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BIOLOGICAL CHARACTERISTICS OF COMMERCIALLY EXPLOITED PENAEIDAE SHRIMP (*PENAEUS SEMISULCATUS)* IN THE NORTH-WESTERN PART OF THE PERSIAN GULF

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ABSTRACT

In this study the results of 40 months of sampling on *Penaeus semisulcatus*, De Hann 1848, in the Bushehr area at the north-western part of the Persian Gulf, is discussed. The spatial and temporal distribution of shrimp is highly variable by month and year. Higher shrimp densities are often found in early summer between the latitudes of 28° and 29°N and extend north and south in August. In later months (September to December) one can find a relatively high-density zone in the northern most part of the distribution area and in the autumn smaller aggregations are found at lower latitudes.
The main recruitment, which the fishery is dependent upon, is from July to August and a second recruitment period occurs from December to February. The timing and strength of both recruitments vary inter-annually. The proportion of pre-recruits in the southern area is always higher and the modes more prolonged than in the northern area. The period of major recruitment starts earlier and lasts longer in the south than the north. A consistent pattern is not seen for the secondary recruitment, which usually occurs in from December to January. Maturity is highly seasonal and exhibits two peaks in the autumn and again the following spring, although the exact timings may vary between years. The spatial distribution of the mature female shrimps in the spawning months (October to June) indicates that the northern part of the study area is an aggregation ground. The size at mass maturity L50% was found to be variable by year in the range of 13.3 to 15.9 cm. The length-frequency distribution of shrimps by sex reveals one to three modes depending on the month and year. In the southern part a more complicated and less consistent pattern of recruitment and growth between years was observed. There is multiple or/and continuous recruitment especially during the summer months. The von Bertalanffy growth parameters were estimated. It was found that both male and female shrimps could attain higher lengths in the southern area with inter-annual consistency throughout the study period. There are two generations of fast and slow growing shrimps, which contribute to summer and autumn recruitment respectively. On the basis of growth parameters there is a possibility of interlocking, by means of contribution of the spring generation to the autumn spawning season, but the autumn generations are too small to take part in the spring spawning season. In this study, the timing and geographical location of recruitment and spawning of *P. semisulcatus* in Iranian waters of the Persian Gulf were identified. The findings will be used to fine-tune the ongoing sampling programme and design new sampling schemes to cover the whole life cycle of this species enabling one to explain the variations in their response to the environment and fishery. The results of this study assist us in building appropriate assessment and management models.

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1 INTRODUCTION

The world catch of shrimp in 2000 was recorded at over three million tonnes. From 1970 to 2000 Penaeidae on average comprised 42.2% of the world catch of shrimps (FAO 2000). Other commercially important families of shrimp are Sergestidae with 14.8% of the total catch and Pandalidae with 12.5% (**Error! Reference source not found.**). Some of the largest shrimp fisheries of the world are in Indonesia, Thailand, India and the Gulf of Mexico. The great value of shrimp is closely linked to shrimp management, especially since substantial increases in global shrimp production are not expected. Shrimp management has to consider the unique life history, population dynamics and character of shrimp fisheries.

Penaeid shrimps are fast growing and short lived, commonly with a life cycle of about one year. Natural mortality rates are therefore high and determination of the optimum sizes at capture is sensitive to estimates of growth and mortality (Gulland 1984).

It is difficult to determine maximum biological and/or economical sustainable yield and the effort required in attaining it. In some fisheries it becomes an important issue, how to allocate the fishing effort between artisanal (inshore) and industrial (offshore) sectors.

Shrimp trawls have limited selectivity and often harvest large quantities of finfishes as by-catch (up to 95%). Due to the price difference between shrimp and finfishes, a substantial quantity of the by-catch is discarded. Total discards of fish in the shrimp fishery in the 1970s were estimated at almost twice the shrimp catch (Gulland 1984) with the greatest quantities occurring in North America and the north-western part of South America.

In this study, *Penaeus semisulcatus* De Haan, 1844, commonly known as grooved tiger prawn or green tiger prawn is studied. It is distributed throughout the Indo West Pacific and is fished commercially in many countries in the region. It has recently colonised the east Mediterranean through the Suez Canal and now forms the basis of an important fishery in that region (Somers 1991).

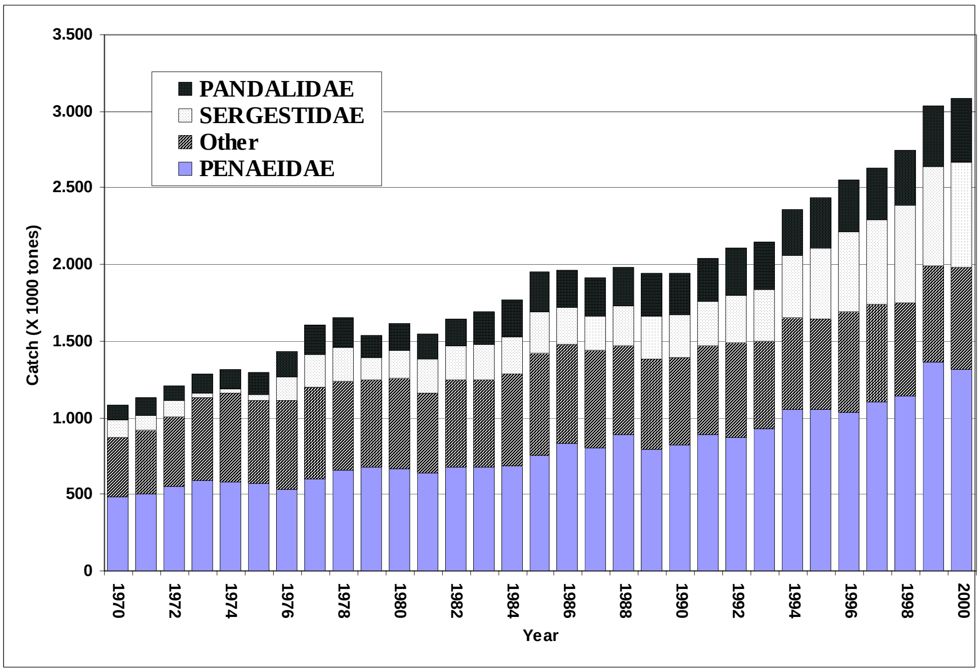

Figure 1: World shrimp catch (FAO 2000).

1.1 The shrimp fishery in the Persian Gulf

Catches of shrimp in the Persian Gulf are dominated by a single species *P. semisulcatus*. Fisheries by large-scale industrial fleets expanded rapidly in the 1960s and later artisanal fisheries got established after the modern method of trawling had been adopted for artisanal application (van Zalinge 1984).

The richest shrimp resources were found on the Iranian side of the Gulf and it was there that industrial shrimp fishing started around 1959. In 1961 a Kuwaiti company began exploitation of Iranian and Kuwaiti stocks. Shrimp fishing in Saudi Arabia started in 1963, Bahrain in 1966 followed by Qatar in 1969. In Iran landings reached 9600 tonnes in 1964-65 and in Kuwait 3335 tonnes in 1966-67, while industrial landings from Saudi Arabia and Bahrain peaked at 7400 tonnes in 1973-74. The period from 1959-69 was a boom phase in the Industrial shrimp fisheries, characterised by high catch-rates, increasing landings and the appearance of new companies.

Increased involvement of the artisanal sector in the shrimp fishery was motivated by local demand, high price and easy catch. It was also favoured by local regulations imposed on the industrial sector (closure of the Kuwait Bay to the industrial sector and limitations on foreign companies). After a short period of rapid growth the fishing effort by the small-scale shrimp fishery (over 1000 dhows in 1978) exceeded that of the industrial fleet at its maximum expansion in 1969. Substantial increases in fishing effort, especially in shallow fishing grounds, where the dhows could effectively fish for shrimp, resulted in the gradual disappearance of the industrial sector. This, in part, shows the growing importance of small-scale fisheries.

Growing fishing effort, decreasing catch rates and competition with passive types of fishing techniques gradually led to regulatory management measures such as decreases in fishing effort, temporal and spatial closures and in some cases total closure of the shrimp fisheries. (The last reported catch of shrimp in Qatar was in 1991 (FAO 2000)). Other important management measures in all the countries of the Gulf include a total ban on finfish trawl fisheries.

The target species of the Iranian shrimp fishery in the northern part of the Persian Gulf is *P. semisulcatus*, while in the southern part (Hormoz Strait), *P. merguensis* (Banana shrimp) is the dominant species (**Error! Reference source not found.**).

The present study is on the *P. semisulcatus* in the northern part of the Gulf in Bushehr province. The rapid increase of small out-board engine fibreglass boats in the shrimp fishery from almost none in the early 1990s to over 1000 in 2000 and using advanced technologies by dhows, has resulted in a large increase in fishing effort which is discussed below.

1.2 The shrimp fishery in Bushehr Province

The shrimp fishery is important in the Iranian part of the Persian Gulf. The prospect of acquiring a relatively high income in a short period of time makes fishermen yearn for the opening of the season.

At present, the shrimp fishery in Bushehr has limited-entry, input and output control one with closed seasons and closed areas. The length of fishing season is flexible. The opening time is based on pre-season surveys estimating abundance, the size of the shrimp and the time of closure is based on CPUE trends (kg/boat-day) during the fishing season and/or a final catch rate.

There are three main implications for the management of the shrimp fishery:

- Biological: High mortality and a short life span call for a suitable framework of harvesting the shrimp for maximising yield. High inter-annual fluctuations in the stock and being an easy prey in the food chain affect the higher trophic levels.
- Economical: Management based on stock assessment reduces the uncertainties in investment due to undefined and non-predictable stock fluctuations. High domestic demand, good export markets, a high price, value adding possibilities and employment make this fishery important to the fishing, processing, marketing and management sectors.
- Social: The shrimp season lasts about six weeks in the summer when there is little activity in the finfish fishery due to migration of fishes to colder waters. By involving themselves in the shrimp fishing the fishery sector can stay active during this period. Harvesting a high and delicate yield requires an immediate semi-skilled labour force. Shrimp is also an important source of protein and of high nutritious value. It is delicious and easy to prepare, causing high demand.

A better understanding of the shrimp stock provides a better prediction of the optimum opening date and stock size.

1.2.1 Effort and catch

The Bushehr shrimp fishery extends for about 300 miles along the northern coast of the Persian Gulf and can be divided into two sectors, industrial and artisanal. About 46 steel trawlers 20 to 25 m in length with an engine power of 257 to 588 kW (350 to 800 hp) operate in the industrial sector. The industrial shrimp trawlers tow two trawls simultaneously with outriggers, flat trawls, semi-balloon or balloon trawls. The industrial sector, fishing more effectively in the later half of the season, accounts for almost 20% of the total production of shrimp. After the closure of the shrimp fishery in Bushehr, the industrial fleet continues its activity in the banana shrimp fishery in the Hormozgan waters of the strait of Hormoz and in the Oman Sea. The artisanal sector of the shrimp fishery consists of two fleets. The dhow fleet is comprised of approximately 450 wooden traditional vessels, around 16 m in length and 73 to 160 kW (100 to 220 hp) inboard engines and the other 1000 to 1500 (based on stock size) small fiberglass outboard engine trawlers of about 7 m in length and 25 to 45 hp engines. The traditional wooden boats, "dhows" and outboard engine boats tow a single shrimp net. The latter also uses a relatively smaller net. The cod-ends are made of two layers of netting of 30-40 mm mesh-size and a protective chafer. However, smaller mesh-size is frequently used in coastal waters.

The fishing season lasts approximately one and half months. It is opened around the 7th of August and closed when the CPUE index indicates that 20% (or less) of the shrimp stock remains which on average corresponds to about 40 kg/day. The shrimp catch has been highly variable ranging from 250 to 4000 tonnes. The average annual yield for the past 10 years is 1650 tonnes. The artisanal sector, fishing in coastal waters, now accounts for almost 70% of the total production of shrimp (Khorshidian 1995). License control measures have been undertaken to avoid an increase in fishing effort, but there has been a substantial increase in effort due to the use of modern fishing and navigational devices as well as an increase in engine power.

