FISHERIES TRAINING PROGRAMME

P.O. Box 1390, Skulagata 4

120 Reykjavik, Iceland

Final Project 2007

MONITORING AND EVALUATING THE PRESENT STATUS OF THE SHRIMP TRAWL FISHERY OFF THE WEST COAST OF SRI LANAKA

M.D.S.T. de Croos
Department of Aquaculture and Fisheries,
Wayamba University of Sri Lanka,
Sri Lanka
dileepa_dc@yahoo.com, dileepa@wyb.ac.lk

Supervisor
Hreiðar Þór Valtýsson
University of Akureyri/Marine Research Institute
Iceland
hreidar@unak.is

ABSTRACT

A well established shrimp trawl fishery exists in the coastal waters off Handala and Negombo off the western coast of Sri Lanka. These were investigated from 1997 to 2004 to assess production fluctuating trends, population parameters, mortality rates and stock status. Growth parameters (L_∞ and K), mortality coefficients (Z, M and F), growth performance index (Ǿ) and exploitation ratios were estimated for *Metapenaeus dobsoni* and *Penaeus indicus* using FiSAT software. Probabilities of capture and recruitment patterns were stimulated for both species. Relative yield per recruit (Y´/R) and biomass per recruit (B´/R) curves were plotted to derive reference points and evaluate the exploitation rates of the two species. Dynamic biomass models were used to fit time serious catch and effort data in R package as an alternative approach to evaluating stock status. Total catch, effort, CPUE and by-catch showed seasonal variations. Monthly and annual shrimp abundance fluctuation analysis revealed that CPUE values recorded from May to September were significantly different from other periods ($P<0.05$), which apparently coincide with the southwest monsoonal period of the country. *M. dobsoni*, *P. coromondalica* and *P. indicus* were reported as major shrimp species from both fisheries. Mean annual shrimp production for the study period was estimated as 164 t and 125 t from Negombo and Handala respectively. Correlation between Handala and Negombo monthly shrimp production fluctuations showed that the two fisheries are functioning independently ($r^2=0.102$). Both Y'/R and dynamic biomass model analysis concluded that Handala and Negombo shrimp trawl fisheries are operated below the MSY. Hence, there is potential to increase the utilisation based on further investigation on the resource. The present findings can be used as a baseline for future investigations.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

1.1 Fisheries in Sri Lanka

Sri Lanka is an island in the Indian Ocean southeast of the Indian sub-continent. The coastline of Sri Lanka is about 1770 km long and is characterised by several bays and shallow inlets. Though Sri Lanka has sovereign rights over around 500,000 km^2 of the sea, the major fishing activities are restricted to the relatively narrow continental shelf of 30,000 km^2 and on average in 25 km width (Figure 1) (Joseph 1999).

