male dominance in present samples during January suggested migration of females beyond the present limits of Bahrain fishing ground (see chapter 5). This indicates a probable extension of the known main spawning ground (area C) to further offshore during January. Certainly, in penaeids in general, spawning activity is often associated with marked changes in sex ratio from 1:1 (Kunju 1970, Thomas 1974, Garcia and Le Reste 1981, Penn 1980, Garcia 1985, and Bouhlel and Hail 1985). In inshore (Tubli Bay) waters, where the immature population of *P. semisulcatus* was found, the sex ratio did not show a dominance of either sexes.

The sudden appearance of bigger females with spent ovaries in the Bay suggested post-spawning migration of *P. semisulcatus* back to shallow water.

IV.2 *P. latisulcatus*

P. latisulcatus is less widely distributed and found in lower numbers than *P. semisulcatus* in Bahrain waters as it is in other part of the Arabian Gulf (Lewis et al. 1973, FAO 1978, Department of Fisheries 1984, Mohammed et al. 1981). Spawning and recruitment timing for *P. latisulcatus* showed general similarities to those for *P.semisulcatus*, supporting Rothlisberg et al. (1987) who also indicated similarities in spawning seasons and areas for both *P. semisulcatus* and *P. latisulcatus*. In other studies juveniles of both species were collected together from shallow water within the open sea area A (IUCN n.d.), and from Tarut Bay (Saudi Arabia) nursery grounds (Water Resources and Environment Division 1990). However in the present study the appearance of *P. latisulcatus* most abundantly in areas B and D indicates a different spatial distribution for this species when compared with *P. semisulcatus*. This difference may be related to bottom sediments; *P. semisulcatus* showed preferences for sediments with a high mud content (Moller and Jones 1975, Branford

1981, Somers 1987 and 1994), but the distribution of *P. latisulcatus* was negatively correlated with the percentage of mud (Branford 1981, Somers 1987).

IV.3 *M. stebbingi*

Due its small size, *M. stebbingi* is of low commercial value in Bahrain (FAO 1978), Saudi Arabia (Price and Jones 1975, Water Resources and Environment Division 1990) and Kuwait waters (Mohammed et al. 1981, Bishop and Khan 1991). The appearance of mature females in Tubli Bay indicates spawning of this species in these shallow waters, and plankton samples collected at the same time of year provided further evidence for this Bay as a spawning ground (see chapter 3). However, the occurrence of mature females also in the open sea suggests a wider spawning areas for this species, which usually extends from spring to early summer in offshore and inshore waters. Habib-Ul-Hassan (1992) found that the *M. stebbingi* spawning period extended from spring to early summer, and it was found to spawn from April to October in the Suez Canal area (Egypt) see Gab-Alla et al. 1990. Nevertheless the appearance of juveniles in the Bay from February indicates the importance of Tubli Bay as a nursery ground for this species.

IV.4 *M. kutchensis*

Here all the previous work carried out on *M. affinis* in the Gulf area will be compared to the current findings. This is done because of the presumed misidentification of *M. kutchensis* as *M. affinis* (see chapter 1). *M. kutchensis* (*affinis*) is reported as a commercially important species in Kuwaiti waters (Mathews 1989).

The presence of mature females in Tubli Bay in the present study suggests a spawning migration of this species into the Bay during spring and early summer. Moreover plankton collections provide further evidence for this conclusion (see chapter 3). Thus both *M. kutchensis* and *M. stebbingi* showed shallow water spawning behaviour (see also IV.3). Al-Shoushani (1985) found that *M. kutchensis* (*affinis*) spawning season in Kuwaiti water was from May to June and sometimes extended to September, while Mathews (1989) found that the spawning period extended from March to August in the same areas.

M. kutchensis juveniles were absent from the Tubli Bay beam trawl samples, while *P. semisulcatus* and *M. stebbingi* juveniles were common in these samples. This indicates differences in environment selection between *M. kutchensis* juveniles and the juveniles of *M. stebbingi* and *P. semisulcatus*.

IV.5 *T. curvirostris*

The absence *T. curvirostris* from Tubli Bay otter and beam trawl samples of the current study indicates that it is not an important species in Bahrain waters at any stage of its life cycle. Similarly this species is also found absent from Tarut Bay (Saudi Arabia) and Kuwait Bay (Water Resources and Environment Division 1990, Al-Attar 1982, Bishop 1989).

Mature females of *T. curvirostris* were found only in July while its abundance period in the open sea extended from March to July. Ho Kim et al. (1984) found that the spawning season for *T. curvirostris* extended from May to September in Korean waters.

IV.6 *M. stridulans* and *M. mogiensis*

Both *M. stridulans* and *M. mogiensis* were absent from Tubli Bay otter and beam trawl. Similarly, these species were found absent from Tarut Bay (Saudi Arabia) and Kuwait Bay

(Water Resources and Environment Division 1990, Al-Attar 1982, Bishop 1989).

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CHAPTER FOUR
BIONOMICS OF PENAEID SHRIMPS OF BAHRAIN

SUMMARY

The biological requirements of penaeid shrimps change throughout their life cycle. These changes influence the fishery of these species, resulting in seasonal variation in catches. This chapter aimed to highlight biological aspects of penaeid shrimps of Bahrain. Two major benthic surveys were completed. The first was conducted from June 1980 to June 1981 using an industrial trawler and covered the entire shrimping ground, except Tubli Bay. A second survey was carried out on the shrimp population in Tubli Bay in three time periods: (1) May 1991 to June 1992, (2) November 1992, and (3) April to June 1993. Seven penaeid species were collected in these surveys: *Penaeus semisulcatus*, *P. latisulcatus*, *Metapenaeus stebbingi*, *M. kutchensis*, *Trachypenaeus curvirostris*, *Metapenaeopsis stradulans*, *M. mogiensis*. The main recruitment period for *P. semisulcatus* was from April to July. A prolonged spawning from August to April was determined. Tubli Bay and area south of Fasht Al-Adhom were determined to be shrimp nursery grounds within Bahrain waters. Spawning and recruitment timing for *P. latisulcatus* showed general similarities to those for *P. semisulcatus*. But *P. latisulcatus* was less widely distributed and found in lower numbers in Bahrain waters. Both *M. stebbingi* and *M. kutchensis* demonstrate shallow water spawning behaviour in Tubli Bay during spring and early summer.

CHAPTER FIVE

MIGRATION OF PENAEID SHRIMPS

I. INTRODUCTION

Understanding of migration patterns is of a vital importance for the management of commercial stocks of invertebrates and fish stocks; it provides crucial information when estimating such population parameters as growth and mortality rates. Penaeid shrimps are known to migrate over large distances within a relatively short period of time (Garcia and Le Reste 1981). Migration studies of Gulf penaeid using tagged shrimps have been used to study the migrations of *Penaeus semisulcatus* in Kuwait waters (Farmer and Al-Attar 1981, FAO 1980 and Mohammed et al. 1981), but shrimp movement studies more generally in the Arabian Gulf are lacking. Recognizing the lack of tagging data for Bahrain penaeids, the present work set out to study the migration pattern for all penaeid shrimps of Bahrain, based on size differences of contemporary shrimp samples collected from defined areas within the shrimping ground.

II. MATERIALS AND METHODS

Data used in this chapter were derived from shrimp trawl surveys conducted by an industrial vessel from June 1980 to June 1981(see chapter 4). Data from the sampling stations were grouped in five open sea areas A to E as also described in chapter 4.

From length frequency data for each open sea area, the monthly mean carapace length and their standard deviations were calculated. For each month, the differences in the mean carapace length values between adjacent pairs of areas were then tested by one way analysis of variance, and significant differences determined by the Scheffe test at 5% level. This test was done for all penaeid shrimp species found in Bahrain waters, the rationale being that if for any one species there were consistent size differences between adjacent areas then migration between those areas may be likely.

III. RESULTS

III.1 *P. semisulcatus*

Carapace length frequency data averaged for whole shrimping ground are shown in Figure 1. Unimodal frequency curves are seen throughout the period with a major recruitment occurring from April to July. A clear modal progression was seen from October to January which coincided with decrease in shrimp numbers. This decline is more likely to have been a response to migration of shrimp out of the fishing areas into deeper water, than to heavy fishing mortality. Evidence for this interpretation is the rapid reduction in the abundance which occurred after January (Figure 1), with no increase in commercial catches at that time. Combined industrial and artisanal catches recorded for December 1980, January 1981 and February 1981 were 61.2, 42.1 and 28.3 tonnes respectively. In addition the sex ratio in January showed a marked dominance of males (Figure 2). This apparent increase in males seems much more reasonably caused by the migration of females into deeper water rather than to fishing mortality, which would be expected to affect both sexes equally.

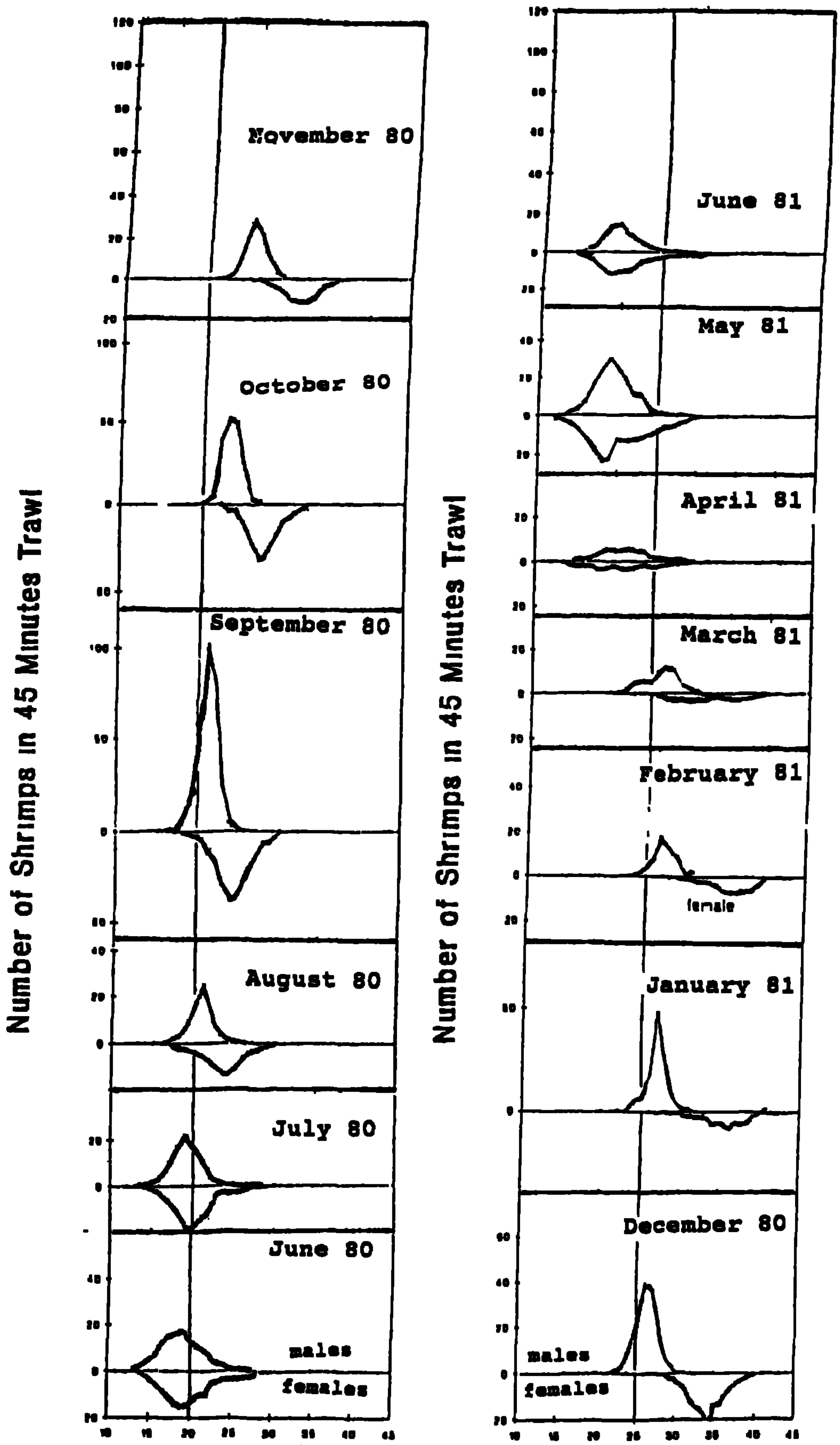

Figure 1. Monthly length frequency values for average 45 minutes haul, based on *P. semisulcatus* data pooled for the whole Bahrain shrimping grounds.

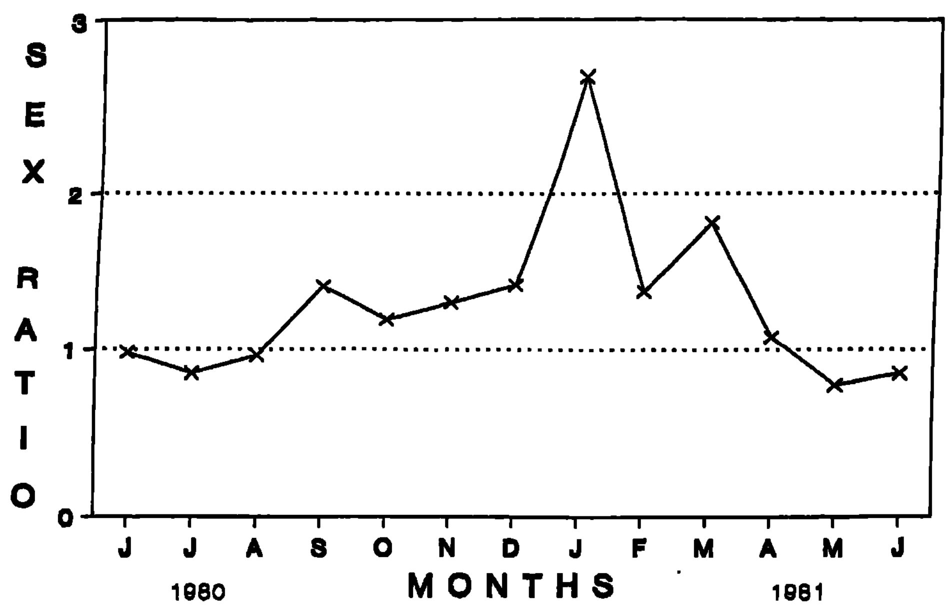

Figure 2. *P. semisulcatus* sex ratio (number of males/number of females) averaged for the open sea area from June 1980 to June 1981.