In 1990, 435 dhows and 54 steel boats were active in the shrimp fishery. Since then, the number of trawlers has fluctuated somewhat but there is no temporal trend. Rather, the fishery itself affects the number of active vessels. Due to increased engine power, the use of advanced fishing technologies and navigational aids such as GPS, RADAR, wireless communication etc., the total effort has increased. No estimation of this so-called "creeping effort" is available, but some of its effects can be observed indirectly.

The catch per unit of effort (kg/hp-day) for the whole fishery (gillnet, trap, shrimp, etc.) was 6.5 kg/hp-day in 1991 decreasing to 2.2 kg/hp-day in 1999. Meanwhile the effort rose from nine million hp-days to 12 million hp-days.

Due to the implementation of a CPUE based management measure on the closure of the shrimp fishery from 1991 onwards; all creeping effort will be compensated for by a shortened shrimp season. The utilised horsepower has remained almost constant around 2.34 million hp-days$\pm$ 14% in the shrimp season (The fishing effort exerted by boats has not been accounted for). The recent increase in (creeping) fishing effort has resulted in the shortening of the fishing season from three months in 1990 to an average of 45 days at present (Khorshidian 2000).

Due to the importance of shrimp for the export market a complete census is run on landings. The wholesale price of shrimp is approximately US$ 8/kg and the catch is mainly exported to Japan and the EU.

1.2.2 Fishing grounds

There are three major green tiger prawn fishing grounds in the northern part of the Iranian waters of the Persian Gulf, namely Bahrekan, Tangestan and Motaf (**Error! Reference source not found.**). These fishing grounds are mostly muddy bottoms. The green tiger prawn does not recruit to these fishing grounds simultaneously. The general pattern is that the massive recruitment occurs in a limited area (Tangestan) in early August but later the fishing ground expands to a wider area. After a week or two, recruitment begins at Motaf and in late August shrimps are recruited to the northern fishing ground, e.g. Bahrekan. In some years, however, Bahrekan shrimps have been recruited earlier than Motaf shrimps. From recent research on population discrimination by serologic methods, it has been found that there are significant differences in the serology of green tiger prawns in at least these three areas (Matinfar 1999). These areas coincide with the observed recruitment patterns in these fishing grounds.

1.2.3 Target species and by-catch

The dominant target species in Bushehr is the green tiger prawn (>80%) and fishing mainly takes place during daylight hours. The Iranian shrimp fishery is typical of many tropical shrimp fisheries worldwide, being characterised by a wide variety of by-catch species and variable but often high by-catch to shrimp ratios. The Shilat (Iranian Fisheries Company) has grouped the by-catch in this fishery into three major categories: small adult fish, juveniles, and large adults. Large fish comprise approximately 8-10% of the total catch by weight and other by-catch species 60-65%. Shrimp comprises the remainder of the catch.

1.3 Objective of the study

The primary objective of this study is to gain a better understanding of an important part of the life cycle of *P. semisulcatus* after recruitment to the fishery. The available data consist of 40 months of trawl survey data for shrimp in known Iranian distribution areas of *P. semisulcatus* covering almost three cycles, which can form relatively good background information. The knowledge acquired will be used to improve the management of the fishery, define new studies and design a sampling scheme to cover the entire life cycle of the species.

2 LITERATURE REVIEW

Penaeid shrimps have for many centuries been considered a good source of food. Most species are found in shallow, inshore tropical and subtropical waters and many have been bred and cultured in ponds. Approximately 125 species are known from the broad west Indo-Pacific region (Dall *et al.* 1990).

P. semisulcatus is distributed over a large area in the west Indo-Pacific region. Relatively extensive literature on this species is available from Australian studies, which form the basic understanding of its biology. Comparing and contrasting the dynamics and life cycle of *P. semisulcatus* in the Persian Gulf and Australia in this report is believed to be a proper approach to understand the biology of this species in Persian Gulf and its variations. While reviewing the literature section in this report, it should be kept in mind that the references are mainly from Australia in the Southern Hemisphere and the Persian Gulf in the Northern. Hence the months of the year differently reflect the seasons and periods of warm and cold.

2.1 Biology

2.1.1 Life cycle

Penaeid prawns have four distinct types of life cycles, defined by the habitats of each life stage (Box 1).

Box 1: Classification of different life history patterns of Penaeid shrimp according to Dall (1990).

-Type 1: All stages of the life history are estuarine and the eggs may not be completely demersal. Some or all of these species may move into sheltered inshore waters to spawn.
-Type 2: The postlarvae migrate to estuarine nursery grounds. As the juveniles mature, they migrate from the estuaries; some species spawn relatively close inshore, while others move into deeper waters of the continental shelf for spawning. Some species may have pelagic eggs.
-Type 3: The postlarvae migrate to shallow inshore waters, often with seagrass and algal beds where the salinity is high; offshore migrations are similar to those of Type 2. Some species in the group have pelagic eggs.
-Type 4: The entire life cycle is in offshore waters. Species probably do not have a benthic phase (indicated by a separate cycle). Others are deep-water species with benthic juveniles and adults; eggs of these two sub-groups are probably pelagic.

P. semisulcatus has a Type 3 life cycle. It spawns offshore and the larvae develop there while the juveniles develop in sea grass or algal beds inshore and in the lower reaches of estuaries (Jackson *et al.* 2001).

Given the wide geographical distribution and the range of habitats occupied by different life-history stages, it is not surprising that penaeid prawns exhibit rather complex life-history patterns. Dall (1990) has proposed three life history patterns namely, equatorial, tropical/sub-tropical and temperate. The *P. semisulcatus* in the Persian Gulf should logically exhibit the tropical/sub-tropical pattern.

In tropical and sub-tropical areas, bimodal spawning and recruitment is common but seasonal rainfall and lower winter temperatures often result in one or the other of the generations being dominant in the offshore phase.

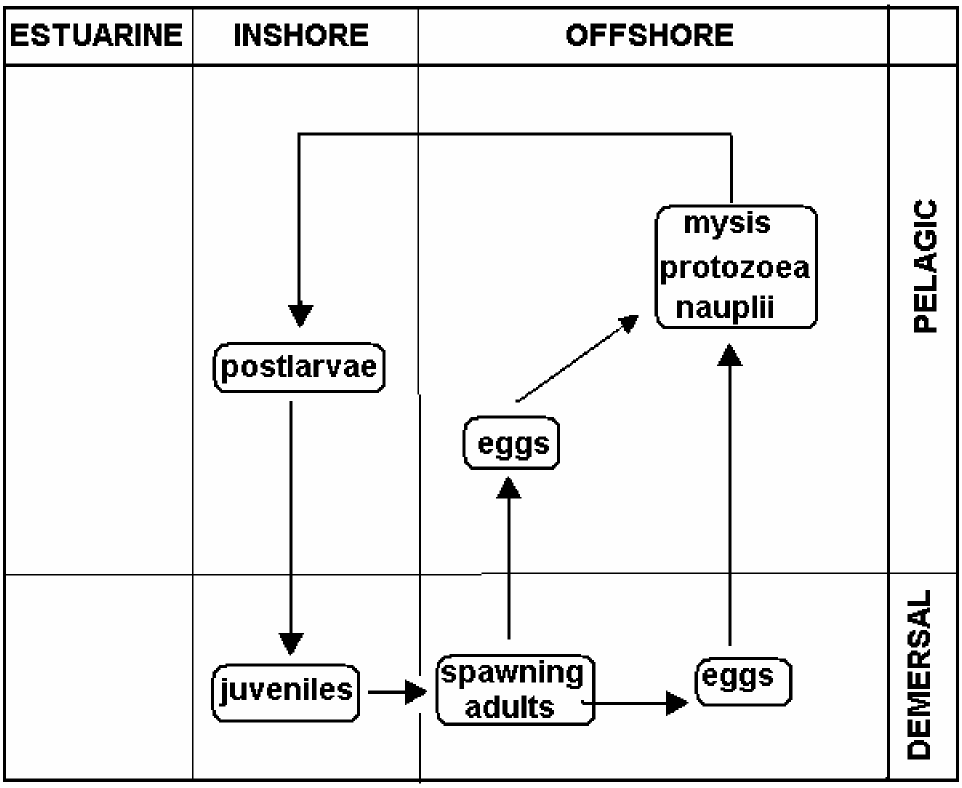

Figure 2: Schematic diagram of the Type 3 life cycle of Penaeid shrimp (Dall *et al.* 1990).

Examples of this type of strategy have been reported for *P. semisulcatus* in Kuwait, where minor spawning occurs in the autumn and main recruitment in the spring (Dall *et al.* 1990). However, this and similar examples are based on indices of spawning population abundance, using catch per unit effort data collected from heavily-fished populations, where the basic pattern may have been altered by fishing activities. Another example of bimodal spawning and the disproportionate contributions of the two generations to the offshore population are *P. semisulcatus* in northern Australia (Somers *et al.* 1987).

2.1.2 Migration

As in the various life history stages penaeids often occupy different habitats, they have to migrate between these habitats to complete their life cycle. Four types of migrations are found (Dall *et al.* 1990):

1. Larval and post larval migration from spawning to nursery ground
2. Juvenile emigration out of the nursery area
3. Adult migration, usually to deeper waters offshore
4. Spawning migration in some species

Most penaeids species spawn offshore, while the juveniles utilise estuarine or inshore habitats (Types 2 and 3). Active vertical migration during the pelagic larval phase, coupled with transport by water currents, is the most likely mechanism that brings postlarvae to their nursery areas. The larval stage of penaeids is relatively short, about three weeks. Jackson *et al.* (2001) report that the larvae may move as much as 100 km between the offshore spawning ground and the inshore nursery habitats. In an Australian study, Lonergan (1994) found that the post-larvae of *P. semisulcatus* in the Gulf of Carpentaria settle coastal and estuarine in seagrass beds. The juvenile nursery habitats can vary according to species. In this study juveniles of *P. semisulcatus* were found in the beds of sea grass and algae in shallower waters within 200 m of the inter-tidal mark. This was despite the fact that seagrass beds of high biomass were found nearby, in only slightly deeper water (2.5 m). Only the seagrass beds in shallow waters appear to be important in settlement and nursery areas for tiger prawns in the Gulf of Carpentaria.

At the end of the nursery period, the juveniles migrate offshore, to deeper water, a migration that may involve a considerable movement parallel to the shore (Dall 1990). Somers (1987) reports that juveniles of *P. semisulcatus* are found mainly at a depth of <20 m and the distribution of sub adults extends further. The migration from one habitat to another requires the prawns to respond either to some internal physiological cue associated with size, or to some change in their environment, or both (Dall 1990). Care must be taken in generalising from the results of studies on cues for emigration (size, rainfall or low salinity, temperature, food etc.), as different species may show opposite trends. *P. semisulcatus* has been found to migrate chiefly around the full and new moon.

After leaving the nursery grounds, most penaeids move into deeper water, usually further offshore. Gulland (1984) reports on a possible latitudinal gradient in migratory behaviour of penaeid shrimps. Tagging experiments in Kuwait, have shown that adult migration is generally limited. The maximum-recorded distance was 85 km, but most of captures were of much shorter distance and no marked shrimps were reported from other countries. (van Zalinge 1984).

As the prawns grow and mature, many species move even further offshore. Some authors call this movement "spawning migration", but do not identify the spawning sites. It is likely that most of these offshore migrations are really movements between juvenile and adult habitats and not strictly spawning migrations.

2.1.3 Spawning

All Type 3 species appear to spawn on the continental shelf, mostly below 100 m depth. The larvae from demersal eggs are able to migrate into the upper layers. Although offshore spawning is considered to be the norm of Type 3, an inshore migration prior to spawning has also been observed in *P. semisulcatus.* Life history dynamics vary markedly both between and within species, probably in response to differing environmental conditions (Dall *et al.* 1990).