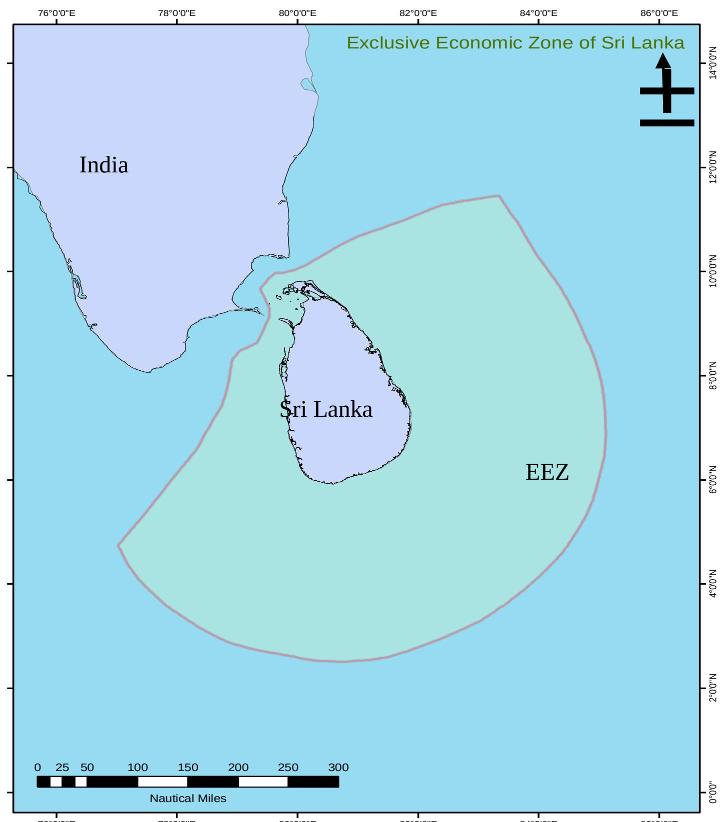


Figure 1: Sri Lanka territory and Exclusive Economic Zone

The fisheries sector is considered as one of the major potential fields for the expansion of the economy. It has an important role in terms of employment opportunities, income generation, foreign exchange earnings, and provision of animal protein for the population (FAO 2003). In 2006, fisheries accounted for 2.8% of the GDP and 2.6% of the GNP (Central Bank of Sri Lanka 2004, 2005) and marine products account for 65% of the animal protein consumed in the country (Sydnes and Normann 2003).

Marine fisheries in Sri Lanka can be broadly categorised into coastal and offshore fisheries. Coastal fisheries account for 67% of the marine fish production and are still considered as the backbone of the Sri Lankan fishing industry (Dissanayake 2006). Within the coastal waters the fisheries vary according to the distance from shore. In the inshore areas (up to 5 km), there are high concentrations of small pelagics such as sardinellas and anchovies and small demersals such as ponyfish and snappers. Invertebrate resources such as shrimps, lobsters, crabs and sea cucumbers are also common in the some parts of the coastal waters (Wijerathne 2001). Most of these fisheries are seasonal and related to the monsoons.

Both culture and capture fisheries for shrimp are important in Sri Lanka. Shrimp resources have been exploited for the last 200 years from lagoons, estuaries and the adjacent coastal waters of Sri Lanka. Several shrimp species are exploited by different fishing gears for local as well as international markets. Shrimp aquaculture in Sri Lanka is a very recent development as it started in the early 1990s. The primary species in aquaculture is *Penaeus monodon*. The aquaculture production was 13490 mt of shrimps in 2006 (NAQDA 2008). However the shrimp culture collapsed in the late 1990s due to the White Spot Disease and is now in a recovery stage.

Shrimp fisheries contribute a substantial amount of foreign exchange to the Sri Lankan economy. The value of the exports of fishery products accounted for US$ 98 million in 2006 (MOF 2007) and 40% is from shrimp and shrimp related products.

Apart from foreign exchange earnings the shrimp industry is responsible for rural job creation especially for females who frequently have less employment opportunities. Many of them are involved in the peeling operations of the shrimp processing industry. Therefore shrimp fisheries and aquaculture have clearly provided benefits both to fishermen and farmers, to processors and traders, as well to distributors and consumers in the country.

1.2 General characteristics of shrimps

Shrimps are important components of estuarine and marine ecosystems. Nearly 2,500 shrimp species are known and, slightly less than 300 are of economic interest (Fischer and Bianchi 1984). Peneied shrimps (superfamily penaeoidea) are economically the most important group and the bulk of the world catch is represented by eight species: *Artemisia, Metapeneopsis, Metapenaeus, Parapenaeopsis, Parapenaeus, Penaeus, Trachypenaeus* and *Xiphopenaeus* (Holthuis 1980).

1.2.1 Geographical distribution of shrimps

Shrimps are widely distributed in marine, brackish and fresh waters from the equator to the polar region (Gulland and Rothschild 1984). The majority of the shrimp species occupy shallow or moderately deep water and some are found at depths of nearly 5,700 m. However most of the commercial shrimps are taken on the continental shelves at depths of less than 100 m. In the western Indian Ocean only two deeper water shrimp species (*Holiporoides triarthrus* and *H. woodmasoni*) are at present commercially exploited. Many shrimps are pelagic but the majority by far is benthic, living on a large variety of bottoms such as rocks, mud, peat, sand, fragments of shells or mixtures of these materials. In addition, some are found in coral reefs and a few species live in sponges and other invertebrates (Khan and Latif 1995).