Despite the unimodality of the pooled length frequency (Figure 1), suggesting uniformity of growth for the whole stock, *P. semisulcatus* did show some significant differences in mean sizes between different areas (Table 1 and 2). Such size differences seem unlikely to have resulted from differences in growth or mortality rates between areas, but were more likely to have resulted from movement of shrimp from one area to another. Similar mesh-sizes used in the both artisanal and industrial sector throughout the area indicates similar fishing mortality over the whole stock. Moreover, area C, which is regarded as the main fishing area, often had shrimps of greater mean size than, say area A suggesting that greater fishing effort in area C did not result in smaller mean size of the population in that area.

A reasonable hypothesis to explain areal differences in mean size is therefore that shrimp migrated from one area to another. This is illustrated in Figure 3 which plots the significant differences in mean size between pairs of adjacent areas (Table 1 and 2). There are consistent increases in size from shallow areas A and E to deeper waters in areas B, D and C (Figure 3), which suggest shrimp movement between these areas. Two movement patterns are accordingly determined, from May to September (Figure 3a), the general tendency was for shrimp to move from areas A and B, D and E to area C, while from October through April (Figure 3b), shrimps also appeared to migrate from area C to parts of area D to the north. This northward movement of shrimps also supports the conclusion reached that from February to April *P. semisulcatus* migrated beyond the present fishing grounds (see page 136).

The population of *P. semisulcatus* in the main Bahrain fishing ground (area C) appears to recruit from two main grounds, namely area A and E. Of these two, area A appears to be the more important since there are significant correlations in shrimp abundance between area A and area C for both males ($r = 0.5651$, $n = 13$) and females ($r = 0.628$, $n = 13$). Correlation coefficients comparing abundance in areas E and C were not significant for either males ($r = 0.1732$, $n = 13$) or females ($r = 0.0406$, $n = 13$), suggesting that area E is less important than area A as a nursery ground for the main Bahrain fishing ground in area C.

Table 1. Monthly mean carapace length (mm), standard deviation and number in the standard 45 minutes hauls for *P. semisulcatus* males at all stations sampled in areas A to E. Asterisks indicate where there are significant differences in mean size at the 5% level between two adjacent areas. Members of the adjacent pairs of areas between which significant differences occurred are indicated by a common number.

		AREAS				
MONTHS		A	B	C	D	E
June 80	mean	18.7	19.4	19.7	18.1	17.4
	s.d.	1.9	2.6	2.6	3.5	1.9
	n	40	1264	311	392	259
	*			2,3	1,3	1,2
July	mean	19.0	18.2	19.5	19.1	18.5
	s.d.	3.5	2.1	2.0	1.6	4.0
	n	87	321	668	367	302
	*		1	1,3	2	2,3
August	mean	20.6	21.2	20.9	20.5	19.8
	s.d.	1.6	1.0	2.5	1.6	1.9
	n	432	180	658	41	190
	*	2	2	1		1
September	mean	20.8	21.3	21.7	21.1	20.8
	s.d.	1.7	1.2	1.3	2.2	1.4
	n	1117	626	955	2535	142
	*	1,2	1,5	2,3,4,5	3	4
October	mean	23.0	23.6	23.2	23.6	23.3
	s.d.	1.0	1.4	1.3	1.3	1.2
	n	519	69	977	349	1012
	*	1,2	2	1,3	3,4	4
November	mean	24.6	25.5	25.2	25.8	25.3
	s.d.	2.8	1.1	2.0	1.3	2.6
	n	166	447	741	204	376
	*	1,2	2	1,3	3	
December	mean	26.0	26.7	26.5	26.8	26.4
	s.d.	1.9	1.2	1.8	1.1	1.5
	n	1328	222	1273	134	183
	*	1,2	2	1		
January 81	mean	26.7	26.9	27.5	27.2	26.8
	s.d.	2.2	1.6	1.3	1.2	1.3
	n	1072	57	615	235	5
	*	1		1		
February	mean	26.8	27.1	27.6	28.1	28.0
	s.d.	2.6	2.8	2.1	1.0	0.8
	n	378	68	554	26	4
	*	1		1		

Table 1 (cont.)

March	mean	25.1	25.5	27.0	27.4	24.0
	s.d.	2.6	3.8	2.2	1.2	5.7
	n	502	24	488	86	2
	*	1		1		
April	mean	19.4	22.0	22.9	25.7	22.8
	s.d.	2.2		2.8	2.6	1.5
	n	375	1	344	58	4
	*	1		1,2	2	
May	mean	17.8	18.6	20.3	20.8	18.8
	s.d.	1.7	1.8	2.7	1.9	4.0
	n	1075	135	2104	31	8
	*	1,2	1,3	2,3		
June	mean	18.6	19.0	20.4	20.3	19.8
	s.d.	3.7	1.4	3.1	2.5	2.8
	n	711	256	539	9	23
	*	1	2	1,2		

* denotes significant difference.

Table 2. Monthly mean carapace length (mm), standard deviation and number in the standard 45 minutes hauls for *P. semisulcatus* females at all stations sampled in areas A to E. Asterisks indicate where there are significant differences in mean size at the 5% level between two adjacent areas. Members of the adjacent pairs of areas between which significant differences occurred are indicated by a common number.

		AREAS				
MONTHS		A	B	C	D	E
June 80	mean	20.5	20.1	22.2	19.2	18.7
	s.d.	3.5	4.3	4.5	6.0	5.2
	n	62	1090	339	501	312
	*		3	1,2,3	2	1
July	mean	20.5	19.4	21.0	20.2	19.6
	s.d.	3.6	2.6	5.2	3.9	2.8
	n	117	429	789	349	366
	*		1	1,2		2
August	mean	23.3	24.7	23.9	22.8	21.2
	s.d.	2.8	3.0	2.1	2.3	3.2
	n	386	233	665	50	229
	*	3,4	4,5	2,3,5	1	1,2
September	mean	23.6	24.2	25.6	24.4	22.9
	s.d.	2.2	2.0	2.2	2.3	3.0
	n	1093	525	765	1389	67
	*	3,4	3,5	2,4,5,6	1,6	1,2
October	mean	26.8	28.0	27.8	28.0	27.1
	s.d.	1.9	2.0	4.1	2.1	3.6
	n	401	91	813	282	882
	*	1		1,2	3	2,3
November	mean	30.3	31.8	30.8	32.2	30.7
	s.d.	2.7	2.5	2.7	1.8	1.8
	n	148	455	556	172	158
	*	1	1,3	3,4	2,4	2
December	mean	33.8	34.3	34.2	34.8	33.3
	s.d.	2.2	3.5	2.6	2.0	2.2
	n	528	192	1290	174	45
	*	1		1	2	2
January 81	mean	34.9	35.5	35.6	36.2	36.0
	s.d.	3.7	3.2	3.0	3.3	
	n	336	41	282	78	2
February	mean	34.3	33.9	36.1	35.3	30.0
	s.d.	3.5	3.3	2.4	3.2	
	n	133	30	567	22	1
	*	2	1	1,2		

Table 2. (Cont.)

March	mean	29.4	28.6	34.1	34.2	40.5
	s.d.	3.1	3.3	4.5	3.9	4.9
	n	171	20	357	51	2
	*	2	1	1,2		
April	mean	20.0	25.5	24.5	29.1	23.5
	s.d.	3.4		6.2	5.3	4.9
	n	454	2	211	57	2
	*	1		1,2	2	
May	mean	18.0	18.7	22.2	23.2	20.2
	s.d.	4.2	4.0	6.8	2.9	4.2
	n	1377	227	2551	35	13
	*	1	2	1,2,4	3,4	3
June	mean	19.3	20.3	23.3	22.5	20.1
	s.d.	4.9	4.0	5.1	3.0	2.2
	n	886	248	621	10	36
	*	1	3	1,2,3		2

* denotes significant difference.

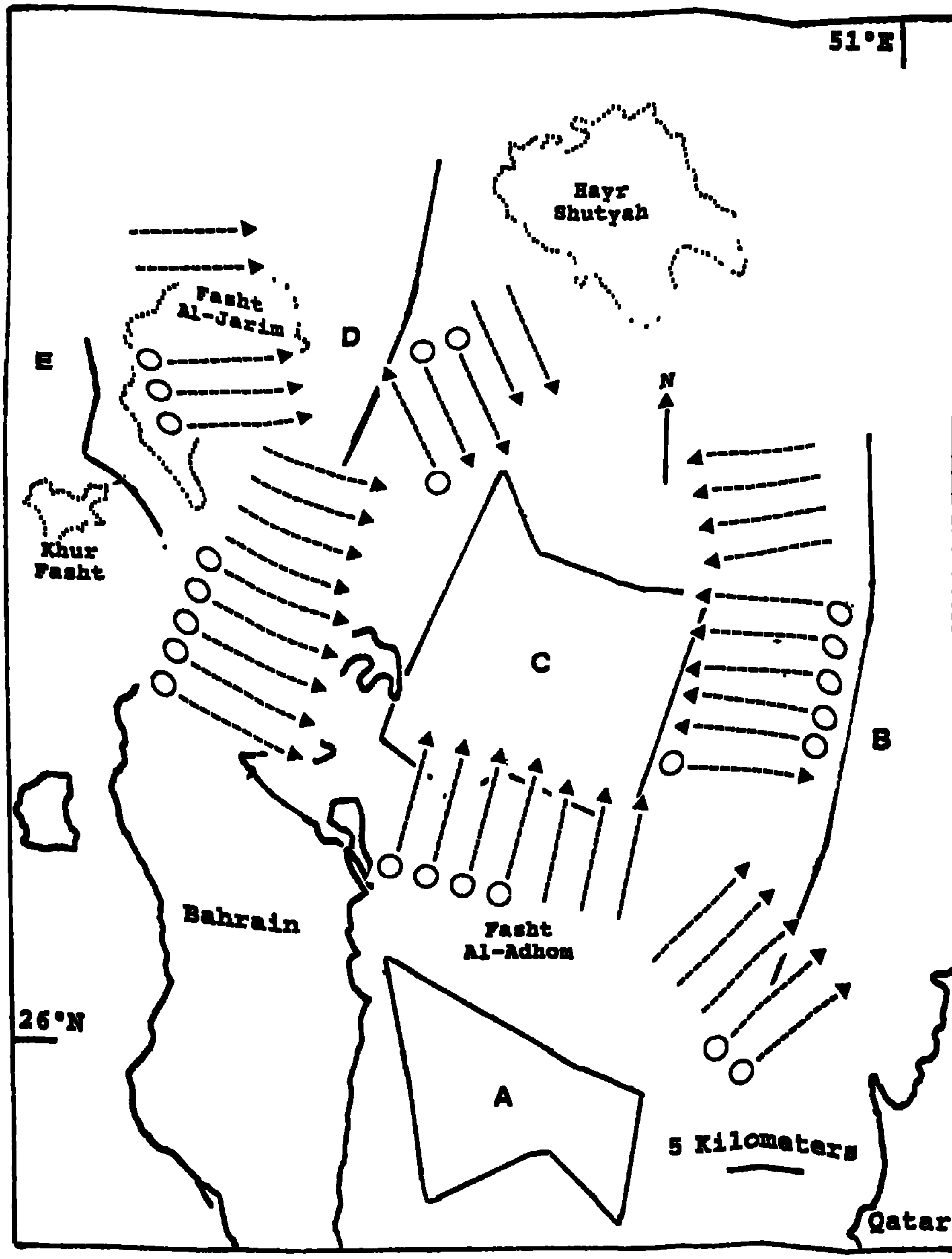

Figure 3a. Shows the movement pattern for *P. semisulcatus* within the sampling areas for males (--->) and females (O--->) during the period May to September. Based on table 1 and 2. Arrows point towards a statistically greater size when comparing mean carapace length values between adjacent pairs of sampling areas. Each arrow represents one monthly comparision.