2.1.4 Growth

A description of growth over the whole of the life cycle has not been documented for any species of penaeid. Piecing together the descriptions of different life history stages, however, shows that penaeids appear to conform to the typical crustacean growth pattern of a sigmoidal or S-shaped growth form. Most estimates of growth refer to the later life history stages after the inflection point and include the change in growth rate with size, using expressions such as the von Bertalanffy curvilinear growth model (Dall *et al.* 1990).

2.1.5 Seasonality

During a six-year study on this species in Australia, there was a consistent bimodal seasonal distribution in the abundance of juveniles but the magnitude of catches varied from year to year (Jackson *et al.* 2001). The population dynamics are complex with up to three cohorts of adults (6, 12, 18 MO) moving in and out of the fishing area. The existence of three cohorts will result in a wider length/age distribution and hence a broad spawning period from August to February. Furthermore, variation from year to year in the number and strength of cohorts may result in bi-modality in spawning. The reproductive activity of *P. semisulcatus* (in Australia) may peak twice, about September and January to March (spring and autumn). *P. semisulcatus* spawns in deep waters from 40 to 70 m. It has an extended spawning season and broad geographic range; therefore the protozeae of *P. semisulcatus* occurs at a wide range of temperature (21 to 30° C) and salinity (28 to 35 ppt). The larvae may move as much as 100 km between the offshore spawning grounds and the inshore nursery habitats (Jackson *et al.* 2001).

2.1.6 Maturity

Crocos (1987) found that the length at first maturity of female shrimp is 29 mm carapace length (CL) and the length at 50% maturity is 39 mm (CL), corresponding to 13.4 and 17.2 cm total length (TL) respectively. Egg production was markedly seasonal, with a major spawning peak from August to September (spring) and a minor one in February (early autumn). The seasonal spawning leads to two peaks in recruitment and these peaks are area dependent and have different strengths. A strong February (autumn) peak occurred only in a particular area within the spawning grounds. The basic pattern of spawning for *P. semisulcatus* is an initial spawning when some individuals of a cohort breed at approximately six months of age, but the major spawning occurs at 10-12 months of age. The success of these spawnings can be estimated from the subsequent recruitment of juveniles.

The spawning pattern, in the Persian Gulf, as measured by the variation in percentage of mature females and by post larval occurrence, shows two peaks per year, one in spring and the other in autumn. These peaks vary in relative importance from year to year, although the spring peak is the more important one. Recruitment in autumn apparently stems from the spring spawning, while the autumn spawning produces recruitment the following spring. Age at spawning is thus 12 months for the majority of the shrimps. Spawning occurs near shore on muddy sand bottoms (van Zalinge 1984).

2.1.7 Recruitment pattern

Recruitment intensity is the number of recruits per time unit, and recruitment pattern is the variation of recruitment intensity in time (Sparre *et al.* 1989). The term recruitment is widely used in fisheries to specify the degree of vulnerability to the fishing gear of new generations of fish. However, the same terminology is used to indicate the entry of other stages of the fishes to areas like nursery grounds or estuaries, etc. In these cases the term recruitment will bear its own specific definition in relation to the stages of the fishes.

In a review of exploited prawn populations, Garcia (1985) suggested that most Penaeus stocks have a seasonal offshore recruitment pattern, with a main generation recruited during summer and autumn and a secondary generation recruited in spring. Seasonal recruitment patterns for *P. semisulcatus*, which is distributed throughout the west Indo-Pacific region, vary considerably by stock.

P. semisulcatus recruits to the fishery in the warmer months of the year (October toApril). Somers (1987) found that in the Gulf of Carpentaria, there is some spatial as well as temporal separation in peaks of abundance. Catches of juvenile *P. semisulcatus*, which had peaked in November and January (summer), were followed by a secondary peak in autumn (March to April).

In the Persian Gulf recruitment of *P. semisulcatus* occurs in spring although secondary recruitment may in some years occur in late autumn (FAO 1982). van Zalinge (1984) stated that recruitment to the artisanal fishery is from April to June and September to November, while catch-rates show a major peak from May to June.

Somers (1987) reports that the CPUE for *P. semisulcatus* peaked in February and April (autumn) while juvenile abundance peaked in January and March (summer). The bulk of the catch of adults (97%) comes from depths of 21 to 40 m.

3 MATERIALS AND METHODS

3.1 Survey area

The main fishery for *P. semisulcatus* in the Iranian side of the Persian Gulf is in the Bushehr area, where almost 80% of the shrimp caught is of this species. It also comprises 20% of the catch in the Hormoz Strait where the Banana shrimp, *P. merguensis,* is the dominant species. The areas under investigation are the Motaf, Tangestan and Bahrekan fishing grounds in the north of the Persian Gulf (**Error! Reference source not found.**). For the sake of analysis the area was divided into northern and southern areas as recruitment patterns have been found to vary with latitude. In most of the years the fishing season in the northern area has lagged behind by at least two weeks, which is a reflection of a different recruitment time and average size of shrimps. There are also important hydrological and physical differences between the two areas (Reynolds 1993). The northern area receives two of three major rivers flowing into the survey area. There is a southward current in this area, which is opposite to that in the southern area. The two areas are separated by a coral island (Kharg).

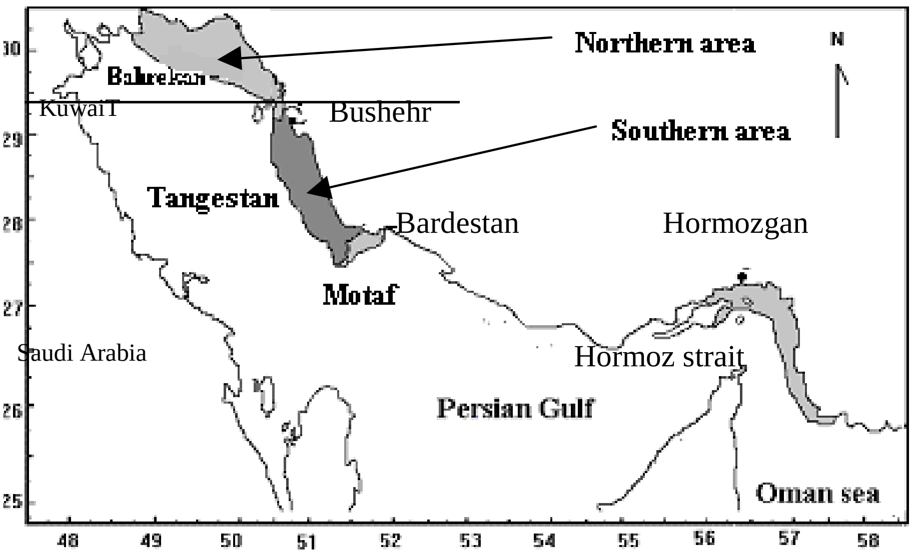

Figure 3: Known areas of distributoin of *P. semisulcatus* in the Iranian side of the Persian Gulf and the divisions of the study area.

3.2 Survey design

The study area covers the fishing grounds of *P. semisulcatus.* It is roughly 4000 sq. miles and covers all depths down to 40 m. The depth range is divided into four strata of six –10,10-20, 20-30 and 30-40 m. A total of 40 monthly surveys were conducted from December 1998 to February 2002. In 14 equidistant transects a total of 50 stations were sampled monthly, from Bahrekan in the north to Bardestan in the south (**Error! Reference source not found.** and **Error! Reference source not found.**). Sampling was done with two trawl nets each with 28 m head rope and 35 mm mesh size at the cod-end and 57 mm in body. They are towed by R/V Lavar 02, which is a double rig bottom trawler of 200 tonnes GRT.

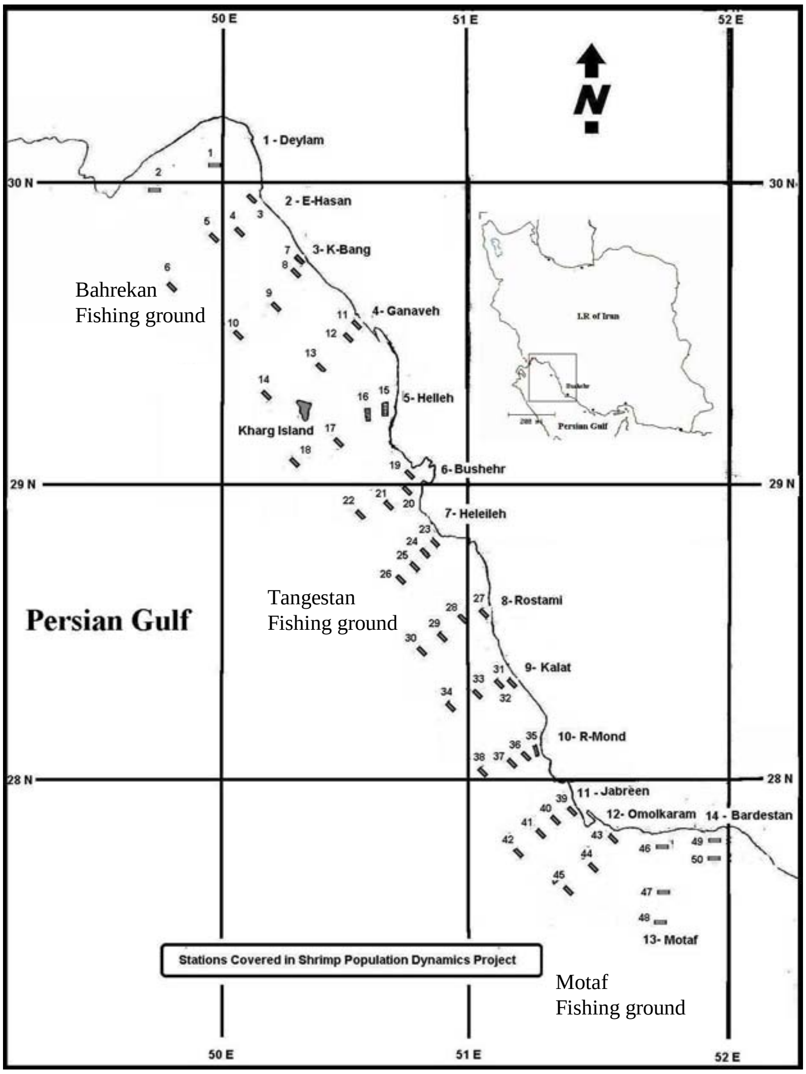

Figure 4: Distribution of stations in the study area and major fishing grounds for *P. semisulcatus* in the Iranian waters of the Persian Gulf.

At each station a one-hour haul was taken at three knots. The direction of each tow was set so as to avoid any depth change and/or deviation from a straight line. The station data include time, depth, the position at the start and finish of each haul, pH, salinity, dissolved oxygen, surface and bottom temperature.

The shrimps were sorted from the rest of the catch, weighed and the following procedure was observed:

- When more than 5 kg of shrimp were caught, a random sample of almost 5 kg was taken and weighed using a scale of ±25 g precision.
- The sample was then sorted according to species and the total in weight of each species recorded.
- The sample of *P. semisulcatus* was sexed and the total weight of each sex recorded.
- The total length of shrimps (from tip of rostrom to end of telson) was measured to the nearest 5 mm.

- In order to estimate relations between different body parameters, subsets of samples were periodically taken to the laboratory and precise measurements of total length (±1 mm), carapace length (±0.1 mm), total weight and tale weight (±0.1 g) recorded. A total of 1420 shrimp were included in the sub-sample.

The maturity stages of female shrimps were visually determined and recorded.

The maturity stages have been classified according to simple macroscopic criteria such as ovary appearance and colour (King 1995), which have already been validated through histological studies. The maturity level in *P. semisulcatus* is divided into 5 stages as follow:

- Stage 1: Ovary not evident, gut and muscles visible at joint between cephalothorax and abdomen (immature).
- Stage 2: Ovary is milk-white and translucent but not visible through carapace, gut and muscles are visible (maturing).
- Stage 3: Ovary is pale green and hardly visible through carapace, gut and muscles are visible (maturing).
- Stage 4: Ovary is green and quite visible through carapace, muscles are partially obscured (ripe).
- Stage 5: Ovary is deep green and its lobs cover most of internal organs. Muscles are obscured (spawning - spent).