Distribution of penaeid shrimps ranges from the south and east African coast (Subramanian 1990) to India, Bangladesh and Sri Lanka (De Bruin 1965, 1970, 1971) including Madagascar and the Red Sea. They are absent or very rare in the Gulf of Oman and the Gulf region. Further east it extends to Indonesia, South China (Dore and Frimodt 1987), Malaysia (Agasen and Mundo 1988) and north Australia (Grey *et al.* 1983). The majority of the penaeid species live in waters more than 20^{o}C and very few occur below 15^{o}C (Dall *et al.* 1990).

Penaeus indicus inhabits shelf areas from the coastline to depths of about 90 m but is most abundant in sand or mud with a slight preference for the sandy substrates in waters less than 30 m. Post larvae and early juvenile of *P. indicus* prefer detritus rich muddy substrates in lagoons and estuaries (Fisher and Bianchi 1984). *P. indicus* is a euryhaline species since those in the Red Sea have been shown to tolerate salinity exceeding 45‰ (Fischer and Bianchi 1984). *Metapenaeus dobsoni* is one of the most abundant penaid shrimps in Asia and it is common in mud and sandy habitats around 30 m in depth. They form massive schools together with the *Parapenaeopsis coromandelica* which can be found in the mud and sandy bottoms at the depths of 10 to 25 m (De Bruin *et al.*1994).

1.3 Important aspects of the shrimp life cycle with respect to utilisation

In most shrimps, the sexes are separate but certain species such as some *Pandalus* commonly first undergo a male phase and later are transferred into females.

All penaeid species except *Metapenaeus elegans* release their eggs directly into the sea and the larvae undergo and extensive metamorphosis which requires both oceanic and brackish waters. The members of the genus *Penaeus* spawn in the shallow coastal waters at depths of about 10 to 80 m and female release 50,000 to 1,300,000 eggs depending on the size and species (Garcia 1988). Eggs hatch within a few hours, releasing very small simple larvae and they undergo five nauplii, three protozoea and three mysis stages. The larvae are planktonic and are carried out by currents towards the shore where they become migrate post larvae. The post larvae invade inshore, brackish water, abandon their planktonic way of life and become bottom dwellers living in shallow littoral areas. In these rich nursery grounds they grow rapidly, develop into juveniles and gradually go back towards the mouth of bays or estuaries where they become sub-adults, finally reaching the spawning grounds (Figure 2) (Khan and Latif 1995).

The shrimps are exploited at various stages of their life cycle. The post-larvae have been traditionally exploited by artisanal fisheries as wild ‘seed’ for aquaculture in most of the Southeast Asian countries and in the Bay of Bengal areas with the aid of push nets, bag nets and brush piles (Funegaard 1986).

The sub-adults (post larvae) are fished with stake nets, cast nets and scoop nets during their migration from sea to brackish waters. This is categorised as a high valuable product and used as fresh or dried products locally or exported as a frozen product. This gives a significant source of income to artisanal fishermen. Further, the small shrimps are also exploited for recreational purposes and exported to the developed countries (Edwards 1978).