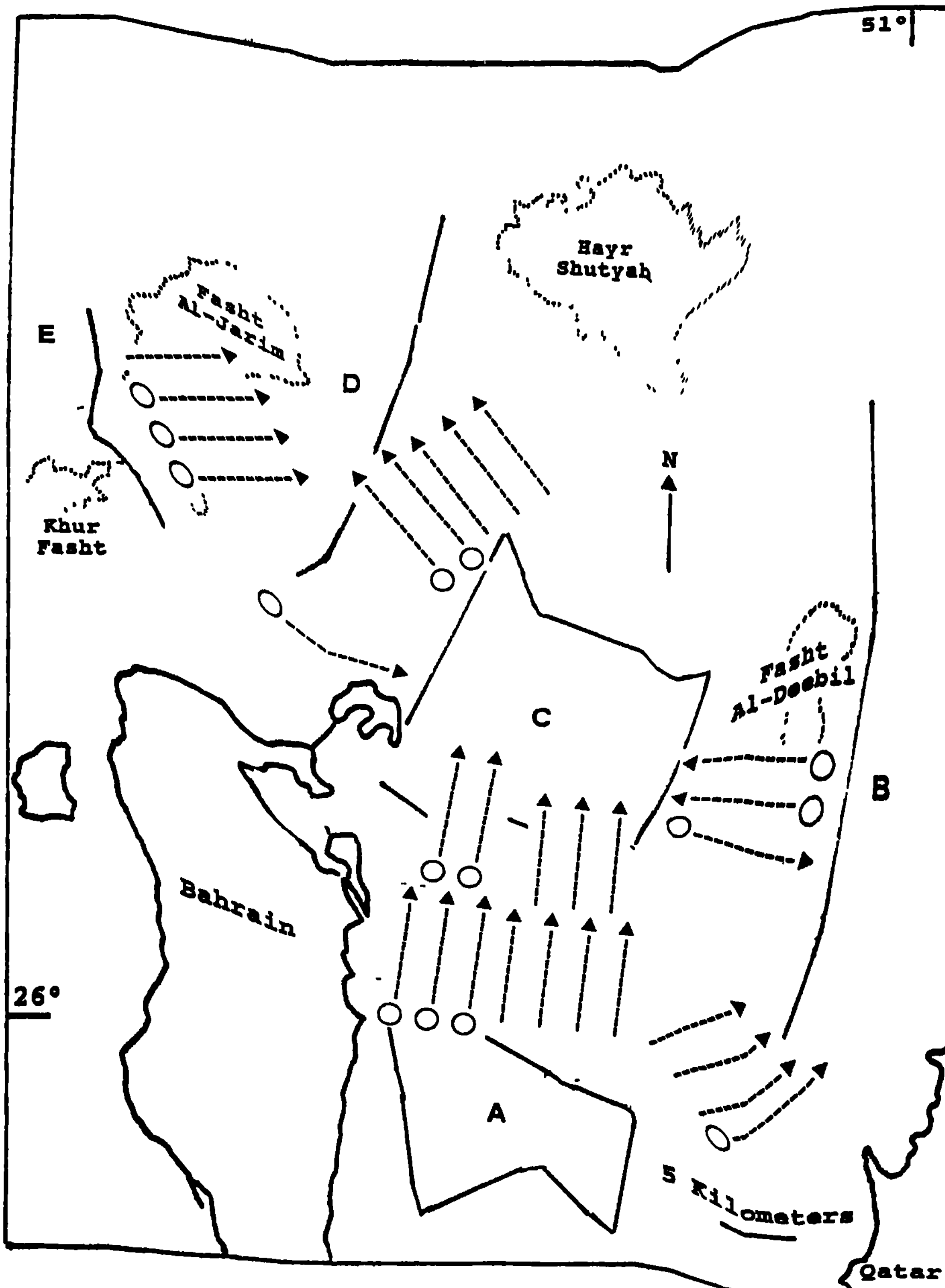

Figure 3b. Shows the movement pattern for *P. semisulcatus* within the sampling areas for males (---▸) and females (○---▸) during the period October to April. Based on tables 1 and 2. See Figure 3a for additional explanation.

III.2 *P. latisulcatus*

In Arabian Gulf waters, *P. latisulcatus* does not form an independent fishery, but it appears as a minor species in the commercial catches of *P. semisulcatus*. The presence of post-larvae, juveniles (see chapters 3 and 4) and mature individuals (Figure 5) of this species in Bahrain waters indicates that an identifiable stock of this species occurs in these waters. The length frequency curves show that recruitment of this species occurred from March to September (Figure 4), and greatest percentages of mature females were found from October to December 1980 (Figure 5). Except for December, no clear dominance of either sex was found in the population of this species (Figure 5).

Because of the low numbers caught significant differences between mean carapace lengths for *P. latisulcatus* found in different areas were apparent only in case of males in September, November, January, and June (Tables 3 and 4). These significant areal size differences, illustrated as arrows indicating the direction of the bigger sizes (Figure 6), suggest migration from area B to C to D in September, November 1980 and January 1981 (Table 3).

III.3 *M. kutchensis*

The occurrence of this species only in areas A and C suggests restriction of this stock to Bahrain waters. Pooled carapace length frequency data shows that substantial numbers of this species were found only in May and June 1981 (Figure 7), when spawning occurred in the shallow waters of Tubli Bay (see chapter 4). Accordingly, it seems most likely that aggregation for spawning was the main reason for the appearance of this species in open sea area. Significant differences between mean carapace lengths were determined in males in May and in females in May and June (Tables 5 and 6). These size differences showed a consistent pattern, with size increases of both sexes from area A to area C, suggesting movement northwards from area A to area C (Figure 8).

III.4 *M. stebbingi*

M. stebbingi was more widely distributed during the sampling period than *M. kutchensis*; it was found in areas A, B, C and D (Tables 7 and 8). Unimodality of the pooled length frequency data of this species was apparent during the months of highest abundance from March to June 1981 (Figure 9). This period was the spawning period for this species in both open sea and shallow water of Tubli Bay (see chapter 4).

Significant size differences between males and females in adjacent open sea areas are presented in Tables 7 and 8 and illustrated as arrows pointing toward the larger sizes in Figure 10. No consistent pattern was apparent between areas A and B, but there were consistent size differences suggesting that females migrated into area C from areas A and B.

III.5 *T. curvirostris*

T. curvirostris was found in the open sea areas A to D, where the highest abundance occurred from March to July (Figure 11) when unimodal distribution of pooled length frequency data occurred. Significant size differences between adjacent areas for both sexes are shown in Tables 9 and 10 and plotted as arrows pointing toward the larger sizes in Figure 12. No clear consistent pattern was apparent for this species.

III.6 *M. stridulans* and *M. mogiensis*

Tables 11 and 12 show mean carapace lengths, standard deviations and numbers of shrimp in the samples for *M. stridulans* males and females in open sea areas A, B, and C. Few significant size differences were determined, and a consistent pattern was apparent (Table 11 and 12).

M. mogiensis occurred in low numbers and was restricted to the areas A and C. Tables 13 and 14 shows mean carapace lengths, standard deviations and number of shrimp in samples for males and females in areas A and C. Shrimp found in both areas showed no significant size difference (Table 13 and 14).

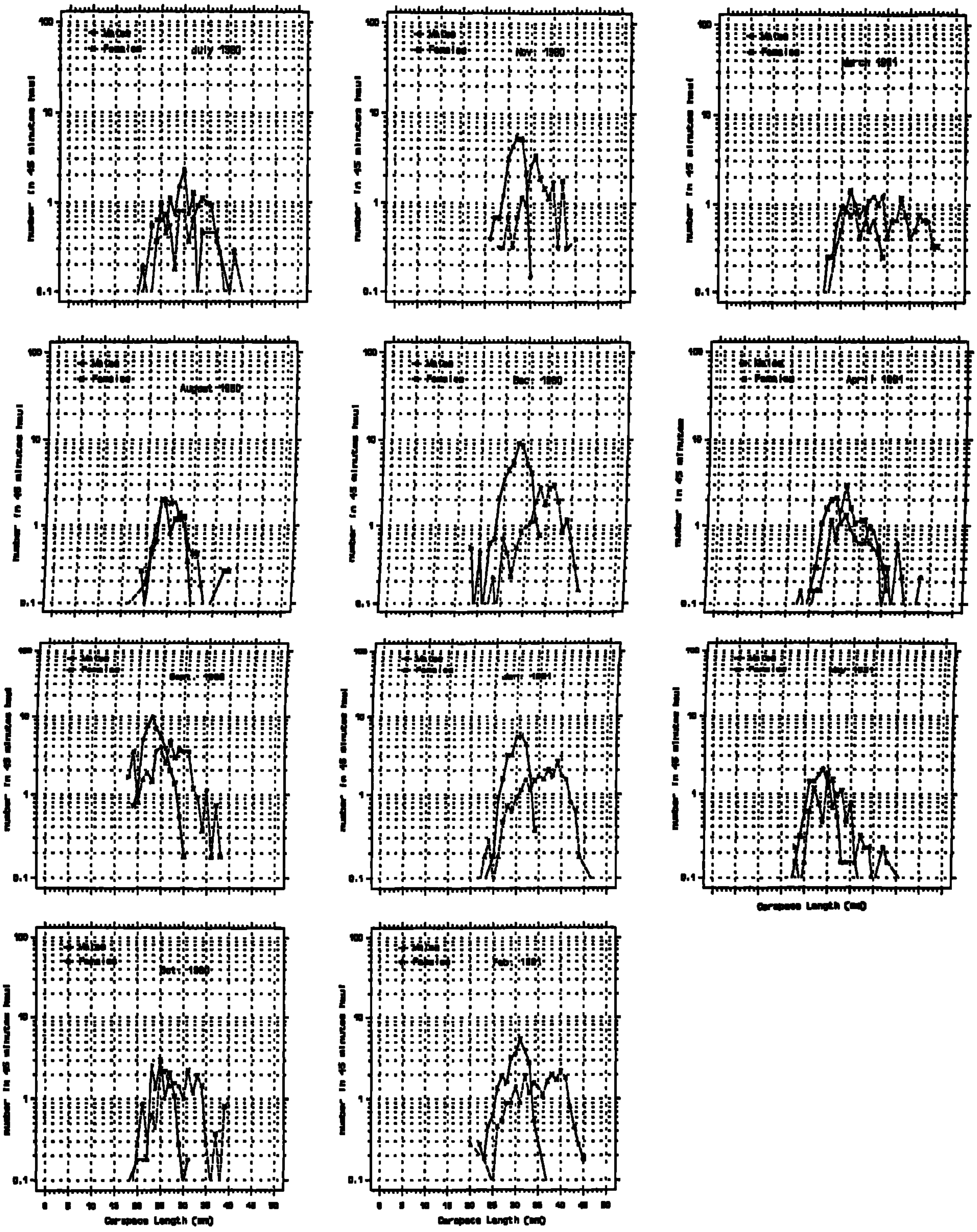

Figure 4. *P. latisulcatus* **length frequency curves for males (solid line) and females (dotted line) averaged for open sea areas.**

Table 3. Monthly mean carapace length (mm), standard deviation and number in the sample for *P. latisulcatus* males in subareas B to D. Asterisks indicate where there are significant differences at the 5% level between two subareas; members of these pairs of subareas are indicated by a common number.

MONTHS		AREAS B	AREAS C	AREAS D
July 80	mean	21.4	16.0	25.4
	s.d.	2.7		3.4
	n	30	1	93
August	mean	25.2		23.1
	s.d.	2.5		1.7
	n	89	0	22
September	mean	22.9	23.9	23.6
	s.d.	1.0	2.6	2.5
	n	74	94	321
	*	1	1	
October	mean	24.1	24.5	25.5
	s.d.	2.3	2.2	2.4
	n	13	32	90
November	mean	26.9	25.7	26.6
	s.d.	1.3	2.3	2.0
	n	122	84	99
	*	1	1,2	2
December	mean	27.4	28.6	28.9
	s.d.	3.2	2.0	3.7
	n	438	57	118
January 81	mean	27.8	30.5	30.2
	s.d.	1.3	1.6	2.5
	n	19	42	226
	*	1	1	
February	mean	27.9	30.5	31.9
	s.d.	2.4	2.7	1.7
	n	99	117	68
March	mean	27.4	29.4	25.4
	s.d.	2.4	3.6	2.6
	n	52	39	15
April	mean		28.0	26.8
	s.d.			4.1
	n	0	1	199
May	mean	22.4	23.7	
	s.d.	2.8	3.3	
	n	7	144	0
June	mean		24.1	26.3
	s.d.		2.3	2.6
	n	0	19	50
	*		1	1

Table 4. Monthly mean carapace length (mm), standard deviation and number in the sample for *P. latisulcatus* females in subareas B to D. Asterisks indicate where there are significant differences at the 5% level between two subareas; members of these pairs of subareas are indicated by a common number.

MONTHS		AREAS B	AREAS C	AREAS D
July 80	mean	22.6		27.7
	st. dev.	3.7		5.5
	n	27	0	99
August	mean	26.1		24.3
	st. dev.	5.0		3.7
	n	132	0	25
September	mean	24.3	26.1	26.9
	st. dev.	3.3	4.2	4.9
	n	72	59	347
October	mean	27.0	28.8	29.1
	st. dev.	3.0	5.0	4.4
	n	22	75	126
November	mean	31.9	31.4	
	st. dev.	3.3	3.9	
	n	120	131	0
December	mean	32.4	33.8	34.4
	st. dev.	4.6	4.4	5.8
	n	100	61	133
January 81	mean	31.3	36.4	36.0
	st. dev.	4.4	3.8	4.9
	n	30	41	181
February	mean	31.4	35.9	39.7
	st. dev.	4.4	4.8	2.4
	n	102	89	72
March	mean	30.0	33.7	35.9
	st. dev.	3.7	5.5	6.5
	n	25	57	112
April	mean		29.0	29.0
	st. dev.			5.3
	n	0	1	198
May	mean	24.9	25.9	30.2
	st. dev.	4.6	5.9	4.0
	n	7	113	18
June	mean		27.6	30.9
	st. dev.		4.5	4.7
	n	0	31	56

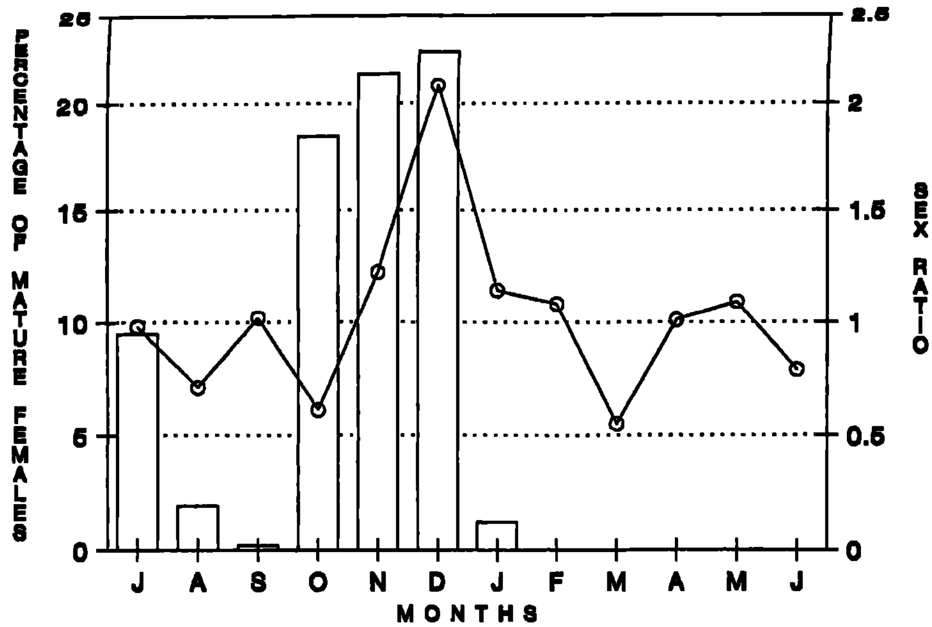

Figure 5. *P. latisulcatus* percentage of mature females (histogram) and sex ratio (number of males/number of females) averaged for open sea areas during July 1980 to June 1981.