The collected data were stored in three databases as described below:

1- The first category is the "station data" which defines the certain characteristics of the sampled station and has 1572 records of the following format: Sample id number, year, month, day, latitude, longitude, stratum, depth.
2- The second database is the "catch data" which contains information on the species and amount of catch and has 1572 records of the following format: Sample id number, species, total catch, sample weight, female weight, male weight.
3- The third database is the "biological data" in which information on length and maturity measurements by sex are stored. This database contains 21536 records and is in the following format: Sample id number, species, length, maturity, sex, number

The sample id number is the common field that enables one, to join these databases together and is created by using the following formula:

Sample id number = (year*10000)+(month*100)+(station number)

3.3 Abundance and distribution

To estimate temporal and spatial abundance, the variation of CPUE (number/hr), as an index of abundance was used. In this case the catchability of shrimp is assumed to be temporally and spatially constant. Monthly isoplots of CPUE in g/hr were used to define spatial and temporal distribution.

3.4 Reproduction

To estimate the spawning season, plots of proportion of ripe and spent female shrimp (stages 4 & 5) with respect to time was used. Periods of high ratios of ripe and spent shrimp were defined as the spawning period.

To estimate length at 50% maturity (L_m) the data at different stages of maturity during the spawning season was weighted by respective monthly CPUE and pooled for all years. After estimating the proportion of mature shrimps at length to the total no of shrimps, two methods of estimation were used:

a) The least squares method. In this method a logistic curve of the form:

$$P = 1/\left(1 + e^{-r(L - L_1)}\right) \quad (1)$$

is fitted to observed maturity proportions at length by minimising the difference between square of the differences between observed and predicted values. Here, r is the steepness of the curve and L_1 is the length at 50% maturity.

b) The linearised logistic curve. Equation (1) describes a logistic (S-shaped) curve and can be transformed to a straight line through the following mathematical procedures:

$$1 = P + P\left(e^{(-r\,(L-L1))}\right)$$
$$(1-P)/P = e^{(-r\,(L-L1))}$$
$$\mathrm{Ln}((1-P)/P) = r(L-L_1)$$

This is a straight line where the slope is -r and L_1=a / r the length at 50% maturity.

In this method, the log transformed observed proportions of maturity at length are plotted against length. The proportions are adjusted so that the highest proportion is one. A straight line is fitted through the linear portion of the transformed observations and the parameters of the regression line are estimated the length at 50% maturity is then calculated. To identify spawning grounds, areas of high densities of ripe and spawned shrimp (number/hr) in the spawning seasons were plotted.

3.5 Length at recruitment

The same analogy, which is used to estimate length at 50% maturity (L_m), is also applied to estimate the length at which the shrimps are recruited to the fishery. In this method the period of appearance of new recruits was identified by studying the monthly length frequency distribution. The weighted number of shrimps at length from June to August was estimated and pooled. Then the proportion of each length to the total number at that length was calculated. The plot of obtained proportions at length against length describes an inverse S-shaped logistic curve. By subtracting the proportion from one, the shape of the curve transforms into an S-shaped logistic curve described in equation (1). Here the variable L_1, represents the length at which mass recruitment occurs and can be used as a measure of recruitment. The peaks in plot of variation in abundance of the shrimps under L_1 with respect to time show the periods of high recruitment.

3.6 Growth

3.6.1 Normal separation and modal progression analysis

Using a simplified version of the Mcdonald and Pitcher method of splitting a mixed distribution into its constituent normal components (Stefansson G. personal communication), cohorts in each monthly length frequency distribution were identified (Macdonald and Pitcher 1979). The mean, variance and size of each cohort, by sex and area, were estimated. This method is based on the least squares method of fitting a line to observed data. The estimated means were plotted against time in a scatter diagram. The progression of modes was detected in time.

The curvilinear von Bertalanffy growth equation was used to describe the growth of *P. semisulcatus:*

$$L_t = L_\infty\left(1 - e^{-K(t-t_0)}\right)$$

where L_t is the length at time t; L_∞ *is* the asymptotic length; K is the growth coefficient, which describes the rate at which asymptotic length is approached; and t_0 is the hypothetical age when the size is zero assuming that the animal has always grown according to the von Bertalanffy growth equation (Dall *et al.* 1990).

3.6.2 The least squares method

The least square method is the non-linear parallel to linear regression analysis. In this method a series of pairs of observations of length and corresponding age (from modal progression analysis in this study) are used. The method estimates the growth parameters in such a way that the sum of the squares of the deviations between the model (von Bertalanffy growth equation) and the observations is minimised, i.e. it minimises the sum with respect to one or more of the parameters L_∞, K and t_0.

3.6.3 The Powell-Wetherall method

Though this method is primarily used for estimating mortality, it is used to estimate $L\infty$, the asymptotic length. This is a special application of the equation:

$$Z=K*(L\infty-Lbar)/(Lbar-L')$$

where Lbar is the mean length of fish of length L' and longer, while L' is "some length for which all fish of that length and longer are under full exploitation". L' is the lower limit of the corresponding length interval. As L' can take any value equal to and above the smallest length under full exploitation, the above equation can give a series of estimates of Z, namely one for each choice of L'. This makes it possible to turn the equation into a regression analysis with L' as the independent variable. A series of algebraic manipulations shows that this is equivalent to:

$$Lbar -L' = a + b* L'$$

where $Z/K = -(1+b)/b$ and $L\infty = -a/b$ or $b = -K/(Z+K)$ and $a = -b* L\infty$.

Thus, plotting Lbar -L' against L' gives a linear regression from which a and b can be estimated and hence $L\infty$ and Z/K (Sparre *et al.* 1989).

4 RESULTS

4.1 Distribution and abundance

The spatial and temporal distribution of shrimp is highly variable by month and year. Higher shrimp densities are often found in early summer (June to July) between the latitudes of 28° and 29° degrees and extend north and south in August. In later months (September to December) one can find a relative high-density zone in the northern most part of the distribution area. In January and February smaller aggregations are found at lower latitudes of around 28° (Appendices 1 to 4).

The CPUE during the three-year study period shows a regular pattern of relatively low catches in March and April and peaks in July to August (**Error! Reference source not found.**).

The catches increase about one month earlier in the south. While maximum primary (main) abundance usually occurs in July each year in the southern area, the same occurred after about a month (August) in the northern area. In 1999 the southern second peak occurred in October around the latitudes 28° 30 and 29°. In 2000 and 2001 a secondary peak in abundance occurred in December to January in the south around 28°, and a peak occurred also in November of 2000 in the northern area at 29°30.

In order to understand if the second peak is due to migration of larger individuals or growth, the length at which recruitment takes place was investigated.

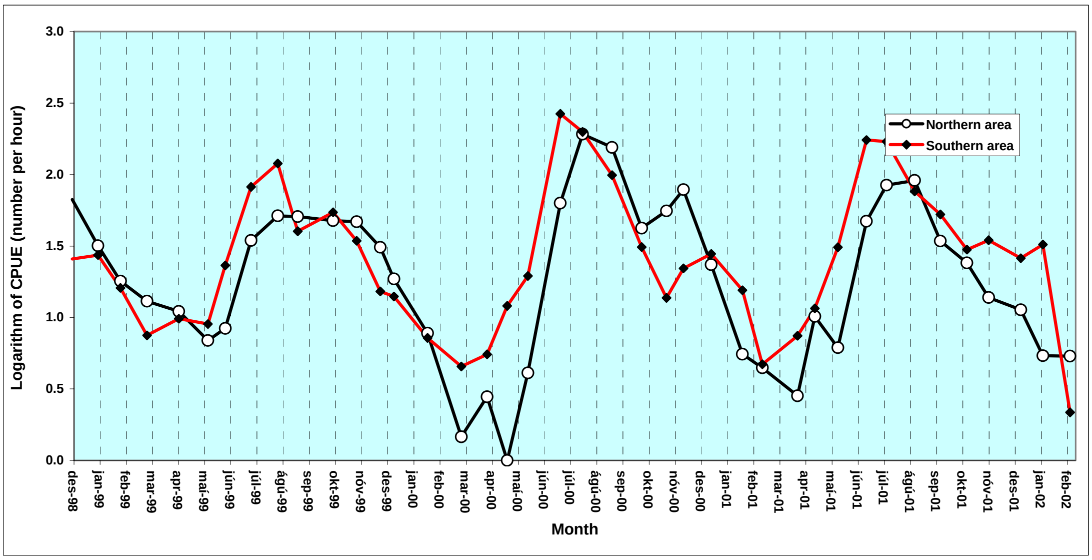

Figure 5: Temporal and spatial variation in CPUE of *P. semisulcatus* during monthly surveys.

4.2 Recruitment to the fishing grounds

The length at mass recruitment is variable by year. During the study period a length range of 11.4 to 13.2 cm was observed. The results of estimations from log-transformation of proportions of small shrimps at length (King 1995), are summarised in Table 1 and ts of estimations are grouped in Error! Reference source **not found.**.
Fitting the logistic curve using minimisation methods resulted in a different range of Lr from 10.5 to 13.6. Results of estimations are grouped in **Error! Reference source not found.**.

Table 1: Estmation of Lr using the linearised logistic curve.

Year	**1999**	**2000**	**2001**
Slope	-0.66	-0.58	-0.76
Intercept	8.12	7.66	8.68
R	0.99	0.96	0.97
Lr (cm)	12.3	13.2	11.4

Table 2: Estimation of Lr using the least squares method.

Year	**1999**	**2000**	**2001**
Lr (cm)	12.1	13.6	10.5
r	0.28	0.38	0.49
SSE	1.3	0.8	0.7

The least squares method showed greater variability between years (10.5 - 13.6 vs. 11.4 - 13.2), but the pattern is the same. Thus the size at recruitment was highest in 2000 and lowest in 2001. The mean size at recruitment for all the years and both methods is approximately 12.2 cm. The mean length of the shrimp in the months of highest abundance (June to August) is around the above length. This was used as an index of recruitment. The absolute number and proportion of shrimps below 12.5 cm (closest measurement), to the total number of shrimps at each month was plotted against time (**Error! Reference source not found.**). Two periods of recruitment were found each year.

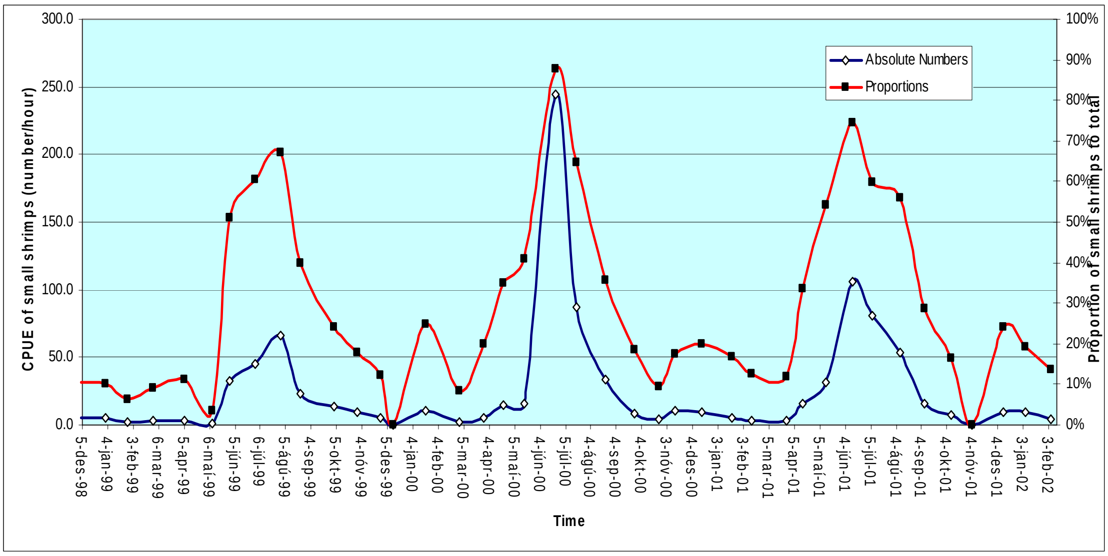

Figure 6 : Proportion and absolute number of shrimp under length Lr by time.