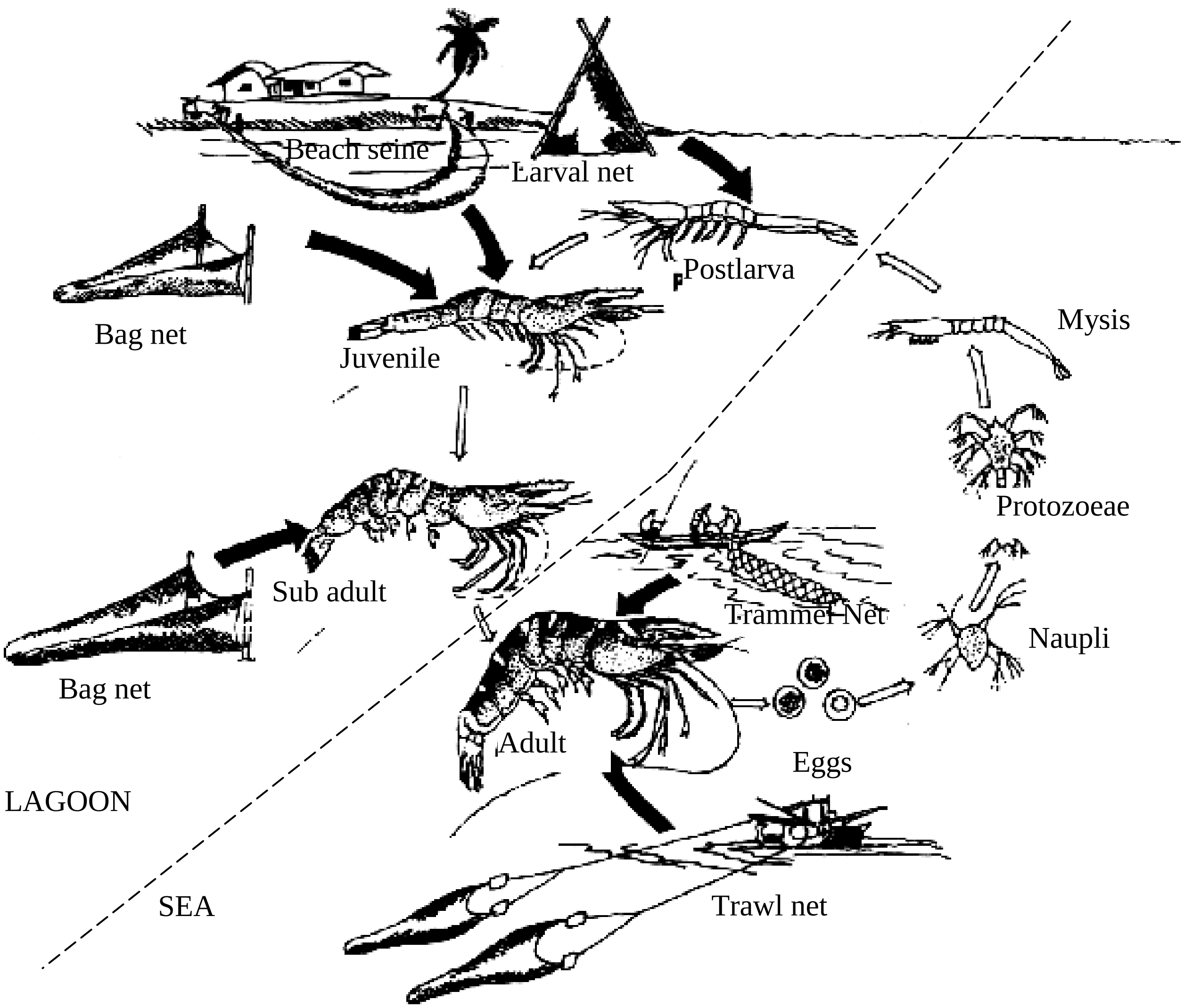


Figure 2: General life cycle of penaeid shrimp which are targeted by different fisheries (Modified from Khan and Latif 1995)

The adults are exploited at sea either in a mixed trawl fishery for fin-fish and shrimps or with specialised industrial "shrimpers" using sophisticated technology such as multiple-rig fishing, automatic sorting by sizes on board and blast freezing.

In coastal areas shrimps are exploited both by industrial and artisanal fisheries using small trawlers and drifting trammel nets and this is a very popular fishery in developing countries in Asia and Africa.

The complexity of the life cycle and the sequential fisheries at various stages of the life cycle is potentially important. Fishing at one stage may reduce recruitment to the next fishery. Ultimately this may affect spawning potential and recruitment and finally marine stocks. So it is essential to evaluate all these competing modes of exploitation carefully before implementing any management measures for the shrimp fishery.