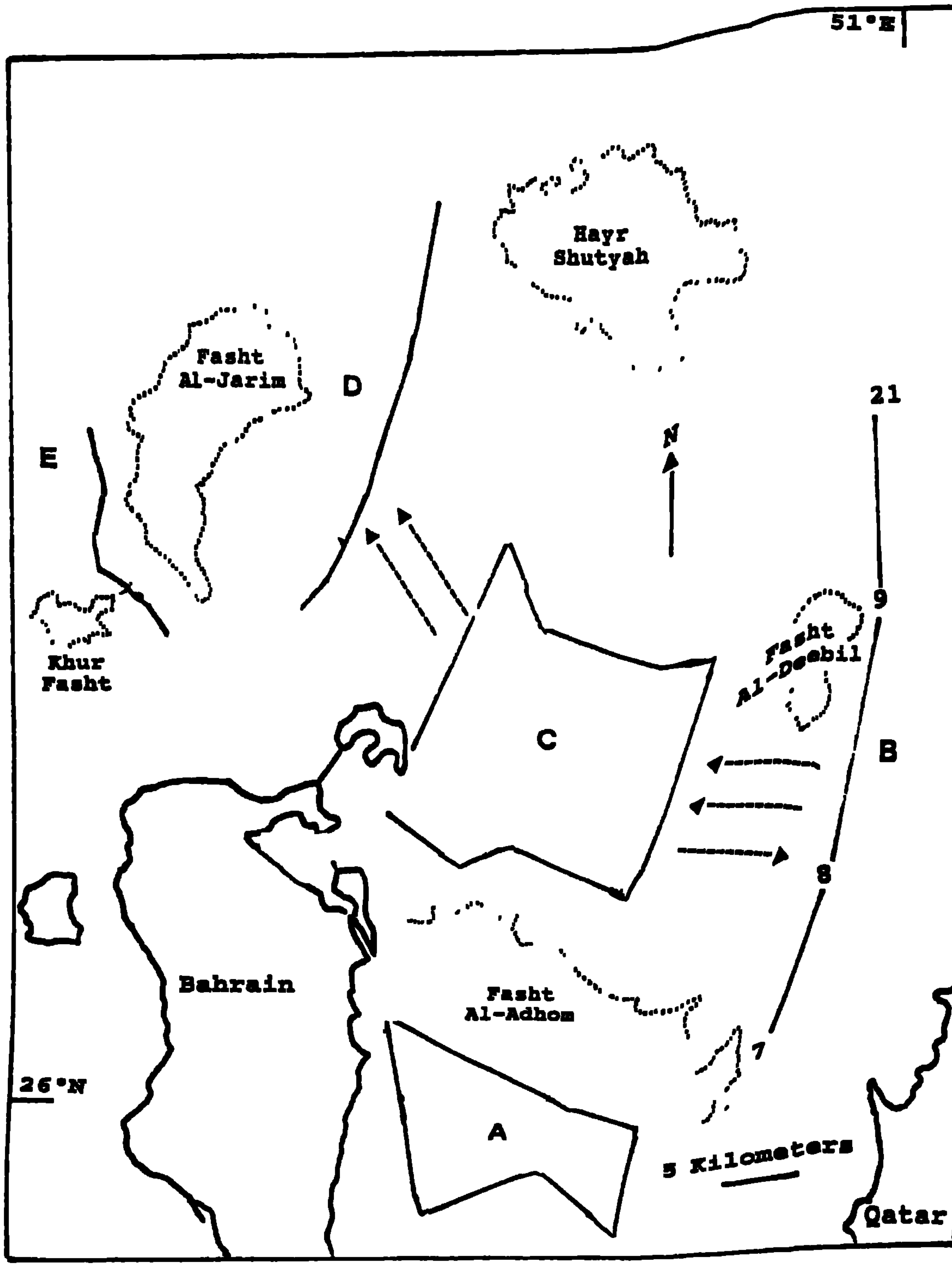

Figure 6. Shows the movement pattern for *P. latisulcatus* within the sampling areas for males (--->) and females (O--->) during the period July to June. Based on tables 3 and 4. See Figure 3a for additional explanation.

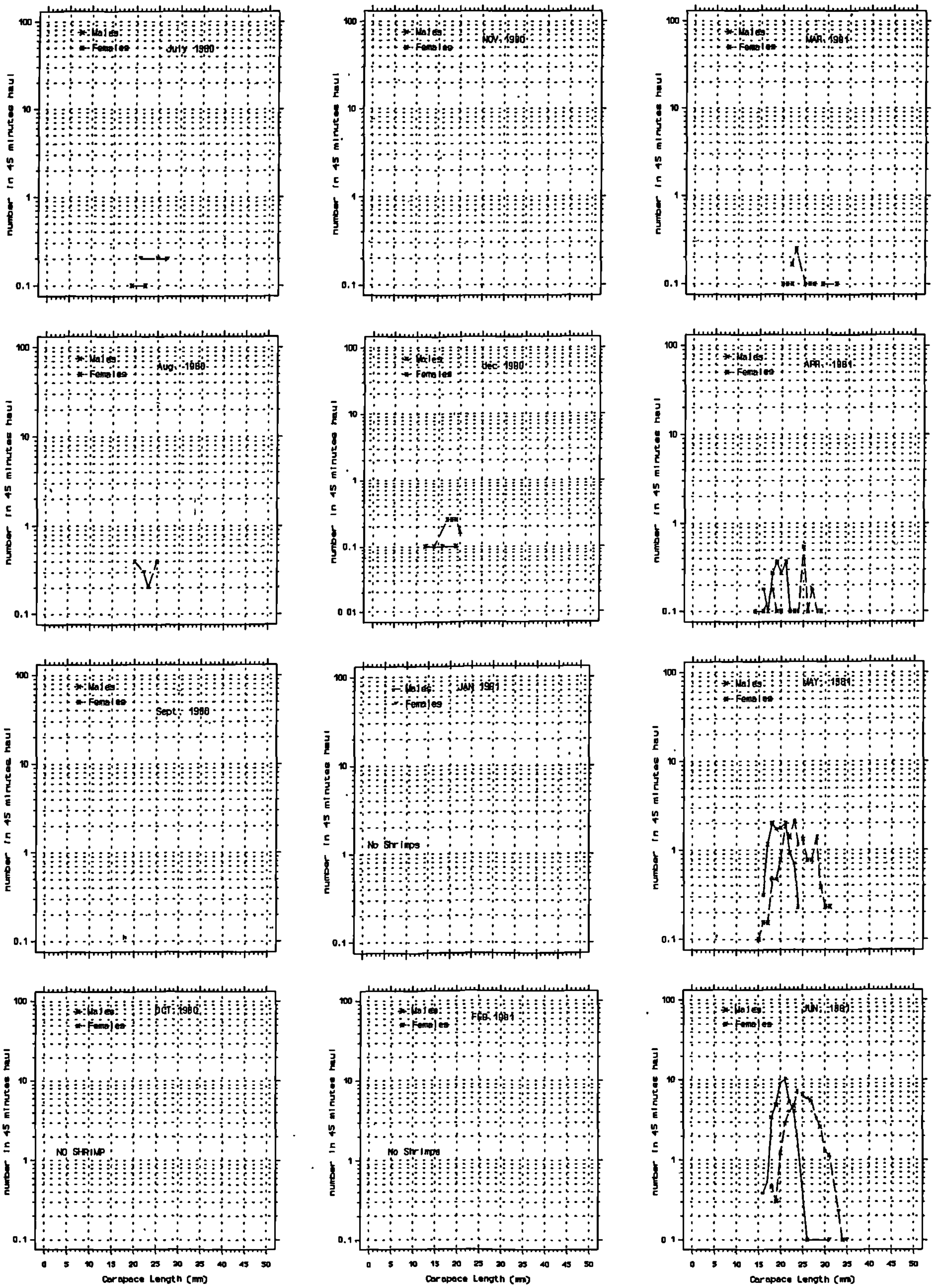

Figure 7. *M. kutchensis* length frequency curves for males (solid line) and females (dotted line) averaged for open sea area.

Table 5. Monthly mean carapace length (mm), standard deviation and number in the sample for *M. kutchensis* males in subareas A and C. Asterisks indicate where there are significant differences at the 5% level between two subareas; members of these pairs of subareas are indicated by a common number.

MONTHS		AREAS A	C
July 80	mean	22.0	19.0
	st. dev.	0	0
	n	1	1
August	mean		
	st. dev.		
	n	0	0
September	mean		
	st. dev.		
	n	0	0
October	mean		
	st. dev.		
	n	0	0
November	mean		
	st. dev.		
	n	0	0
December	mean	15.7	
	st. dev.	3.5	
	n	3	0
January 81	mean		
	st. dev.		
	n	0	0
February	mean		
	st. dev.		
	n	0	0
March	mean	21.0	
	st. dev.	1	
	n	3	0
April	mean	19.1	20.0
	st. dev.	1.8	
	n	17	1
May	mean	18.8	20.0
	st. dev.	1.9	1.9
	n	41	99
	*	1	1
June	mean	20.6	21.0
	st. dev.	3.3	1.9
	n	507	6

Table 6. Monthly mean carapace length (mm), standard deviation and number in the sample for *M. kutchensis* females in subareas A and C. Asterisks indicate where there are significant differences at the 5% level between two subareas; members of these pairs of subareas are indicated by a common number.

MONTHS		AREAS A	AREAS C
July 80	mean	24.5	24.0
	st. dev.	2.6	3.0
	n	4	3
August	mean	22.5	
	st. dev.	2.1	
	n	13	0
September	mean	18.0	
	st. dev.		
	n	1	0
October	mean		
	st. dev.		
	n	0	0
November	mean	25.0	
	st. dev.		
	n	1	0
December	mean	18.0	
	st. dev.	2.0	
	n	12	0
January 81	mean		
	st. dev.		
	n	0	0
February	mean		
	st. dev.		
	n	0	0
March	mean	24.8	
	st. dev.	4.0	
	n	9	0
April	mean	22.5	24.6
	st. dev.	4.6	3.3
	n	15	5
May	mean	22.6	24.3
	st. dev.	2.8	3.7
	n	74	104
	*	1	1
June	mean	25.0	27.0
	st. dev.	3.2	3.5
	n	595	21
	*	1	1

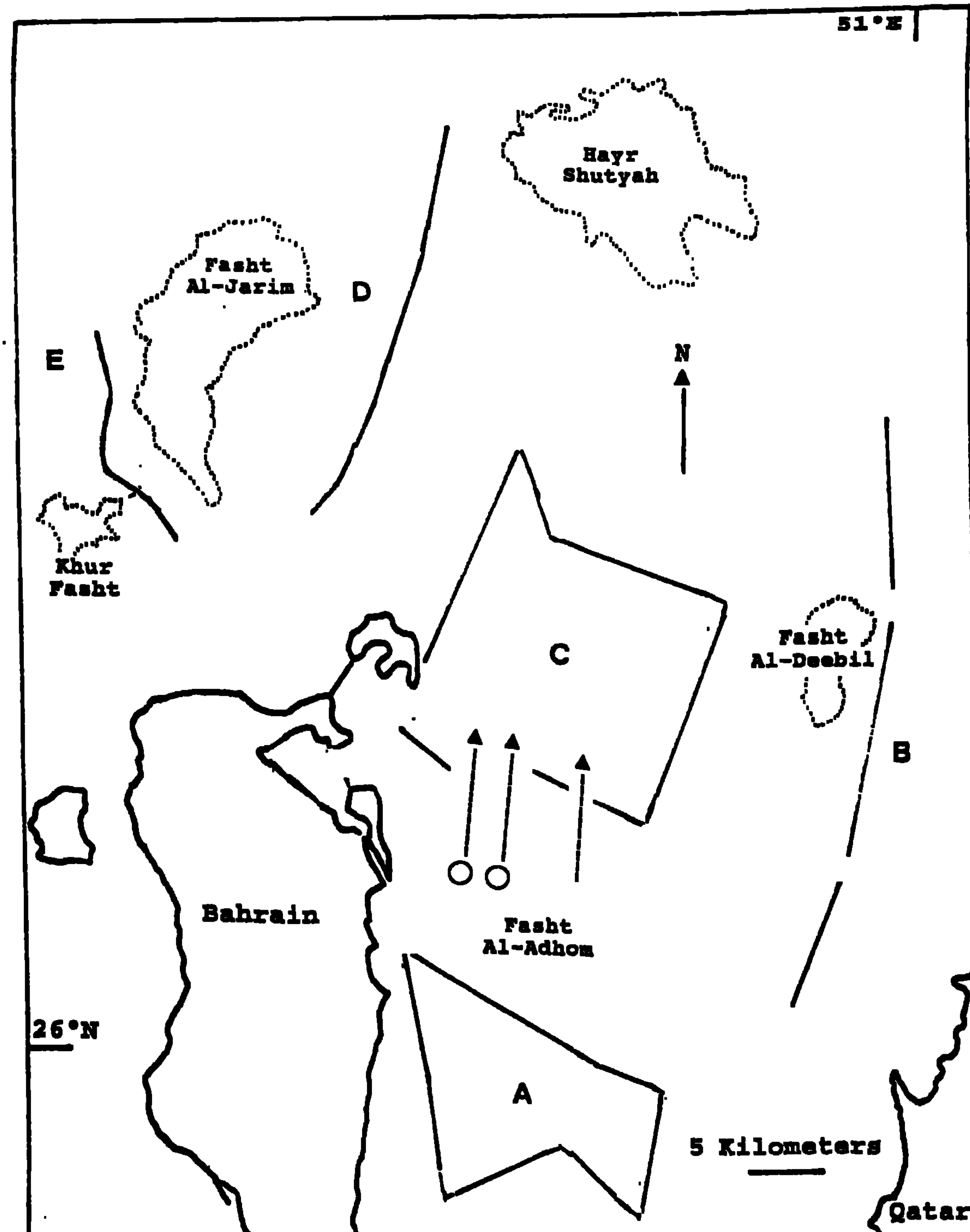

Figure 8. Shows the movement pattern for *M. kutchensis* within the sampling areas for males (--->) and females (O--->) during the period July to June. Based on tables 5 and 6. See Figure 3a for additional explanation.