The main recruitment, which the fishery is depended upon, is in July to August and a second one occurs in December to February. The timing and strength of both recruitments vary inter-annually. The secondary recruitment is roughly one quarter to one third of the main recruitment. The presence of a higher proportion of small shrimps is an indication of new recruitment rather than mere aggregation.
Secondary recruitment is clearly represented by the appearance of new modes of small shrimp in length frequency distribution

In 1999 the secondary recruitment has occurred between the latitudes 29° and 29°30' while in 2000 the second appeared further north well above 29°30'. In 2001 a secondary recruitment occurred in the southern area around 28° latitude. No pronounced secondary recruitment was observed in 2001 for the northern area. (Appendix 1)

The proportion of pre-recruits(< 12.5 cm) in the southern area is always higher and the modes more prolonged than in the northern area. The period of major recruitment starts earlier and lasts longer in the south than the north. A consistent pattern is not seen for the secondary recruitment, which usually occurs in December and January. (**Error! Reference source not found.**)

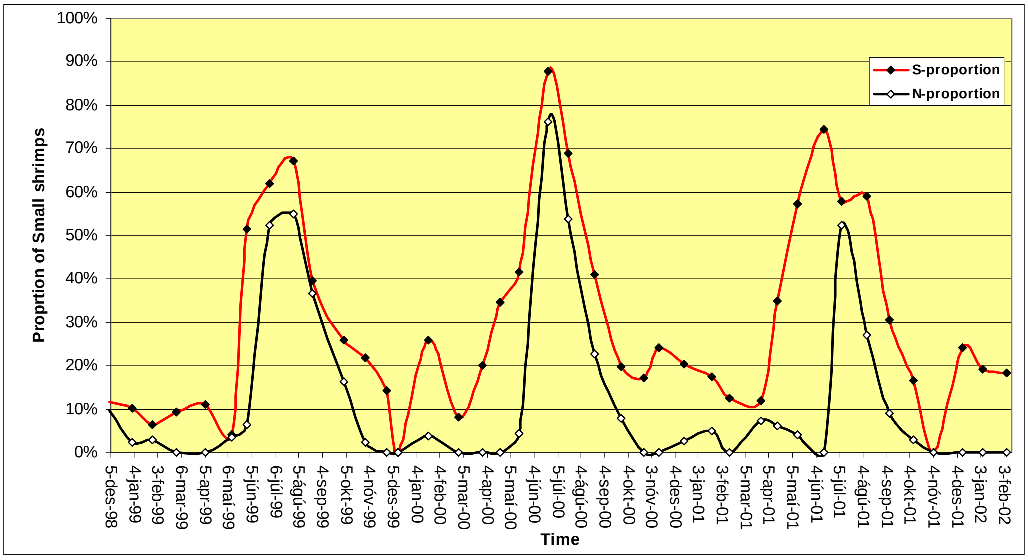

Figure 7: Proportion of shrimp under length Lr by time and area.

4.3 Maturity

Maturity as indicated by the proportion of ripe (stage 4) and newly spent (stage 5) shrimp, is seasonal and exhibits two peaks in the autumn and again the following spring, although the exact timings may vary between years (**Error! Reference source not found.**). Thus autumn spawning took place in January 1999 and November 1999, 2000 and 2001. Spring peaks in spawning activity occurred in early April 1999 and in mid-April in 2000 and 2001.

Although spawning activity is highly seasonal, the availability of ready to spawn and spent female shrimp throughout the whole study period, suggests that spawning can take place at all times of the year.

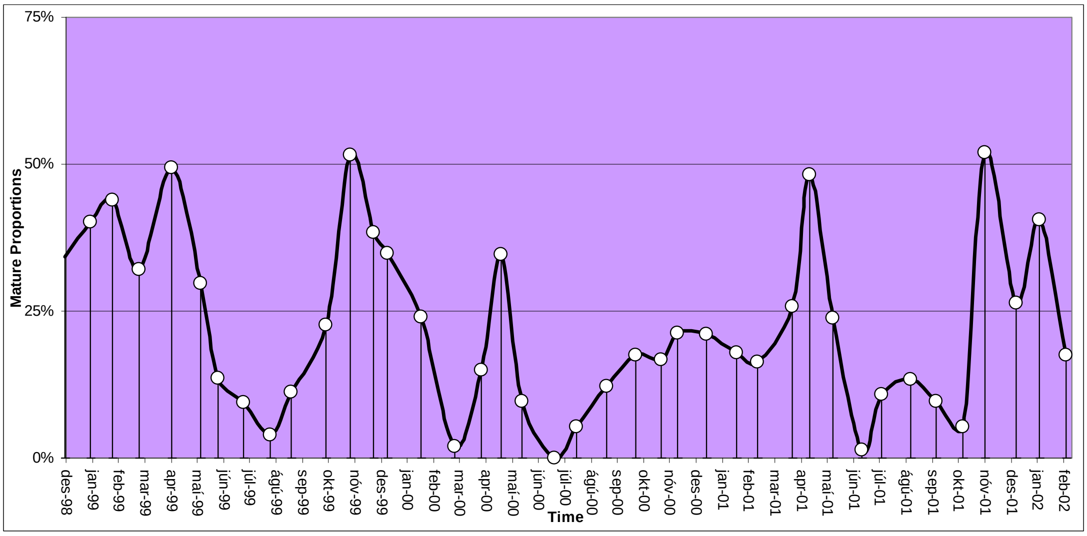

Figure 8: Temporal proportions of mature female shrimp (stages 4 and 5).

Size at sexual maturity was determined for females only (**Error! Reference source not found.**). It was lowest in 1999 when the abundance of shrimp was also the lowest (**Error! Reference source not found.**), and on average almost 15 cm (**Error! Reference source not found.**, **Error! Reference source not found.** and Appendix 4).

Table 3: Estimation of size at sexual maturity using the least squares method.

Year	1999	2000	2001	Pooled
L50% (cm)	13.3	15.9	15.1	14.9
r	1.89	0.45	0.82	0.64
SSR	0.24	0.27	0.08	0.12

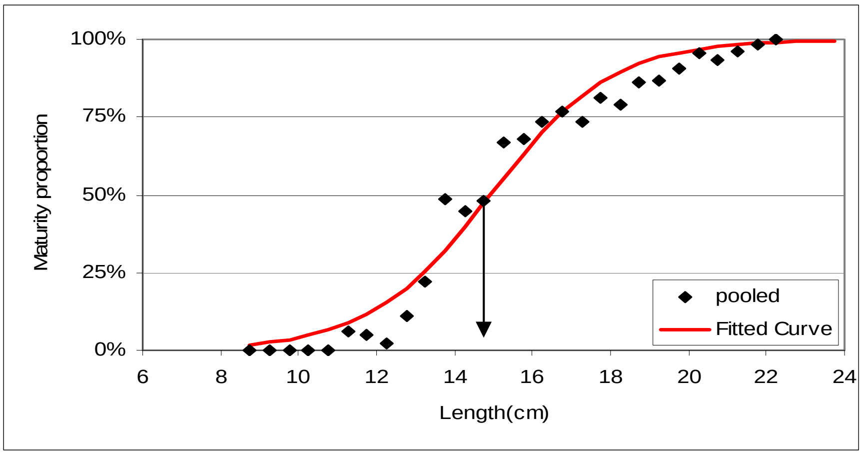

Figure 9: Length at 50% maturity (14.9 cm) for pooled data of 1999 to 2001.

Error! Reference source not found. shows the spatial distribution of the female shrimps by half degree latitude in the spawning months (October to June). It is observed that the northern part of study area (higher latitudes), holds a relatively higher number of shrimps of larger than L50% indicating an aggregation ground for the mature shrimps.

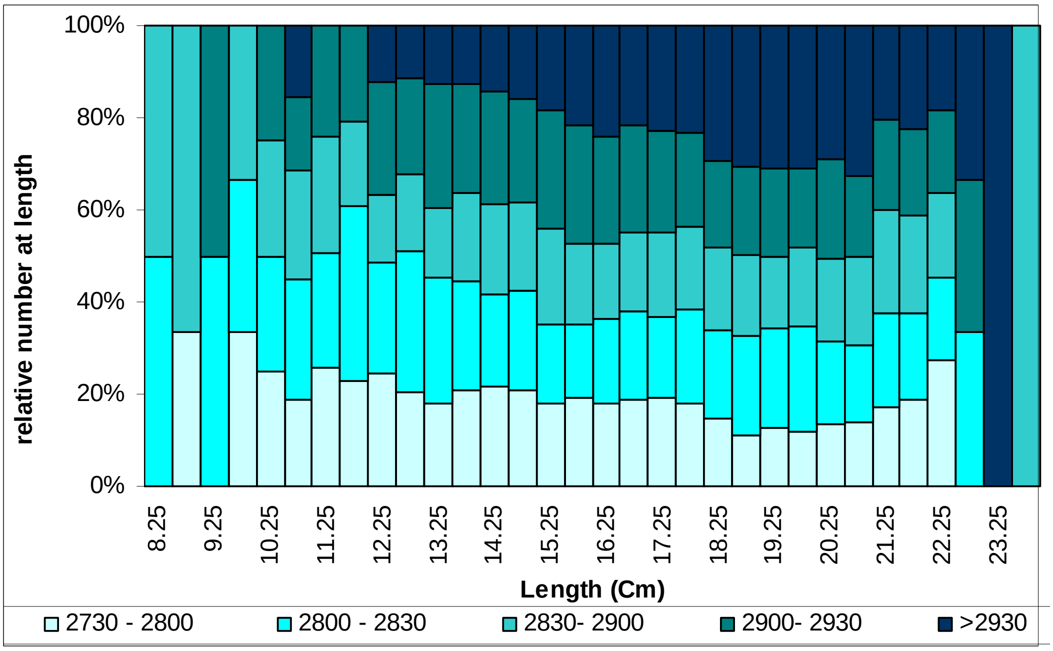

Figure 10: Latitudinal relative number of female shrimps at length.

4.4 Growth

Length-frequency distribution of shrimps by sex, reveal one to three modes depending on the month and year.

The progression of modes could only be determined once the data had been analysed for the northern and southern areas separately. In most months the northern shrimp length frequency distribution by sex is uni-modal. Only during late spring and summer when new recruitment appears is the distribution bi-modal. These two modes are easily identifiable as they belong to two generations with an age difference of one year (**Error! Reference source not found.** and **Error! Reference source not found.**).

The VB growth curve was fitted to the observed modes of the cohorts by month. The growth of shrimp in the north is very consistent inter-annually for both sexes (**Error! Reference source not found.** and Appendix 2). Length frequency distribution of shrimp in the southern part exhibits a more complicated and less consistent pattern between years. There is multiple and/or continuous recruitment especially during the summer months.

The main period of recruitment is during the middle of the year, but the length of the recruitment period varies considerably, from two months in 1999 (June and July) to almost four in 2000 (mid-April to August) and two in 2001 (May and June). This phenomenon obscures the regular pattern of modal progression (**Error! Reference source not found.** and **Error! Reference source not found.**).