1.4 Present status of shrimp fisheries

1.4.1 World fisheries

The shrimp fishery plays a major role in the fishing industry in different parts of the world. The annual exports of shrimps and shrimp products exceeded US$ 10 billion in 2003 and represent almost 20% of the world total export of fish and fishery products (Leung and Engle 2006). Wild caught shrimps as well as cultured shrimps are supplied to the international market both in the northern and southern hemispheres.

Cold water shrimps come from capture fisheries in the northern hemisphere and they are generally small in size. Northern/pink shrimp (*Pandalus borealis*), and common shrimp (*Crangon crangon*) are the most important cold water shrimp species and their production was 446,000 t and 39,000 t respectively in 2004. The principle capture countries of cold-water shrimp are Greenland, Canada, Iceland, Norway and the United States. In fact, cold water shrimp fisheries in the North Pacific and North Atlantic appear to be close to their productive ceiling (Anderson and King 2003).

Warm water shrimps come from capture fisheries as well as aquaculture and this is dominant in tropical and sub-tropical countries of the world. *P. indicus, Penaeus monodon, Penaeus semisulcatus, M. dobsoni, Parapenaeopsis coromandelica* are dominant in the capture fishery.

Output of shrimp aquaculture has more than doubled over the last few decades (Table 1) and black tiger/giant tiger shrimp (*Penaeus monodon*) and white shrimp (*Penaeus vannamei*) are the predominant species used for the culture industry. The world shrimp aquaculture production was 2.5 million tons in 2004, out of which 722,000 tons were from *P. monodon* and 1,386,000 tons from *P. vannamei* (Leung and Engle 2006).

Table 1: Total world supply of shrimp by source (in 1000 tons), 1988 and 1996-2004

Year	1988	1996	1997	1998	1999	2000	2001	2002	2003	2004
Wild	1988	2564	2638	2738	3031	3099	2,957	2,972	3,529	3,602
Farmed	576	917	932	999	1068	1161	1,346	1,495	2,145	2,476
Total	2565	3481	3570	3737	4099	4260	4,303	4,468	5,675	6,078

Source: Leung and Engle (2006).

Shrimps are consumed in all parts of the world with the largest markets in the United States, Japan and the European Union (EU).

1.4.2 Asian fisheries

Both culture and capture shrimp fisheries are dominant in most of the Asian countries. The world largest shrimp producers are in Asia and their production accounts for 71% of the world supply. China is the dominant shrimp producing country followed by India and Indonesia

Table 2: Total world supply of shrimp by country (capture and aquaculture) in 2004.

Country	Thousand tons	%
China	2147	40
India	554	9
Indonesia	490	8
Thailand	471	8
Vietnam	382	6
United states	144	2
Canada	177	2
Mexico	120	2
Malaysia	109	2
Others	1210	20
Total	6078	100

Source: Leung and Engle (2006)

1.4.3 Problems associated with shrimp fisheries

One of the major criticisms associated with the shrimp fishery is the absolute volume of the by-catch associated with trawling (Broadhurst *et al*. 2006, Kennelly 2007). Annual shrimp by-catch of the world has recently been estimated at 1.8 million tonnes (Kennelly 2007). Industrial shrimp trawling in tropical waters is a leading offender in the capture of by-catch and accounts for about 27% of all global discards (Eayrs 2007). Apart from by-catch, habitat destructions and alterations caused by shrimp trawls have also been critically discussed (Turner *et al.* 1999). Discard and impacts due to small-scale artisanal shrimp trawling has rarely been discussed in literature, also use of sorting devices such as TEDs (Turtle Excluder Devices) and BRDs (By-catch Reduction Devices) are not a practical alternative in artisanal fishing. A by-catch estimate of the shrimp trawl fishery in Sri Lanka is scanty.

Even the sustainability of both wild shrimp and shrimp aquaculture production can be adversely affected due to malpractices of aquaculture operators. In many cases farm operators are accused of environmental degradation of mangroves and of displacement of farmers. Actually this was the case particularly in the 1980s and early 1990s when the industry was expanding and gaining experience but it is doubtful how far this would apply on a general basis. Most shrimp operations today can be categorised as operating according to environmentally sound principles and within laws and regulations set by national authorities (Leung and Engle 2006).