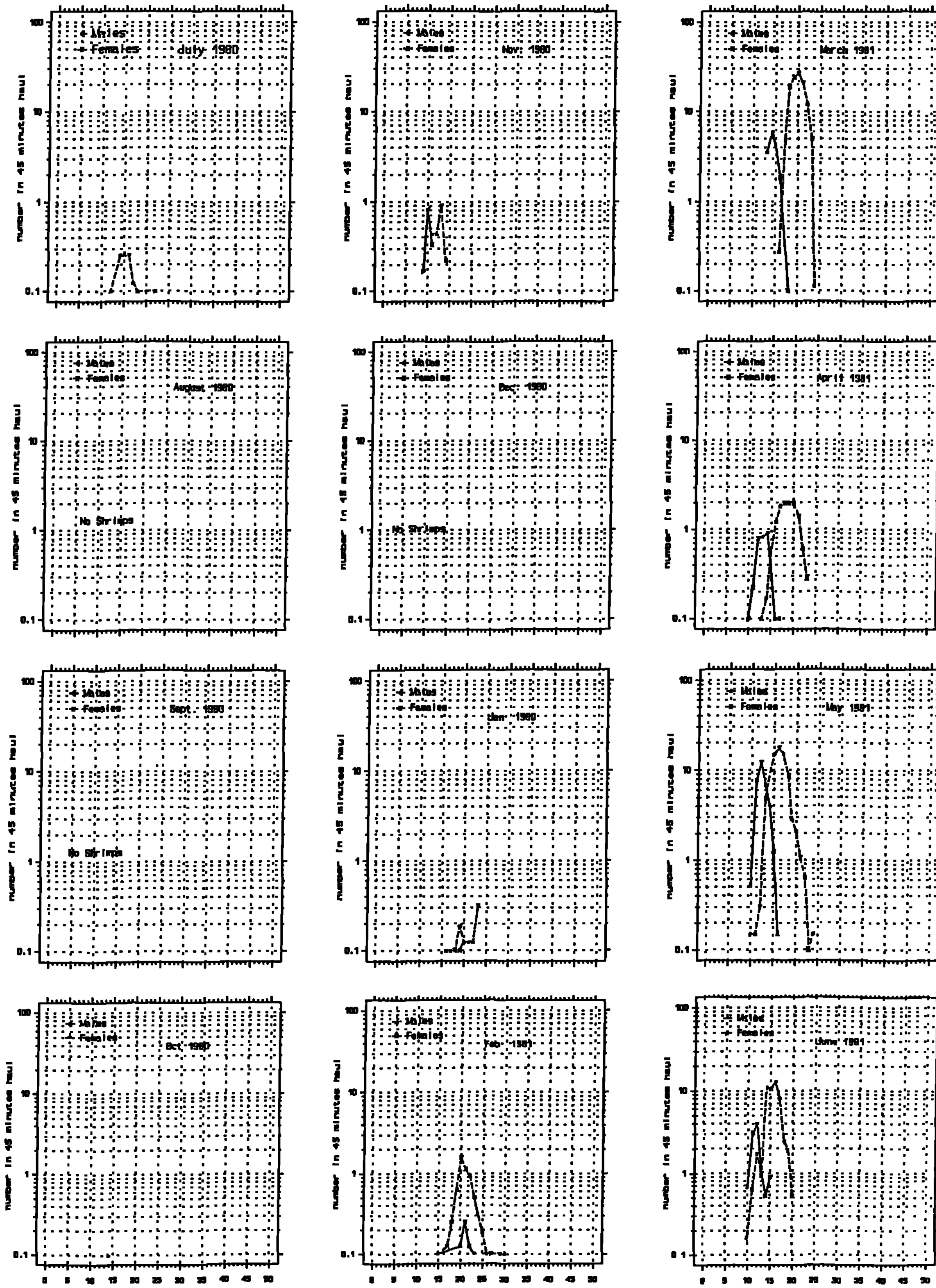

Figure 9. *M. stebbingi* **length frequency curves for males (solid line) and females (dotted line) averaged for open sea areas.**

Table 7. Monthly mean carapace length (mm), standard deviation and number in the sample for *M. stebbingi* males in subareas A to D. Asterisks indicate where there are significant differences at the 5% level between two subareas; members of these pairs of subareas are indicated by a common number.

MONTHS		AREAS A	B	C	D
July 80	mean				
	s.d.				
	n	0	0	0	0
August	mean				
	s.d.				
	n	0	0	0	0
September	mean				
	s.d.				
	n	0	0	0	0
October	mean				
	s.d.				
	n	0	0	0	0
November	mean		10.1		
	s.d.		0.6		
	n	0	0	24	0
December	mean				
	s.d.				
	n	0	0	0	0
January 81	mean	19.7			
	s.d.	0.6			
	n	3	0	0	0
February	mean	21.4		17.5	
	s.d.	0.9		3.5	
	n	8	0	2	0
March	mean	14.3	14.2	14.5	14.0
	s.d.	1.0	0.7	1.6	0
	n	204	61	12	1
April	mean	13.4	15.0	11.9	13.4
	s.d.	1.5	0	1.3	1.2
	n	33	1	8	17
May	mean	12.3	11.0	13.8	
	s.d.	1.3	0	1.5	
	n	639	1	4	0
June	mean	12.2	10.8	12.0	
	s.d.	1.5	0.8	0.7	
	n	170	8	5	0
	*	1	1		

Table 8 Monthly mean carapace length (mm), standard deviation and number in the sample for *M. stebbingi* females in subareas A to D. Asterisks indicate where there are significant differences at the 5% level between two subareas; members of these pairs of subareas are indicated by a common number.

		AREAS			
MONTHS		A	B	C	D
July 80	mean	15.0	16.0		15.6
	s.d.	0	1.4		2.8
	n	1	2	0	13
August	mean				
	s.d.				
	n	0	0	0	0
September	mean				
	s.d.				
	n	0	0	0	0
October	mean		14.0		
	s.d.				
	n	0	1	0	0
November	mean		12.4		
	s.d.		1.0		
	n	0	0	36	0
December	mean				
	s.d.				
	n	0	0	0	0
January 81	mean	20.5			
	s.d.	2.5			
	n	17	0	0	0
February	mean	22.0	20.8	20.6	
	s.d.	3.6	1.4	2.4	
	n	34	25	36	0
March	mean	19.5	19.9	20.2	20.0
	s.d.	1.6	1.5	1.5	1.9
	n	581	1045	314	89
	*	1,2	1	2	
April	mean	17.9		17.2	19.0
	s.d.	2.1		2.7	2.0
	n	67	0	10	138
May	mean	16.0	17.2	17.6	
	s.d.	2.1	2.3	2.4	
	n	1490	49	30	0
	*	1,2	1	2	
June	mean	15.6	14.3	16.3	
	s.d.	1.6	1.6	2.7	
	n	850	70	34	0
	*	1	1,2	2	

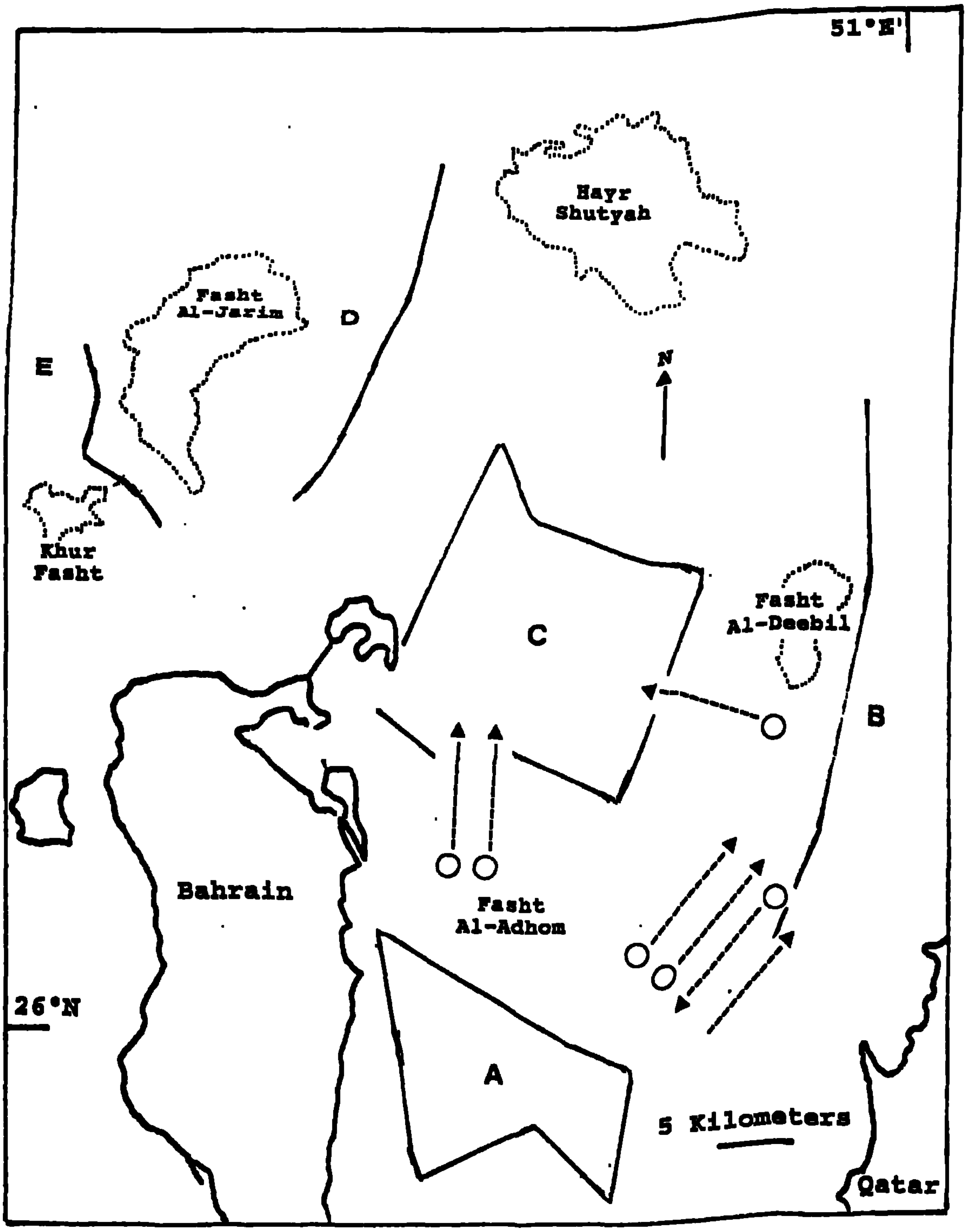

Figure 10. Shows the movement pattern for *M. stebbingi* within the sampling areas for males (--->) and females (O--->) during the period July to June. Based on tables 7 and 8. See Figure 3a for additional explanation.

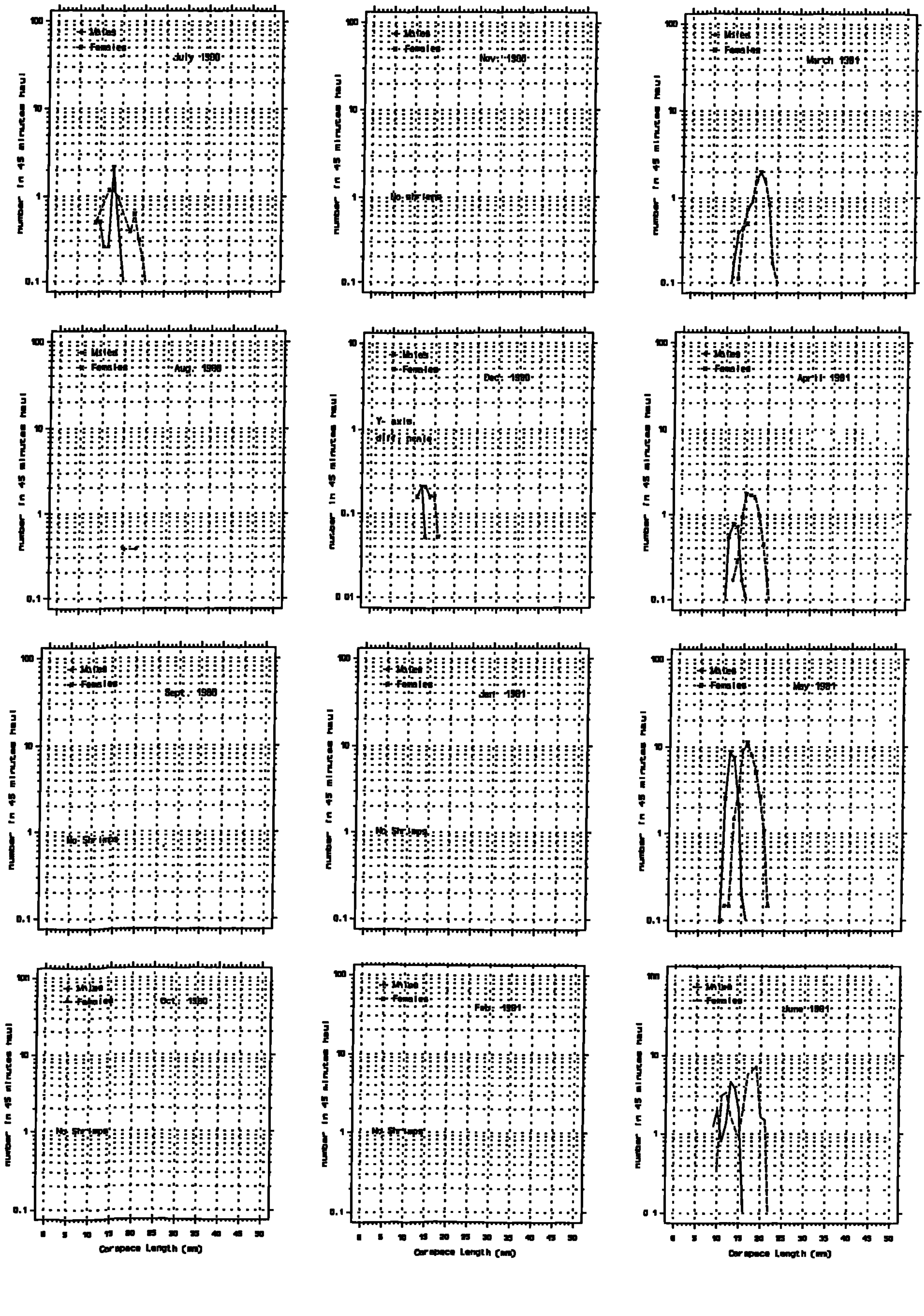

Figure 11. *T. curvirostrus* length frquency curves for males (solid line) and females (dotted line) averaged for open sea area.