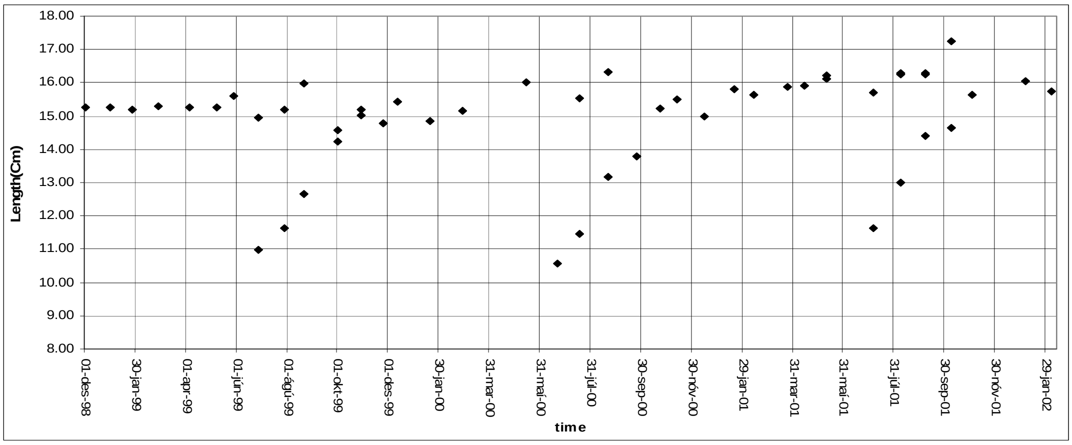

Figure 11: Observed modes of northern male shrimp in time.

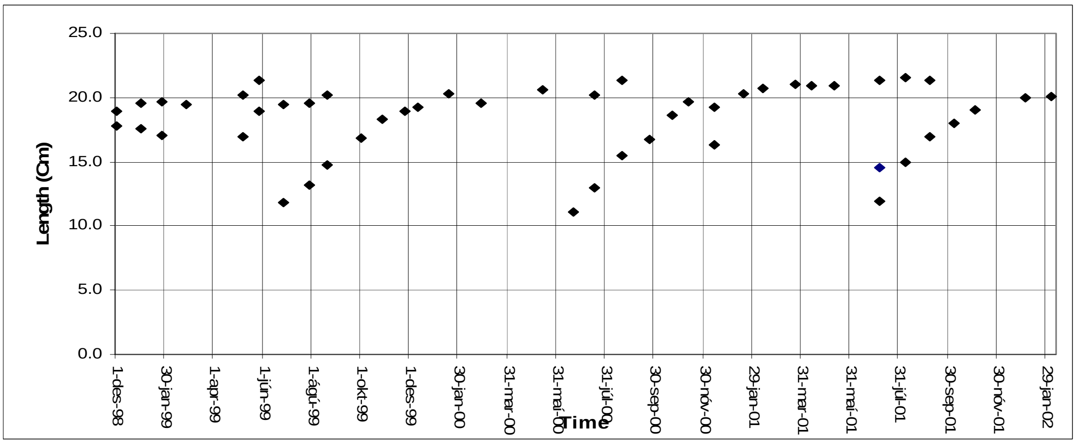

Figure 12: Observed modes of northern female shrimp in time.

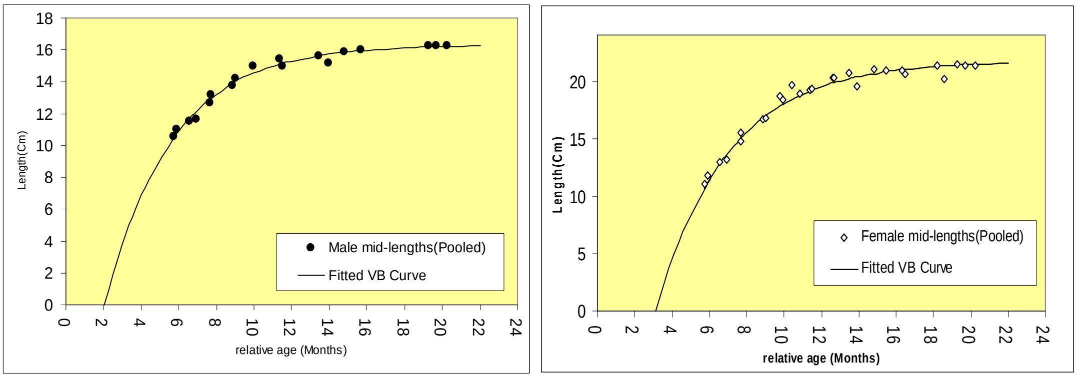

Figure 13: Fitted Von Bertalanffy growth curves to pooled observed female (right) and male (left) modes 1999 -2001 ($L\infty$ =21.7 cm, K =3.1 Y^{-1} for female and $L\infty$ = 16.3 cm, K =3.4 Y^{-1} for males).

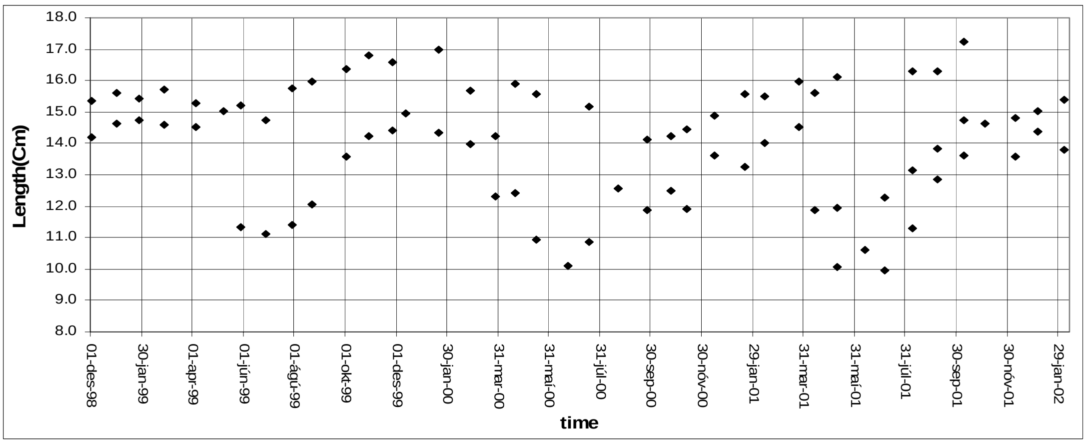

Figure 14: Observed modes of southern male shrimp in time.

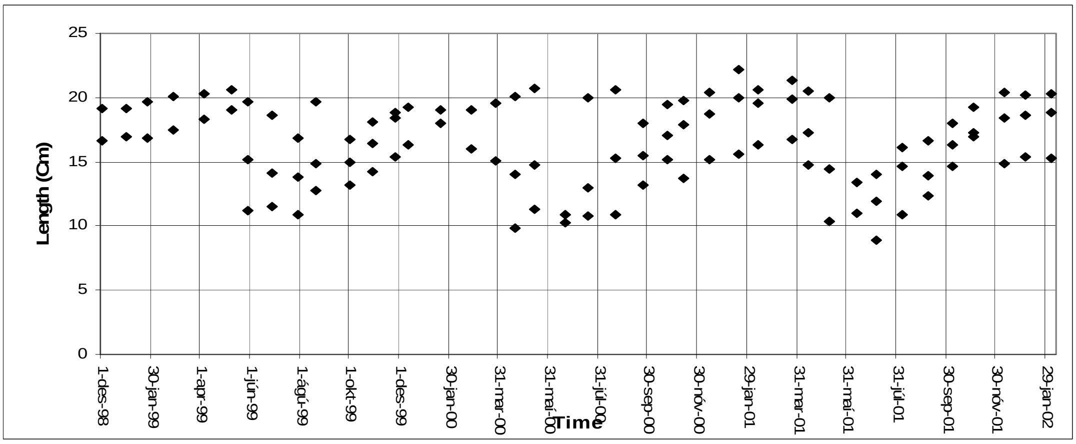

Figure 15: Observed modes of southern female shrimp in time.

At any given time, three modes can be detected one being from older generations. The difficulty in separation or rather following the progression of cohorts prevents one from obtaining a proper estimate of the VB growth parameters. This may be partly due to size-related northward movement of the shrimp and partly due to continuous recruitment.

Further investigations of mean lengths by 0.5-degree latitude suggest a gradient of increase in mean length from south to north. This gradient is consistent in both male and female mean lengths and also by year (**Error! Reference source not found.**).

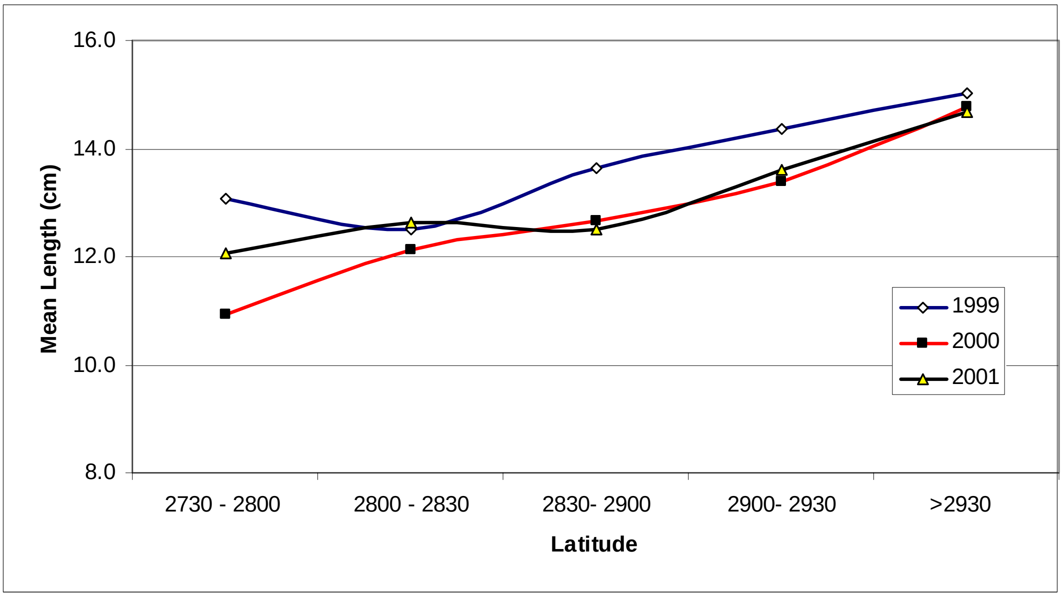

Figure 16: Variation of mean length of shrimp (pooled) by 0.5-degree latitude.

Application of the Powell-Wetherall method, which is usually used to estimate mortality, (Z/K) resulted in the calculation of a series of L∞ for different areas and sexes. **Error! Reference source not found.** to
, summarise the estimations from Powell-Wetherall and the least squares method.

Table 4: Estimations of L∞ for females using the Powell-Wetherall method.

Year class	**1999**	**2000**	**2001**
L∞(north)	20.6	21.0	22.5
Z/K	1.10	1.18	1.63
R	-0.99	-1.00	-1.00
L∞ (south)	21.7	21.4	22.9
Z/K	2.0	1.6	2.4
R	-1.00	-1.00	-1.00

Table 5: Estimations of L∞ for males using the Powell-Wetherall method.

Year class	**1999**	**2000**	**2001**
L∞ (north)	16.0	16.4	17.1
Z/K	0.77	1.29	1.71
R	-0.99	-1.00	-1.00
L∞ (south)	16.9	17.0	17.1
Z/K	2.01	2.55	2.38
R	-1.00	-0.99	-1.00

Table 6: Estimations of L∞ (cm) and K for northern shrimps using the least squares method.

Year class	**1999**	**2000**	**2001**	**Pooled**
L∞ (Male)	16.3	16.4	--	16.3
K Y^{-1}	3.5	3.2	--	3.4
L∞ (female)	21.1	21.6	--	21.7
K Y^{-1}	3.3	3.5	--	3.1

The estimated L∞ using the Powell-Wetherall shows that both male and female shrimp can attain higher lengths in the southern area and shows inter-annual consistency throughout the study period.

5 DISCUSSION

Though the whole life cycle of *P. semisulcatus* has not been covered, results of this study demonstrate reasonable consistency with other studies, in describing its life history after recruitment to the fishery. The general patterns of seasonality in reproduction, recruitment and migration have been found to be in accordance with other published studies.