1.5 Shrimp fishery in Sri Lanka

1.5.1 History

The origin of the shrimp capture fishery in Sri Lanka dates back 200 years while the origin of costal trawling dates back around 100 years (Weerasooriya 1977). Malps made one of the earliest records of the shrimp trawl fishery in 1926 (Jayawardena *et al.* 2004) and Berg (1971) documented exploratory trawling conducted in the east coast of Sri Lanka together with commercial fishing from Pedro Bank. There were several offshore trawling grounds in Wadge Bank, Pedro Bank, Palk Bank and the Gulf of Mannar in the past (Chestnoy 1970) (Figure 3). After the declaration of the 200 mile exclusive economic zone (EEZ) in 1976, these fishing grounds were lost from the Sri Lankan coast (Joseph 1984). Simple square or triangular bags called "Kathumaran del" and "Lensu dela" made out of natural fibres had been used in traditional trawling operations during that period (Weerasooriya 1977).

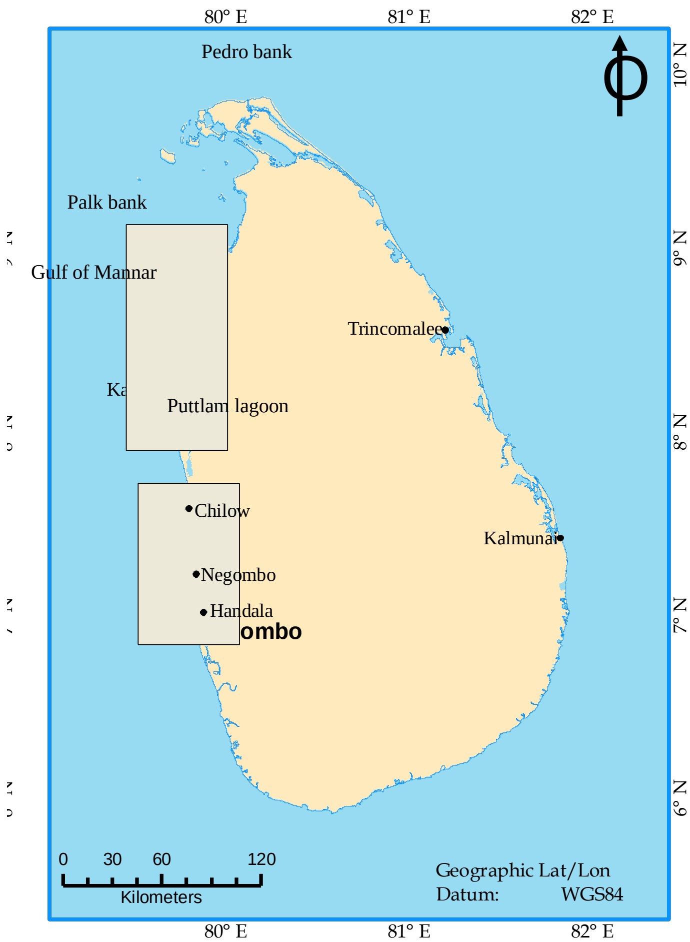


Figure 3: Major shrimp fishing grounds in coastal waters of Sri Lanka

1.5.2 Major fishing areas/fishing grounds

The major shrimp trawling grounds in Sri Lanka have been in the shallow coastal waters off the north-western coast (Kalpitiya) and western coast (Chilaw, Negombo, Handala). In the early 1990s shrimp trawling was banned in Chilaw to resolve a conflict among two fishing communities who shared the same fishery resource. Therefore, shrimp trawling in western coastal waters of Sri Lanka is now exclusively done by Negombo and Handala fishing communities and there is still very productive trawling ground in the northern mouth of Puttlam Lagoon in the Kalpitiya Peninsula of the north-western coast.

Negombo is one of the most famous fishing villages having a long fishing history. It is situated almost 35 km north of Colombo. There is a highly productive coastal ecosystem there as well as a lagoon. The Negombo Lagoon is around 32 km^2 and it is categorised as the one of the most productive lagoons on the west coast of Sri Lanka. The lagoon and the adjacent reef areas function as the major nursery and sheltering grounds for many crustacean groups during the juvenile phase of their life cycle. There is an expanding year around shrimp fishery both in the lagoon and associated coastal system using different varieties of fishing gears.