Table 9. Monthly mean carapace length (mm), standard deviation and number in the sample for *T. curvirostris* males in subareas A to D. Asterisks indicate where there are significant differences at the 5% level between two subareas; members of these pairs of subareas are indicated by a common number.

MONTHS		A	B	C	D
July 80	mean	16.0		12.1	
	st. dev.	0		1.8	
	n	1	0	67	0
August	mean				
	st. dev.				
	n	0	0	0	0
September	mean				
	st. dev.				
	n	0	0	0	0
October	mean				
	st. dev.				
	n	0	0	0	0
November	mean				
	st. dev.				
	n	0	0	0	0
December	mean	11.8	12.0	11.5	
	st. dev.	1.0	0	0.7	
	n	4	2	2	0
January 81	mean				
	st. dev.				
	n	0	0	0	0
February	mean				
	st. dev.				
	n	0	0	0	0
March	mean	12.0	10.5	12.1	11.0
	st. dev.	1.4	1.3	0.8	1.0
	n	6	4	15	3
April	mean	13.0		12.4	14.8
	st. dev.	1.5		1.0	2.2
	n	21	0	20	4
	*			1	1
May	mean	12.3	12.0	12.7	14.0
	st. dev.	0.9	0	2.1	0
	n	248	1	174	1
June	mean	12.8	12.4	12.6	
	st. dev.	1.7	1.4	1.9	
	n	22	20	257	0

Table 10. Monthly mean carapace length (mm), standard deviation and number in the sample for *T. curvirostris* females in subareas A to D. Asterisks indicate where there are significant differences at the 5% level between two subareas; members of these pairs of subareas are indicated by a common number.

MONTHS		AREAS A	B	C	D
July 80	mean	18.4		13.5	19.5
	st. dev.	1.3		2.8	0.7
	n	9	0	76	2
	*	1		1,2	2
August	mean			16.5	
	st. dev.			1.6	
	n	0	0	12	0
September	mean				
	st. dev.				
	n	0	0	0	0
October	mean				
	st. dev.				
	n	0	0	0	0
November	mean				
	st. dev.				
	n	0	0	0	0
December	mean	13.8	14.3	14.3	
	st. dev.	1.0	0.6	1.5	
	n	4	3	4	0
January 81	mean				
	st. dev.				
	n	0	0	0	0
February	mean				
	st. dev.				
	n	0	0	0	0
March	mean	14.6	13.9	16.1	13.8
	st. dev.	2.0	2.3	2.1	1.9
	n	21	10	108	12
	*	3	2	1,2,3	1
April	mean	16.1		15.3	17.1
	st. dev.	1.6		1.5	1.9
	n	69	0	42	34
	*			1	1
May	mean	15.7	16.4	16.8	18.5
	st. dev.	1.5	1.7	1.8	0.7
	n	423	9	410	2
	*	1		1	
June	mean	15.0	18.5	16.4	
	st. dev.	2.7	1.3	3.1	
	n	48	52	574	0
	*	1,2	2,3	1,3	

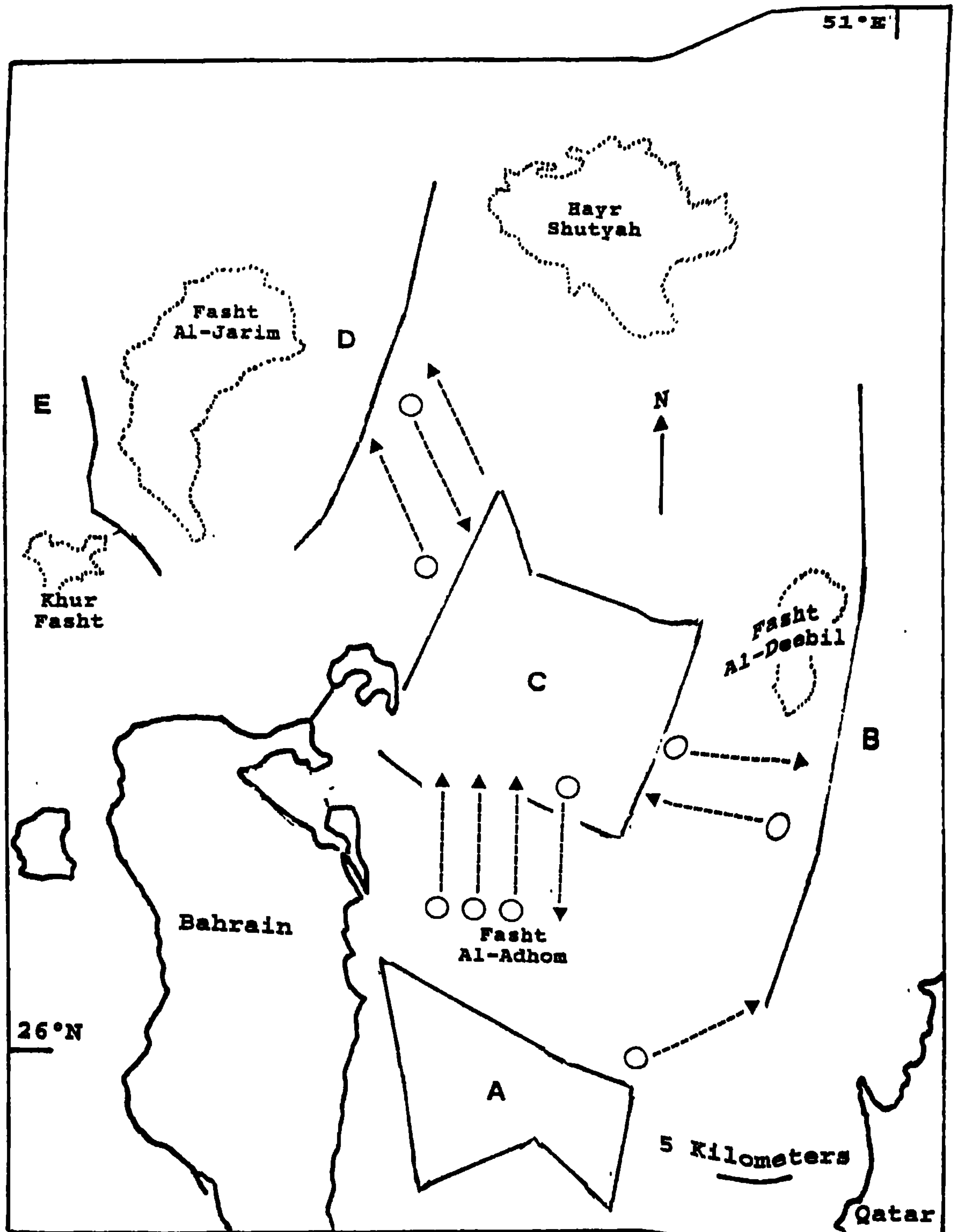

Figure 12. Shows the movement pattern for *T. curvirostrus* within the sampling areas for males (--->) and females (O--->) during the period July to June. Based on tables 9 and 10. See Figure 3a for additional explanation.

Table 11. Monthly mean carapace length (mm), standard deviation and number in the sample for *M. stridulans* males in subareas A to C. Asterisks indicate where there are significant differences at the 5% level between two subareas; members of these pairs of subareas are indicated by a common number.

MONTHS		A	B	C
		AREAS		
July 80	mean			13.0
	st. dev.			
	n	0	0	1
August	mean			
	st. dev.			
	n	0	0	0
September	mean			
	st. dev.			
	n	0	0	0
October	mean			
	st. dev.			
	n	0	0	0
November	mean			
	st. dev.			
	n	0	0	0
December	mean			
	st. dev.			
	n	0	0	0
January 81	mean			
	st. dev.			
	n	0	0	0
February	mean	12.0		13.0
	st. dev.	1.0		0
	n	5	0	1
March	mean	11.4	13.0	12.5
	st. dev.	0.8	0	0
	n	13	1	1
April	mean			
	st. dev.			
	n	0	0	0
May	mean	12.5	12.5	12.4
	st. dev.	0.8	0.7	0.7
	n	1148	2	115
June	mean	12.7	11.8	12.4
	st. dev.	1.3	2.0	1.4
	n	791	21	12
	*	1	1	

Table 12. Monthly mean carapace length (mm), standard deviation and number in the sample for *M. stridulans* females in subareas A to C. Asterisks indicate where there are significant differences at the 5% level between two subareas; members of these pairs of subareas are indicated by a common number.

MONTHS		A	B	C
July 80	mean			12.0
	st. dev.			
	n	0	0	2
August	mean			
	st. dev.			
	n	0	0	0
September	mean			
	st. dev.			
	n	0	0	0
October	mean			
	st. dev.			
	n	0	0	0
November	mean			
	st. dev.			
	n	0	0	0
December	mean			
	st. dev.			
	n	0	0	0
January 81	mean			
	st. dev.			
	n	0	0	0
February	mean	14.2		14.6
	st. dev.	2.1		1.2
	n	6	0	9
March	mean	13.2	13.5	16.6
	st. dev.	1.5	2.1	1.4
	n	40	2	9
	*	1	2	1,2
April	mean			
	st. dev.			
	n	0	0	0
May	mean	14.7	15.0	14.7
	st. dev.	1.1		1.0
	n	877	1	63
June	mean	14.5	14.1	13.8
	st. dev.	2.1	2.2	2.4
	n	701	10	10

Table 13. Monthly mean carapace length (mm), standard deviation and number in the sample for *M. mogiensis* males in subareas A to C. Asterisks indicate where there are significant differences at the 5% level between two subareas; members of these pairs of subareas are indicated by a common number.

MONTHS		A	C
July 80	mean		
	st. dev.		
	n	0	0
August	mean		
	st. dev.		
	n	0	0
September	mean		
	st. dev.		
	n	0	0
October	mean		
	st. dev.		
	n	0	0
November	mean		
	st. dev.		
	n	0	0
December	mean		
	st. dev.		
	n	0	0
January 81	mean		
	st. dev.		
	n	0	0
February	mean		
	st. dev.		
	n	0	0
March	mean		
	st. dev.		
	n	0	0
April	mean	11.7	11.0
	st. dev.	0.7	
	n	26	1
May	mean		16.1
	st. dev.		0.8
	n	0	13
June	mean	12.7	13.0
	st. dev.	1.3	1.1
	n	36	52

Table 14 Monthly mean carapace length (mm), standard deviation and number in the sample for *M. mogiensis* females in subareas A to C. Asterisks indicate where there are significant differences at the 5% level between two subareas; members of these pairs of subareas are indicated by a common number.

MONTHS		AREAS A	C
July 80	mean		
	st. dev.		
	n	0	0
August	mean		
	st. dev.		
	n	0	0
September	mean		
	st. dev.		
	n	0	0
October	mean		
	st. dev.		
	n	0	0
November	mean		
	st. dev.		
	n	0	0
December	mean		
	st. dev.		
	n	0	0
January 81	mean		
	st. dev.		
	n	0	0
February	mean		
	st. dev.		
	n	0	0
March	mean		
	st. dev.		
	n	0	0
April	mean	14.3	14.4
	st. dev.	1.6	1.7
	n	30	7
May	mean		18.6
	st. dev.		1.8
	n	0	11
June	mean	14.4	14.2
	st. dev.	2.5	2.5
	n	31	34

IV. DISCUSSION

IV. *P. semisulcatus*

Offshore migration by maturing males and females is characteristic of many penaeid species (Allen 1966, Penn 1975, Mohammed et al. 1981, Somers and Krikwood 1984, Dredge 1985, Knudsen et al. 1985, Staples et al. 1985, Coles et al. 1987, Crocos 1987ab, Su and Liao 1987, Wassenberg and Hill 1987). Tagging studies on *P. semisulcatus* in the northern Arabian Gulf indicated that the adults migrated offshore to deeper waters as they mature (Farmer and Al-Attar 1981, FAO 1980, Mohammed et al. 1981, Somer and Krikwood 1984). In the north-western Gulf of Carpentaria (Australia) *P. semisulcatus* was found to migrate to depths between 50 and 60 m, and greatest quantities of sub-adults (21-34 mm carapace length) and adults (>=35 mm carapace length) were caught at depths of 20 to 40 m and 20 to 50 m respectively (Somers et al. 1987). The present study was restricted to the existing limits of Bahrain fishing grounds, where the depth does not exceed 20 m, but it appears that the migration pattern deduced from significant size differences between contemporary samples from different areas is also consistent with the above view.

Pending tagging expriments and more sampling the migration pattern observed also provides a reasonable explanation for describing the changes that occur in the fishery throughout the season. Landing records demonstrate that greatest catches of *P. semisulcatus* are taken every year in area A during May to June, whereas by July most of the fishing fleet operate to the north in areas C and E. Also the shrimp barrier traps located on Fasht Al-Adhom between areas A and C (Figure 3) are always erected with their opening facing south. Shrimps moving with the current from area A to area C are trapped in this manner. The substantial shrimp quantities caught in these traps especially during May to June period confirms the movement of *P. semisulcatus* from area A to area C.