The spatial and temporal distribution of *P. semisulcatus* was found to be highly variable by month and year. The new recruits appear for the first time, as a burst to the fishing grounds of the Tangestan area (28° to 29°N) in July and within less than a month, there is a sharp increase in shrimp abundance in all fishing grounds. When the shrimp season opens, within six weeks, the stock is heavily exploited by the shrimp fleet to a targeted 80% of the initial or an economically feasible catch-rate (Khorshidian 1995). The fishermen always choose the densest fishing grounds. This phenomenon makes it difficult to correctly judge the natural distribution and movement of the shrimp during the open season (August to September). The abundance maps in the end of August indicate the highest densities of the shrimp in the northern area. Considering the south to north gradient of the increase in average length of the shrimp and their relative abundance from August onward, a possible size related movement of the shrimps from south to north could be hypothesised.

In October to –December, which corresponds to the peak of the autumn spawning period, one can find a relative high-density zone at the far northern part of the study area. This may be considered as an aggregation ground for spawners.

Recruitment is found to be highly seasonal with two distinct peaks of different magnitude in mid-summer (July to August) and late autumn (December to January). It is also variable by year and area. Recruitment to the fishery first occurs in the southern area in June to August. Recruitment in the northern area occurs almost a month later. This pattern is consistent in the whole study period and may suggest northward migration of the shrimps or a second population, which might have its origin in or outside the study area. van Zalinge (1984) observed two peaks of recruitment in the west coast of the Persian Gulf (Kuwait, Saudi Arabia), one in autumn (September to November) and the second in spring (April to June). This is consistent with general annual double peaks in recruitment of this species but with a time lag.

During the study period, the length at which recruitment occurs has been variable by year in the range of 11.4 to 13.2 cm. This indicates that migration to the fishing grounds might not be only size related. Somers (1991) reports that the length at recruitment of the sub-adults to the fishing grounds of north-western Gulf of Carpentaria has been 10 to 12 cm.

It is found that during the study period, recruitment started in a limited area between 28° and 29°N. This information can be used to identify the probable nursery grounds, which at present are unknown and also earlier detection of recruitment.

The size at 50% maturity in the study area is 14.9 cm. The L50% for the female *P. semisulcatus* in the Bushehr area (current study area) was estimated in 1992 by King

(1995) to be 15.7 cm. The estimated L50% in the Gulf of Carpentaria, Australia shows a higher value of 39 mm (CL), corresponding to 17.2 cm (Crocos 1987). This indicates that *P. semisulcatus* matures at a smaller length in the Persian Gulf.

The growth process in the northern area is found to be consistent for both sexes during the study period. Estimations of $L\infty$ from Powell-Wetherall and the least square method also confirm the same. Occurrence of multiple and/or continuous recruitment and the availability of three cohorts with small differences in mid-length in the southern area, produced uncertainties in following the proper modes, making it difficult to make a reasonable estimation of K. However, using the Powell-Wetherall method, a series of $L\infty$ estimates for both sexes were obtained. It was found that compared with the northern area, *P. semisulcatus* has attained a larger $L\infty$ in the southern area. This result is consistent for all three years of the study and both sexes.

Some $L\infty$ and K estimates of the same species from other sources in Dall (1990), along with estimations from this study (Total length is converted to Carapace length) are summarised in **Error! Reference source not found.**.

Table 7: Estimates of K, $L\infty$ for *P. semisulcatus* from various sources and this study.

Source	**Sex**	**$L\infty$(mm)**	**K** (week^{-1})	**Phi prime**
Jones and van Zalinge (1981)	F	47.7	0.040	1.96
Jones and van Zalinge (1981)	M	48.2	0.050	1.96
Mathews *et al.* (1987)	F	53.2	0.021	1.77
Mathews *et al.* (1987)	M	48.2	0.018	1.62
Kirkwood & Somers (1984)	F	62.2	0.061	2.37
Kirkwood & Somers (1984)	M	38.1	0.025	1.56
This study	F	60.2	0.063	2.36
This study	M	40.5	0.067	2.04

The sequence of development of all known members of the Penaeids, as stated by Dall (1990), is similar. Four types of life cycles have been distinguished, of which *P. semisulcatus* is classified as having a Type 3 life cycle (see section 2.1.1).

One of the general characteristics of the Type 3 Penaeids, which is applicable to *P. semisulcatus* in the Persian Gulf, is the seasonal life history dynamics, double peaked spawning and recruitment.

It is found that there are two spawnings per year, which result in two recruitments six to 10 months later.

Error! Reference source not found. illustrates the superimposed curves of spawning and recruitment pattern of the *P. semisulcatus*. There are two recruitments following two spawning peaks at each cycle. The autumn spawning in 1998 resulted in a major recruitment in the summer of 1999 (July to August). The spring spawning which took place in April 1999 produced a minor recruitment in the following autumn (January 1999). A similar pattern can be observed in the following years. In general, the main recruitment occurs six to eight months after the late autumn spawning. The six to eight month old shrimps contribute to the main recruitment, which are harvested in the fishing season (August to September). The second recruitment, which consists of eight to 10 month old shrimps, is the result of the spring spawning (April).

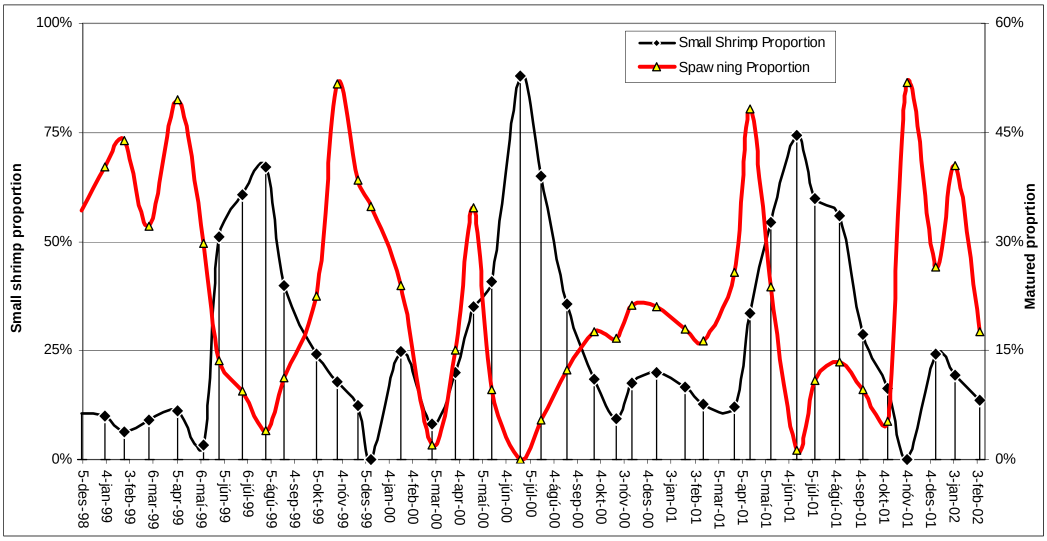

Figure 17: Recruitment and spawning sequence in *P. Semisulcatus.*

The major recruitment in mid-summer (June to -August), which the fishery is depended upon, stems from the late autumn spawning (November to January). These are fast growing six to eight month old shrimps. The spring spawning results in a second recruitment, which is one-third to one-quarter of the major one and occurs from December to January. These are eight to 10 month old slow growing shrimps. The length at 50% maturity for this species is ≅15 cm and the smallest observed spent shrimp in the autumn spawning was 12.5 cm.

There are two definitions of generation: the time between egg and first spawning (which can be as short as six months) and the time between the main spawning period of the parents and the main spawning of their progeny (which is one year) (Dall *et al.* 1990). Accepting the first definition indicates that the eight to 10 month old slow growing shrimps may contribute to the autumn spawninghe.

Thus the major recruitment in the summer is the result of spawning by two generations of one-year and nine-month old shrimps. According to obtained growth parameters, the shrimps that are born in the autumn cannot contribute to the spring spawning since they have not yet attained their proper size. Thus spring spawning is only contributed to by a generation of one-year-old shrimps (the second definition) and a few that have survived to their known maximum age of two years.

Crocos (1987) found that the basic pattern of spawning for *P. semisulcatus* is an initial spawning at six months of age and a major spawning when they are 10-12 months old. On the other hand, the age at spawning in the Persian Gulf, as reported by van Zalinge (1984), is 12 months.

The spring and autumn proportions of mature female shrimps (**Error! Reference source not found.**) do not show the relative importance of one to the other. The major recruitment to the Bushehr fishery stems from the autumn spawning, but the size of the second recruitment is not at all in proportion with what is shown in **Error! Reference source not found.**. Three possibilities can be hypothesised.

- The slow growth rate of this spring generation, as explained by their appearance in autumn, suggests that the climatic conditions might not be too favourable for them and they suffer a higher mortality rate.
- The main fishing season in Kuwait is in the autumn. All or the majority of the spring generation might move westward and contribute to the Kuwaiti autumn shrimp fishery.
- Accepting that there is a spawning stock-recruitment relationship, it can be said that the number of spawners is not as high as in autumn to produce enough offspring.

6 CONCLUSION AND RECOMMENDATIONS

The management on any fish is best implemented, only if the biology of that species is known. There has not been much published scientific research on the life cycle of *P. semisulcatus* in the Persian Gulf. What was known about this important species was merely an extrapolation of the general biology of this species to the Persian Gulf. In this study, based on research data, it was found that *P. semisulcatus* in the Iranian waters of the Persian Gulf conforms with the general pattern of the Type 3 life cycle of Penaeids. Furthermore, the timing and geographical location of recruitment and spawning were identified. Moreover, the link between bi-modal spawning and recruitment in the area was established. The obtained results will be used in:

- Fine-tuning the ongoing project of "Monitoring shrimp resources in the Bushehr area" to best suit its primary objective, which is to describe the population dynamics of *P. semisulcatus.*
- Implementation of shrimp fishery management models from elsewhere and revising them for the Bushehr shrimp fishery.
- Initiating new studies to cover the whole life cycle of the shrimp.
- Designing tagging experiments to discover the movement of shrimp especially in the northern area, which is within a possible migration distance for the shrimp.
- Natural and fishing mortality estimates are available of important biological and fishery characteristics of the shrimp, which are widely used in modelling the fishery. The trend in decaying population numbers during a relatively short fishing season was obscured by continuous recruitment resulting in errors in the estimation of fishing mortality. This phenomenon calls for a more intense sampling scheme during recruitment and the fishing periods.
- Information exchange on a technical level with neighbouring countries.