Somers et al. (1987) found that in Australian waters the greatest quantities of sub-adults of *P. semisulcatus* were caught at depths of 20 to 40 m. It is possible therefore that *P. semisulcatus* off Bahrain migrate to deeper waters beyond the present fishing area which at present is within 20m depth. The Tubli Bay trawl sampling certainly indicated the presence of large sizes of *P. semisulcatus* from November to December 1991 (see chapter 4). Due to the sudden appearance of these shrimp and the spent condition of the ovaries of all the females, this suggests post-spawning movement to shallow water (see chapter 4). However, such movements were not detected by size difference studies in the present work due to the lack of samples from Tubli Bay during the same period.

Area A is probably the most important source for *P. semisulcatus* new recruits to the Bahrain shrimping ground. From May to June large aggregates of small to medium sizes of *P. semisulcatus* usually appear in this area (personal observ.). It contains vast sea-grass beds dominated by *Halodule uninervis* (Atkins and partners 1985), and is therefore similar to other habitats identified as *P. semisulcatus* nursery ground (Price 1976, Staples et al. 1985, Coles et al. 1987).

P. semisulcatus that occur in area E most probably migrated from the adjacent Tarut Bay (Saudi Arabia), which has been identified as an important nursery ground for *P. semisulcatus* (Water Resources and Environment Division 1990). The general anticlockwise circulation of the Arabian Gulf water masses would assist this proposed migration. However, even if there is more than one nursery area, on the evidence of length frequency data (Figure 1) the fished population appears to behave as one stock.

In penaeids, spawning activity is often associated with marked changes in sex ratio from 1:1 (Kunjo 1970, Garcia and Le Reste 1981, Penn 1980, Garcia 1985, Bouhlel and Hail 1985). Except for the subgenus *Litopenaeus* (Farfante 1975) all *Penaeus* species possess a closed thelycum. Thus, females of *P. semisulcatus* can maintain the male's sperm for long period from mating to spawning. During this period males are not required by females and it is possible that females which are larger migrate, irrespective of the males, to deeper waters. Such a disappearance of females would account for the dominance of males in present samples throughout the period from September to March.

IV.2 Other species

For most other penaeid species, it was difficult to detect migration patterns based on their sizes difference. This is explained by low numbers in the samples, as in case of *P. latisulcatus*, or seasonality of occurrence, as in the remaining species. However, the possibility that *P. latisulcatus* follows a similar migration pattern to *P. semisulcatus* is consistent with the findings of Rothlisberg et al. (1987) who found these two species to have similar spawning seasons and spawning areas

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CHAPTER FIVE
MIGRATION OF PENAEID SHRIMPS

SUMMARY

Understanding of migration patterns is of a vital importance for the management of commercial shrimp stocks. Data used for migration studies are derived from shrimp survey conducted along Bahrain shrimping grounds from June 1980 to June 1981 using an industrial trawler. Unimodality of the pooled length frequencies indicated uniformity of growth for the whole stock. Similar mesh-sizes are used in both artisanal and industrial sector throughout the area indicating similar fishing mortality for the whole stock. Therefore, a reasonable hypothesis to explain areal differences in mean size is that shrimp migrated from one area to another. The direction of these movements is assumed to be towards areas that contain bigger average sized shrimp. From length frequency data, the monthly mean carapace and their standard deviation were calculated for each sex and area. For each month, the differences in the mean carapace values between adjacent pairs of areas were tested by one way analysis of variance. Significant differences were determined by the Scheffe test at 5% level. Two movement patterns were determined for *P.semisulcatus*. From May to September, shrimp moved from areas A and B, D and E to area C. While from October through April, shrimp migrated from area C to parts of area D to the north. The *P. semisulcatus* population in the main fishing ground (area C) appears to recruit from two main grounds, areas A and E. Area A appears to be the more important nursery ground. Analysis was extended to all penaeid shrimp species found in Bahrain waters. However, because of either low numbers or seasonal appearance of these species, few consistent size differences were determined.

CHAPTER SIX

GENERAL DISCUSSION AND MANAGEMENT CONCERNS

I. GENERAL DISCUSSION

I.1. Shrimping grounds

The present sediment survey of the Bahrain fishing grounds revealed that most of the present shrimping grounds are found within the areas of average grain size of 400 μ or below, which includes mainly muddy and muddy-sand areas. This conclusion is confirmed by Somers (1987 and 1994) who determined experimentally that *P. semisulcatus* exhibits preferences for mud or muddy-sand areas. From evidence presented in present work (page 136) it seems likely that further movement of *P. semisulcatus* occurs beyond the present known limits of the shrimping ground in January, but the extent of this movement is not yet determined.

I.2. Physical characteristics of sea water

Based on present work and that of Nayar and Al-Rumaidh (1993), a seasonal pattern of temperature change occurred in offshore and inshore waters throughout the sampling period. In winter, warmer water was found offshore and temperatures decreased toward the inshore waters. In the summer only slight differences in temperature occurred, with warmer water found inshore. Raynold (1993) determined similar winter and summer patterns in temperature along the Qatari-Iranian transect. Coincident with these seasonal changes in temperature, *P. semisulcatus* showed different migration patterns during the year. From October to April this species migrated from all coastal areas to deeper warmer waters offshore. Penn (1976) noted on the increase of *P. latisulcatus* catchability with the temperature, suggesting a preference of this species for warmer waters. In Tubli Bay, a temperature rise in February coincided with the commencement of the movement into that locality of *P. semisulcatus* juveniles and *M. stebbingi* and *M. kutchensis* spawners.

Present observations and those of Nayar and Al-Rumaidh (1993) indicate the occurrence of slightly lower salinities offshore to the north of Bahrain, than nearshore. This trend is probably determined by land run off from the Iranian coast (FAO 1981, Raynold 1993), but the difference is small and it probably has no significant impact on the shrimp life cycle.

I.3. Penaeid species

In the current work, seven penaeid species were identified. *P. semisulcatus* was determined as the main species in all shrimp samples collected throughout the sampling period. *P. latisulcatus* was found in low numbers throughout the sampling period but particularly in areas B,C and D, and it showed similar spawning and recruitment behaviour to *P. semisulcatus*. The remaining species mainly appeared in the shrimping ground during spring and early summer. Out of these species, *M. stebbingi* and *M. kutchensis* spawned during this period. *Penaeus* and *Metapenaeus* species were found from shallow inshore to offshore deeper waters, while *Trachypenaeus curvirostrus* and both *Metapenaeopsis* species were found mainly in offshore waters.

I.4 Penaeid shrimps spawning areas and seasons

I.4.1 *P. semisulcatus*

Based on the presence of mature females in the samples, spawning activity of *P. semisulcatus* seems to have occurred throughout most of the year, but most significantly from August to March with peaks in September and December. This was confirmed from plankton collections in Bahrain shrimping grounds in the present study and by Muthu M. S.

(personal communication, 1993) from which the *P. semisulcatus* spawning period was determined from August to March. All the evidence suggests that *P. semisulcatus* exhibits prolonged spawning activity, which is also reported by a number of authors (Thomas 1974, Price 1979, Van Zalinge 1980, Manisseri 1986). In the present study autumn spawning appeared to be more important than spring spawning. Inhibition of spawning at reduced temperatures has been shown in penaeid shrimp by Al-Attar and Ikenoue (1974), Laubier and Laubier (1979), Caubere et al. (1979), Aquacop (1979), Penn (1980) and Price (1979).

Adult shrimp and plankton sampling in Tubli Bay confirmed that *P. semisulcatus* did not spawn in these shallow inshore waters, but that spawning took place offshore as reported by a number of other authors (Price 1979, Rothlisberg et al. 1987, Crocos 1987, Grabe and Lees 1992). *P. semisulcatus* mature females were found to spawn in all open sea areas, but more frequently in area C. Mature females were found to migrate further offshore beyond the present limits of the shrimping grounds in January.

Post-spawning migration of *P. semisulcatus* back to the shallow waters was determined in Tubli Bay during October to December 1991. In the migration patterns determined for *P. semisulcatus* (see chapter V) in Bahrain water, this back migration was not detected, probably because its occurrence is minor in relation to the main offshore movements carried by the population. This is the first report of *P. semisulcatus* post-spawning migration back to the shallow waters.

I.4.2 *M. stebbingi*

Spawning of *M. stebbingi* in Tubli Bay and in the open sea was confirmed, with both spawnings found to occur during spring and early summer. Habib Al-Hassan (1992) determined the spawning period for *M. stebbingi* from spring to early summer in Pakistani waters, while Gab Alla et al. (1990) determined it from April to October in the Suez Canal (Egypt) waters. In addition to Tubli Bay, open sea areas A and B were determined as the main spawning grounds for this species, all indicating shallow water spawning behaviour for this species.

I.4.3 *M. kutchensis*

Shallow-water spawning of *M. kutchensis* in Tubli Bay and the adjacent open sea was confirmed through the presence of mature adults and plankton sampling from spring to early summer. In Kuwaiti waters, the spawning period for this species was determined to be from May to June (Al-Shoushani 1985), and from March to August (Mathews 1989). *M. kutchensis* in the open sea was restricted to the areas A and C; it was found most abundantly in area A which is probably its main spawning area.

I.5 Nursery areas and recruitment

Tubli Bay was identified as a minor nursery ground for *P. semisulcatus*, with area A (south to Fasht A-Adhom) as the main nursery grounds for this species. The importance of area A as a nursery ground was also reported by IUCN (n.d.). Open sea plankton collections contained *P. semisulcatus* post-larvae of 2.0 mm carapace length, while in Tubli Bay beam trawl collections, the minimum size of juveniles collected was 2.14 mm carapace length.

The *P. semisulcatus* recruits into the area E and then area C are considered to originate from additional nursery grounds off the Saudi Arabia coast, where Tarut Bay has been identified as an important shrimp nursery (Water Resources and Environment Division 1990). Such movement from Saudi waters into Bahrain shrimping grounds emphasizes the need for transnational measures for management of this shrimp stock.

P. semisulcatus juveniles were found to enter Tubli Bay during most months of the year, but in highest abundance from February to May, coinciding with the seasonal temperature increase. The occurrence of juveniles throughout most of the year confirms the prolonged spawning activity previously described for this species (in section I.4.1 of this chapter).

In the present study the mean recruitment period for *P. semisulcatus* was from April to June in Tubli Bay and to July in open sea. FAO (1978) reported a minor additional recruitment in Bahrain waters (area A) during November, while off Kuwait recruitment was from May/June to September (Van Zalinge 1980). In Australian waters *P. semisulcatus* recruitment extended for 7 months, from October to April (Somers and Krikwood 1984).

I.6 Migration pattern

From May to September *P. semisulcatus* moved from all areas into area C, and from October to April from area C offshore to area D. These two patterns related to recruitment and to spawning respectively, have potential implications for management of the shrimp stock. Further, otter trawl sampling in Tubli Bay indicated post-spawning migration of *P. semisulcatus* back to this area, which also mentioned in section I.4.1 of this chapter.

II. MANAGEMENT CONCERNS

II.1 Maximum sustainable Yield (MSY) of Bahrain shrimp fishery

A maximum sustainable yield estimate of the Bahrain shrimp fishery can be calculated based on Schaeffer method (Schaeffer 1954) using the catch and effort data (number of fishing hours) for the period from 1979/80 to 1993/94. Complete statistics for both artisanal and industrial sectors are available for this period, collection of which began after a collapse of the fishery in 1978/79. Fishing powers of the artisanal fleets changed considerably during the period since 1979 and the effort data of both fleets have been standardized before pooling to represent the total effort. The artisanal sector is the dominant fishery, so following Gulland (1985), the effort data of the industrial fleet have been standarized with artisanal data as follows:

$$F_{STANDARD} = (F_{INDUSTRIAL} \times (U_I / U_A)) + F_{ARTISANAL}$$

where, $F_{INDUSTRIAL}$ is the effort of the industrial sector.

$F_{ARTISANAL}$ is the effort of the artisanal sector.

U_I is the catch rate of an industrial boat.

U_A is the catch rate of an artisanal boat.

For each fishing season, different values of average catch rates were used, to compensate for the continuously changing fishing behaviour of the artisanal sector. Catch, artisanal effort, industrial effort and total standarized effort are shown in the following table for the 1979/80 to 1993/94 shrimping season.

SHRIMPING SEASON	CATCH (TONNES)	EFFORT IN FISHING HOURS $F_{ARTISANAL}$	$F_{INDUSTRIAL}$	$F_{STANDARD}$
80/81	625.5	26,990	5,066	34,391
81/82	543.5	24,114	5,982	46,891
82/83	685.4	37,451	8,562	75,520
83/84	727.5	41,974	10,205	80,721
84/85	778.1	54,101	10,418	93,601
85/86	1444.2	54,638	7,223	87,268
86/87	1313.2	66,727	5,343	97,627
87/88	1695.1	86,710	11,859	145,641
88/89	1072.6	145,594	12,532	184,671
89/90	1258.2	158,039	15,263	175,842
90/91	1150.8	154,432	7,290	186,453
91/92	620.4	153,807	4,022	163,361
92/93	806.7	159,193	3,479	169,040
93/94	2079.3	229,465	1,825	234,658

Based on the above mentioned catch and effort data, a surplus production model for Bahrain shrimp fishery is presented in Figure 1.

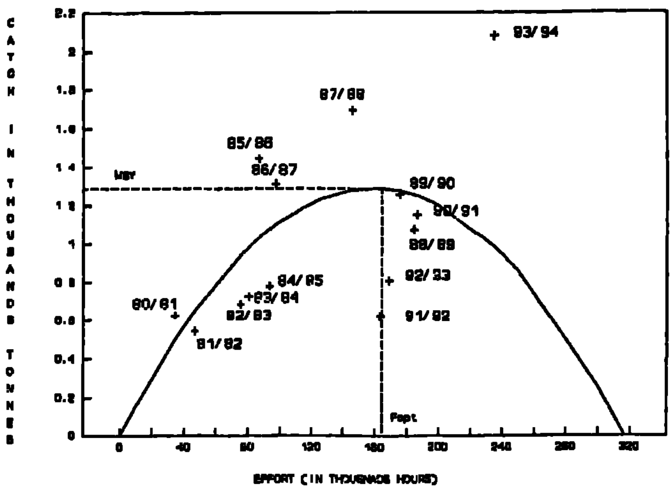

Figure 1. Surplus production model (Schaeffer method) for Bahrain shrimp fishery, 1980/81 to 1993/94 catch and effort data are plotted.