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APPENDIX

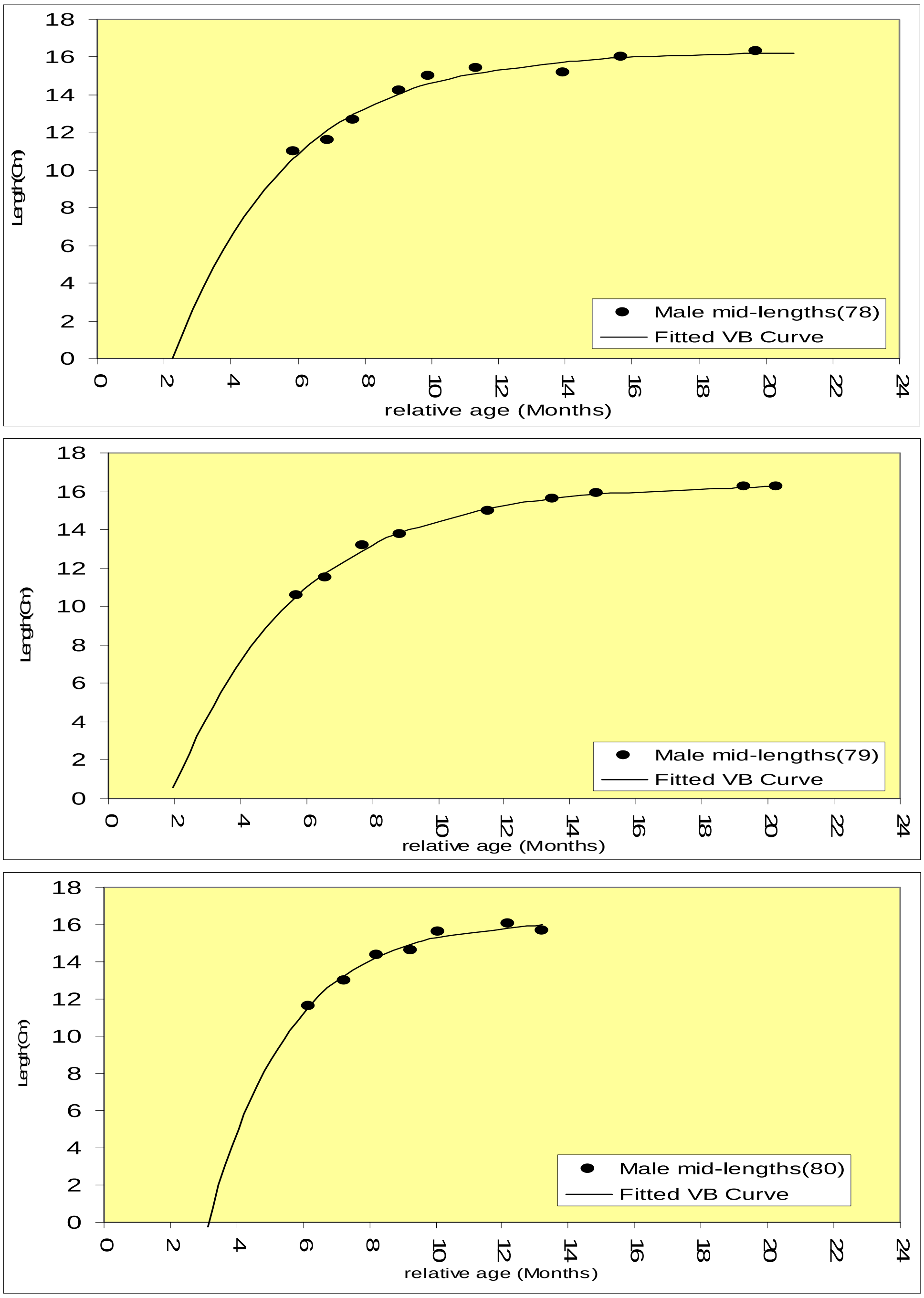
Appendix 1: Distribution Maps

Temporal and spatial abundance of *P. semisulcatus,* in the study area situated at the north-western Iranian waters of the Persian Gulf for year class of 1998.
Note: For maximum clarity, each map page has been grouped to cover a one year cycle starting from months of highest recruitment and scaled to largest index value (number of shrimp/hour) of the corresponding cycle.

Temporal and spatial abundance of *P. semisulcatus,* in the study area situated at the north-western Iranian waters of the Persian Gulf for year class of 1999.
Note: For maximum clarity, each map page has been grouped to cover a one year cycle starting from months of highest recruitment and scaled to largest index value (number of shrimp/hour) of the corresponding cycle.

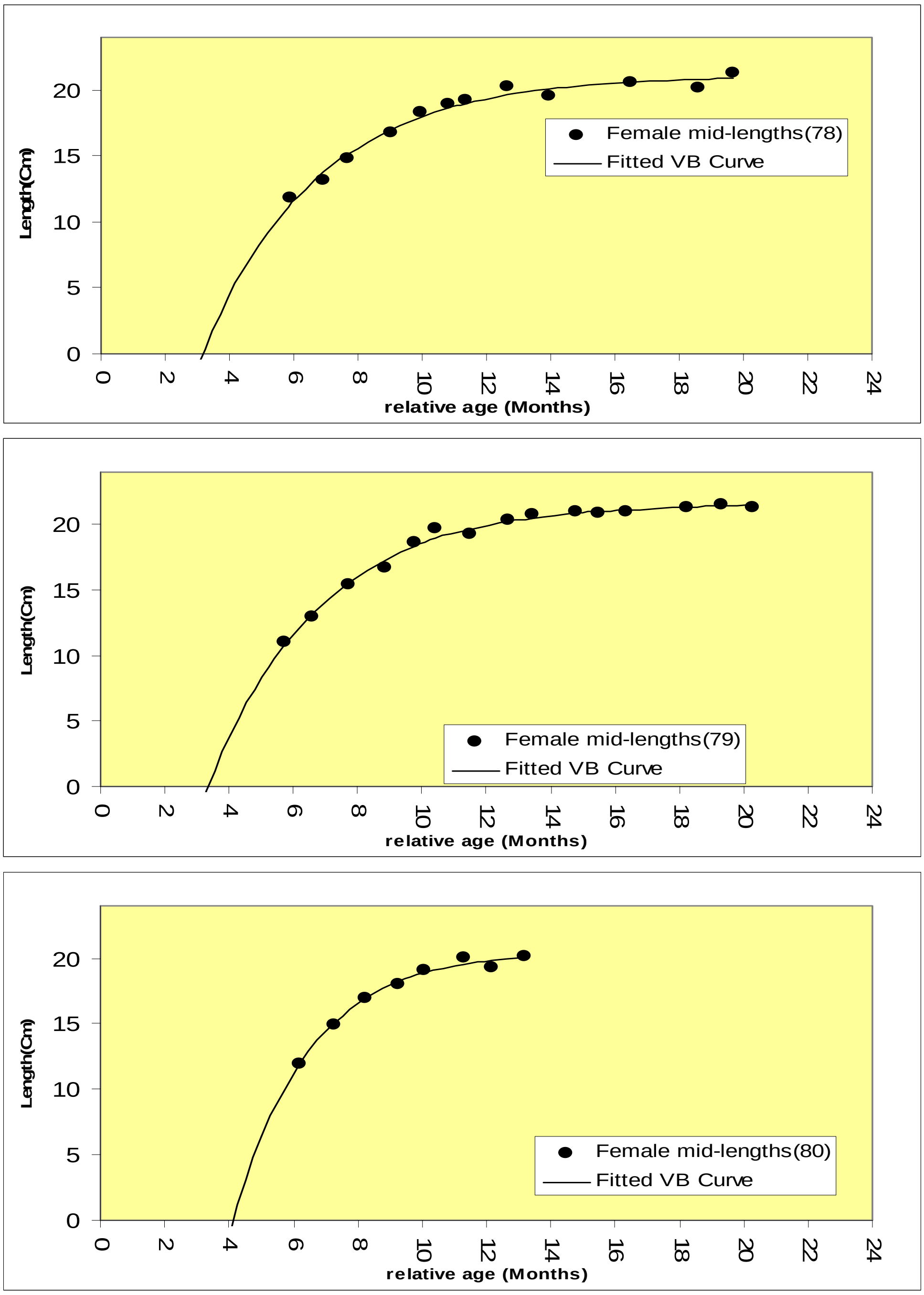
Temporal and spatial abundance of *P. semisulcatus,* in the study area situated at the north-western Iranian waters of the Persian Gulf for year class of 2000
Note: For maximum clarity, each map page has been grouped to cover a one year cycle starting from months of highest recruitment and scaled to largest index value (number of shrimp/hour) of the corresponding cycle.

Temporal and spatial abundance of *P. semisulcatus,* in the study area situated at the north-western Iranian waters of the Persian Gulf for year class of 2001
Note: For maximum clarity, each map page has been grouped to cover a one year cycle starting from months of highest recruitment and scaled to largest index value (number of shrimp/hour) of the corresponding cycle.



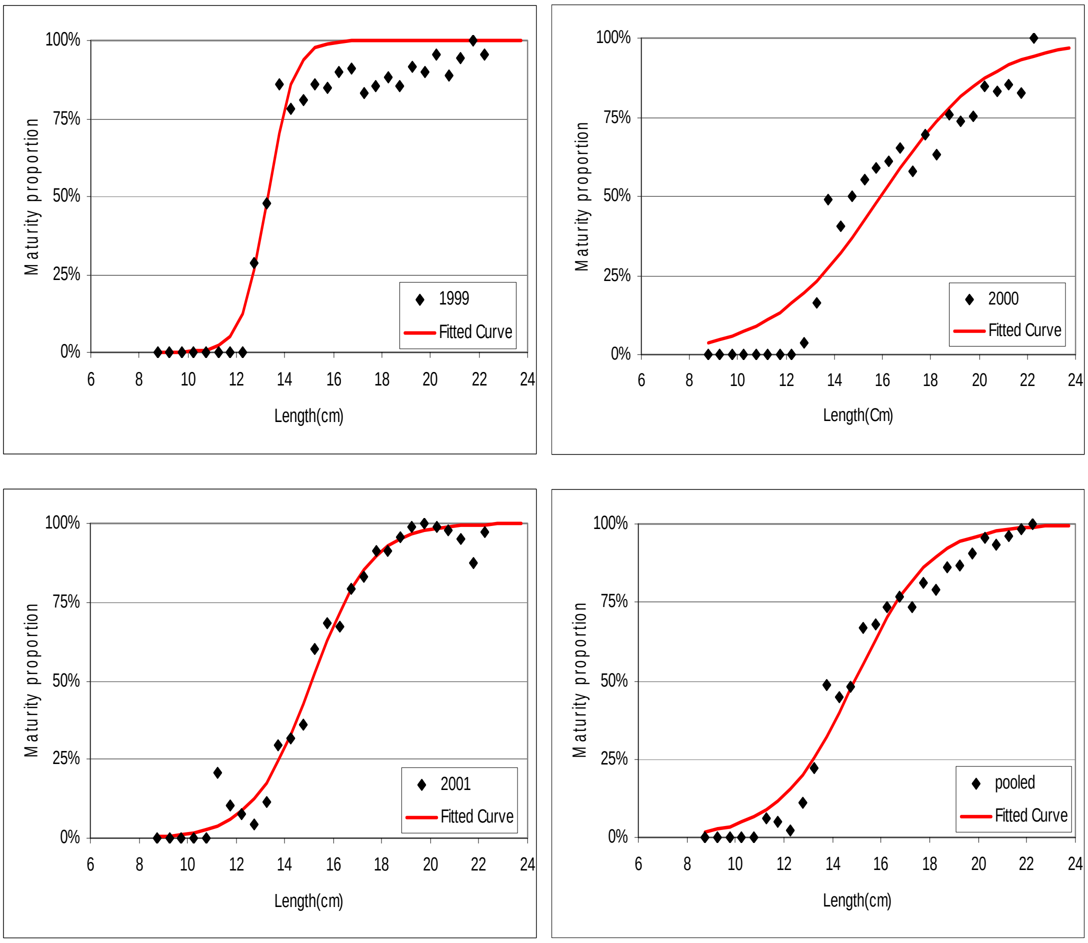
Appendix 2: Male Growth Curves

The Fitted Von Bertalanffy growth curve to observed northern male modes of length frequency of *P. semisulcatus* for the year 1999 to 2000 (Top to Bottom). The estimated VB parameters are $L\infty$ =16.3 cm, K = 3.5 Y^{-1} , For 1999 and $L\infty$ =16.4 cm, K = 3.2 Y^{-1} for 2000. No valid estimation obtained for year 2000 due to incomplete life cycle.



Appendix 3: Female Growth Curves

The Fitted Von Bertalanffy growth curve to observed northern male modes of length frequency of *P. semisulcatus* for the years 1999 to 2000 (Top to Bottom). The estimated VB parameters are: $L\infty$ =21.1cm, K = 3.3 Y^{-1} , For 1999 and $L\infty$ =21.6 cm, K = 3.5 Y^{-1} for 2000. No valid estimation obtained for year 2000 due to incomplete life cycle.



Appendix 4: Length at 50% maturity of female *P. semisulcatus* for the years 1999 to 2001 and pooled data . Estimated L_m for the respective years are 13.3, 15.9, 15.1, 14.9 cm respectively)