The maximum sustainable yield (Y_{max}) calculated is 1,282 tonnes at the optimum effort level (f_{opt}) 164,459 artisanal fishing hours to produce an optimum catch per unit effort value (u_{opt}) of 7.8 kilo per hour at the level of maximum sustainable yield (Figure 1). Using the same data these estimates for Y_{max} and f_{opt} for the Bahrain shrimp fishery have been worked by Mathews et al.(1993). Shrimp biomass at the carrying capacity of the environment (B_{∞}) was determined as 2,106 tonnes. Notably, the maximum sustainable yield determined in this way for the fishery is lower than the reported total catch during several seasons, namely 1985/86 to 1987/88, and 1993/94 (Figure 1), while the optimum effort was also found to be lower than or near to the reported effort for the seasons from 1988/89 to 1993/94. The determined f_{opt} for this fishery is equivalent to the effort of 73 full time artisanal boats, assuming that a vessel operates 2,250 fishing hours in a season. Against this the number of boats licensed for shrimp fishing includes 214 artisanal and 4 industrial vessels. Thus the potential effort is about three times that required to deliver the optimal yield for the Bahrain shrimp fishery.

Although the significance of adopting MSY as a fishery management aim has been criticized by a number of authors (see Pitcher and Hart 1982), the present exercise was able to demonstrate the problem of over-capitalization in shrimp fishery. Hence, because of this over-capitalization, effort reduction and minimizing the fishing pressure should be the main aims for managing Bahrain shrimp fishery at least for the present period. Minimizing fishing pressure can be achieved by gear modification or by introduction of new regulations, such as ban areas. Fishing effort reduction can also be achieved either by decreasing number of licensed boats or shortening the shrimping season. Some of these measures are already in place, as indicated below.

II.2 The present regulations applied in shrimp management

The present adopted regulations can be categorized into three main areas outlined below:

* Control of the fleet size through registration and licensing schemes.

At present, this tool is not effective in managing the shrimp fishery, as the present number of fishing vessels already exceeds by nearly three fold the optimum effort determined for this fishery. However, this regulation can prevent further expansion in the size of the shrimping fleet.

* Shrimp fishing ban period.

Provided that proper enforcement is applied, this regulation can be used effectively to manage the fishery. However, since the introduction of such a regulation in 1981, a considerable amount of illegal fishing has occurred. This illegal fishing continued and has increased during the study period, when recently up to 100 small boats were reported illegally fishing in one locality during the day time. Further measures to limit such illegal fishing are required.

* Cod-end minimum mesh size regulation.

In 1986, minimum mesh size allowed for the cod-end was prescribed to be 30 mm. In practical terms, this regulation was found to be ineffective most of the time, especially when algae, seagrasses or small fishes were found in large quantities and masked the cod-end very effectively. Main and Sangster (1982) showed that masking of the cod-end by fishes made mesh regulation ineffective for managing the fishery, so other measures have to be sought.

The following ministerial decrees were issued since the declaration of the fishing law in 1981;

* Decree No. 16 (1981) concerning the registration of all fishing boats at the Directorate of Fisheries.

* Decree No. 17 (1981) concerning fishing licensing.

* Decree No. 9 (1986) concerning the minimum allowed mesh sizes for number of fishing gears; which includes shrimp trawl which was set at 30 mm at the cod-end.

* Numbers of decrees have been issued to declare starting or ending of the shrimping season.

These decrees are forming the present fishery regulations adopted in Bahrain shrimp fishery management.

II.3 Updated information on the shrimp stock and implications for fishery management

1- *P. semisulcatus* is the dominant species.

Management of the shrimp fishery should be based on the single species *P. semisulcatus*.

2- The Bahrain shrimp fishery is mainly based on a single stock.

Unimodality of the *P. semisulcatus* population (page 100) found in Bahrain shrimping grounds suggested that most shrimps found in the fishery belong to a single stock. Movement from nurseries off the Saudi coast into area E suggested the input of a second stock into the Bahrain shrimp fishery. However there was a low correlation coefficient between shrimp numbers in areas E and C, suggesting that the interaction is small.

3- *P. semisulcatus* has a prolonged spawning season.

It is likely that the prolonged spawning of *Penaeus semisulcatus* is the main reason for the success of the penaeid fishery in Bahrain and Arabian Gulf waters. Accordingly the maximum benefit from ban period regulation can probably best be achieved by aiming for protection of recruits rather than spawners. Recruits certainly appear in the fishery at particular times and localities. On these grounds a fishing ban period should extend from April to the end of July.

4- *P. semisulcatus* spawn in offshore waters.

Mature females move into deeper water during the spawning period and for at least 3 weeks after hatching *P. semisulcatus* larvae are planktonic. Throughout the main spawning period from August to March, various larval and post-larval stages of the species are found in the area at the same time. It should therefore be borne in mind that the presence of the shrimp early stages in the plankton subject the stock to the risk of pollution in the water column, in particular from August to March or during the peaks of abundance in September and December. Coastal reclamation activities which are extensive in Bahrain will not have direct effects on the spawning activities of *P. semisulcatus*, but they may have effects on the nursery grounds of this species (see below).

5- Tubli Bay is nursery and spawning ground for penaeid species.

Due to its importance to the shrimp fishery, Tubli Bay should be closed as a fishing ground, except for small scale artisanal fishing using hook and line, small wire traps and cast nets. Also reclamation of the coastal areas of this Bay should be stopped or minimized, to avoid disturbance of the nursery and spawning grounds of the penaeid shrimps.

6- Open area A (south to Fasht Al-Adhom) contains most of the *P. semisulcatus* nursery grounds

The existence of the Fasht Al-Adhom perpendicular to the generated tidal current (Atkins and partners 1985), and its topography creates a unique environment to the south of the Fasht Al-Adhom coral reef. This environment is characterized by slow tidal currents and accordingly contained vast sea grass areas (Atkins and partners 1985). Due to the importance of the shallow waters within this area as shrimp nursery grounds, the areas within at least 1 km from the shore and around the coral reef should be protected against trawling. Also it is appropriate to declare Fasht Al-Adhom as a marine reserve where fishing, removal of sand, stones and corals, and pollution discharge should be banned. In fact similar procedures are probably necessary on other coral reefs found in Bahrain waters, so it is appropriate to issue a general decree to protect all coral reefs.

7- Open area A (south to Fasht Al-Adhom) is the spawning ground for *Metapenaeus* species.

In addition to Tubli Bay, spawning of both species is likely to take place during spring and early summer in open sea area A. Enforcement of a fishing ban period from April to July will effectively protect the spawning stocks of both *Metapenaeus stebbingi* and *M. kutchensis*.

8- *M. kutchensis* is a shallow water spawner.

M. kutchensis spawning in shallow water indicates that this species is likely to be affected by coastal reclamation activities. This species has a commercial value in the Kuwaiti waters (Mathews 1989), but not in Bahrain waters.

9- Movement of *P. semisulcatus* from area A to the main fishing ground (area C)

Movement of bigger shrimps from area A to the main ground (area C) suggests that it may be most appropriate to fish shrimp in area C rather than in area A. This could be done by concentrating fishing in area C and delay the fishing season in area A. This would require modification of the present ban period regulations, to discriminate between areas with regard to the length of the ban period to be introduced. Such regulation would allow exploitation only of bigger sized shrimps and protect area A from unnecessary damage. Increasing shrimp mean size would affect directly the total earning of the fishermen and effectively compensate for the low catch rates.

10- Saudi shrimp recruit into Bahrain shrimping grounds

The movement of shrimp recruits from Saudi nurseries into Bahrain fishing grounds indicates that interaction between these shrimp stocks should be monitored. It is therefore important to collect fisheries statistics from both localities and exchange such information to develop an integrated picture for fisheries management. Movement of shrimp from area E to area C demonstrating the movement of Saudi recruits into Bahrain shrimping main grounds, also suggests that within

Bahrain waters the fishing ban period should be extended to area E.

11- *P. semisulcatus* post-spawning stock move back to the shallow waters.

The return migration of post-spawning stock confirms that shrimp do not migrate far beyond the present shrimping grounds. This has important implications in managing this fishery, providing support for implementation of the fishing ban period for managing the shrimp fishery of Bahrain.

12- Bahrain shrimp stock is overexploited

Two measures were developed earlier to address the problem of overfishing of Bahrain stock. The first was to minimize fishing pressure through gear modification (e.g. mesh size) and by introducing new regulations (e.g. fishing ban and protected areas). Secondly attempts were made to reduce the fishing effort by taking certain number of boats out of the fishery, or by reducing the length of the shrimping season. Additionally, now it is important for proper management that all fishing vessels should adopt a similar fishing strategy to exploit bigger shrimps in the deeper waters. This strategy requires that every boat should be equipped with a winch for deeper water fishing.

13- Industrial and artisanal sectors fish the same shrimp stock.

Population structure determined here for *P. semisulcatus* confirms that both industrial and artisanal sectors fish the same stock (see chapter 1). The rapid growth of the artisanal fleet by the mid-1980s coincided with a reduction of the industrial fleet (see chapter 1). Also this rapid growth in fleet size increased the total effort and reduced the boat catch rate considerably, which directly reduced incomes in the whole industry. In order to protect the fishery, it is proper to ban the industrial fleet from shrimp fishing in Bahrain waters, and to set new regulations on the maximum boat sizes allowed in the shrimp fishery.

II.4 Proposed measures for further implementations

Enforcement of the regulations is of vital importance in the fishery management process. It is meaningless to implement further regulations in the absence of insufficient enforcement. However, based on the present findings, several areas are identified for further improvements.

1- Emphasize the role of fishermen in the management process.

Fisheries regulations are rational, and the expected consequences are usually appreciated by fishermen. Such advantages should encourage fishery management to set out a regular educational programme to convey appropriate messages to the fishermen. Consequently, fishermen should become aware that the success of fishery management will lead to increases in their earnings from this fishery. Fishermen from their continuous presence at sea, can provide useful information on fishing activities on a daily basis. Fishery management should create the proper channel for utmost utilization of these data.

2- Protection of areas vital to shrimp fishery.

Certain localities are vital to the shrimp stock, and require special attention to prevent damage by pollutants or directly by dredging or reclamation. These areas are as follows:

a) Main spawning ground (open sea area C).
b) Tubli Bay.
c) Fasht Al-Adhom reef and adjacent areas.

3- Develop a single fishing strategy for the shrimping fleet.

A unified fishing strategy would encourage fishermen to exploit shrimps at certain sizes and accordingly prevent harvesting the stock prematurely. Fishery management should set out the upper and lower specifications for the fishing boats and their gear.

4- Fishing ban period

The timing of the fishing ban period should aim for protection of recruits rather than spawners. The main recruitment period for *P. semisulcatus* extends usually from April to July.

It is confirmed that *P. semisulcatus* moves from areas A and E to area C, particularly during the recruitment period. Therefore, it is appropriate to discriminate between these areas in the timing and length of the fishing ban period. Fishing in areas A and E should be delayed to allow migration of the bigger shrimp to area C.

The post-spawning migration of *P. semisulcatus* back to shallow waters of Tubli Bay suggests that the stock remains in Bahrain waters for most the period. This indicates the validity of fishing ban period regulation in managing Bahrain shrimp fishery.

5- Fishing ban areas

Tubli Bay and shallow areas south of Fasht Al-Adhom are determined as nursery grounds for *P. semisulcatus*. Fishery management should declare these areas as closed areas, where shrimping is banned throughout the year.

6- Reduction of the fishing effort

Due to the present unbalanced condition between number of boats and capacity of the shrimp stock, management should discourage catch maximization, but on other hand should ensure modest revenue from the fishery. This can be achieved by allowing certain boat sizes (see above item No. 3) for shrimp fishing. Accordingly, bigger boat sizes should be withdrawn from the fishery and replaced by smaller boats.

In case it is not possible to reduce the trawler number, it is recommended to control the fishing effort through the length of the fishing season.

7- Promote alternatives for shrimp fishing.

It is most likely that if the shrimp fishery is properly managed, this will consequently promote fin-fish fisheries. This is because juveniles of several commercial fin-fish species are prematurely fished along with shrimp. Fishery management should motivate the appropriate schemes (e.g. loan schemes) to encourage shrimp trawlers to spend more time in fin-fish fishing.

III. Future investigations

For continuing management of the penaeid fisheries of Bahrain the following requirements are necessary;

* to conduct shrimp surveys similar to the 1980/81 survey, extended if possible to include Saudi and Qatari grounds.

* to survey more regularly shallow waters to determine more fully the location of nurseries.

* to conduct mark recapture studies on shrimp movement, particularly between areas A and C, and E and C, using tagging techniques.

* to conduct plankton studies regularly and more systematically in shrimping grounds to determine the precise areas and periods of spawning.

* To conduct studies on the economics of shrimp fishing in Bahrain.

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CHAPTER SIX
GENERAL DISCUSSION AND MANAGEMENT CONCERNS

SUMMARY

This chapter is comprised of two parts. In the first part the findings of the chapters 2, 3, 4 and 5 are discussed, in the second part the management aspects of the Bahrain shrimp fishery are discussed. The calculated MSY of the Bahrain shrimp fishery is 1,282 tonnes at the optimum effort level (f_{opt}) 164,459 artisanal fishing hours. This f_{opt} is equivalent to 73 full time artisanal boats. In 1993 the number of licensed vessels increased to 214 artisanal and 4 industrial boats. This indicates over-exploitation of the shrimp stock. Several areas were identified for further improvements: (1) emphasize the role of fishermen in the management process; (2) protection of areas vital to shrimp fishery; (3) develop a single fishing strategy for the shrimping fleet; (4) enforcement of fishing ban period; (5) enforcement of fishing ban areas; (6) reduction of the fishing effort; (7) promote alternatives for shrimp fishing. Emphasis was placed on the importance of the enforcement for the success of Bahrain shrimp management. Further, the future investigations for continuing management of shrimp fishery were highlighted.