Handala is situated about 12 km north from Colombo and there is a seasonal shrimp fishing activity in the shallow coastal waters.

Very popular shrimp fishing grounds are in the Puttlam Lagoon and associated coastal waters in Kalpitiya Peninsula of the north-western coast of Sri Lanka. The Puttlam Lagoon with a surface area of around 327 km^2 is one of the largest and most productive "basin estuaries" and there is seasonal fishery for shrimp within the lagoon. Shrimp trawling has been carried out the last two decades in the Portugal Bay area which is in the north of the mouth of the Puttlam Lagoon. This is a separately operating year around fishery (Dayaratne *et al.* 1997).

1.5.3 Major shrimp species

There are 31 commercially important shrimp species recorded from Sri Lanka and penaeid shrimps such as *Penaeus monodon, Penaeus merguiensis, P. indicus, Penaeus semisulcatus*, *M. dobsoni* and *Parapenaeopsis coromandelica* are dominant in the catches (Fischer and Bianchi 1984). *Penaeus dobsoni* was one of the most abundant shrimp species in Sri Lankan waters until the early 1980s and contribution of juveniles to the estuarine fishery was significant (De Bruin 1965, 1970, 1971, Fischer and Bianchi 1984). *P. indicus* has recently contributed almost 60% of the total annual shrimp landing of the west coast (Jayawardena *et al.* 2004). Devenport *et al.* (1999) reported that *P. indicus* dominated the shrimp catches from the artisanal shrimp fishery in Rekawa Lagoon in Sri Lanka making 94% of total shrimp catch in the lagoon.

1.5.4 Major fishing gears and vessels

A variety of fishing methods have been used in the Sri Lankan shrimp fisheries in the last 200 years of its history. The use of triangular shape drag net bags (Weerasooriya 1977), trammel nets, cast nets, push nets, brush piles and various types of traps such as kreels (De Bruin 1970), cover pots, snares (Gabriel *et al.* 2005) in the lagoon have been discussed. However, cover pots and snares have gradually disappeared from the lagoon fishery as a result of the introduction of trammel nets in the mid 1980s.

Stake seine nets have been operated in the lagoon mouth since the 18th century. Nets are fixed during the night with the onset of the high tide and carried out until the time of low tide. Shrimps which immigrate to the lagoon in high tide and the opposite direction during the low tide are targeted in this fishing method. This is still practised in Negombo Lagoon (De Bruine 1970, Siddeek 1978, Amarasinghe *et al*. 1996-1997, Jayawardena and Perera 2003).

Trawls have been the most dominant gear used in the coastal waters over the last few decades; the adults are exploited through this method. Few studies have been conducted in the recent past to evaluate the shrimp trawl fisheries of Sri Lanka (Jayawickrama 1992, Siddeek 1978, Jayawadena *et al.* 2003) and the information on shrimp trawling in Handala is scanty. Still there are well established shrimp trawl fisheries in Negombo, Handala in the west coast and Kalpitiya in the north-western coast of Sri Lanka.

Non-mechanised fishing vessels as well as mechanised vessels have been used in both lagoon and coastal waters since the existence of the shrimp fishery in Sri Lanka. Non-mechanised vessels such as theppam, canoes and wallam were dominant in the lagoon shrimp fishery in recent past and the introduction of mechanised vessels such as Fiberglass Reinforced Boats (FRP) with 15, 25 HP outboard motors (mechanised vessels) took place in late 1990s.

Sail driven large dugout canoes have been used as the major vessels to operate trawl nets in coastal waters of off Negombo and it is known as non-mechanised trawling. Mechanised crafts which are known as “3.5 ton type” are used as the major fishing vessels to operate trawl nets in Handala and “11 ton type” are used in Kalpitiya. These fishing operations are known as mechanised trawling. The 3.5 ton vessel is 10.4 m in length and powered by inboard diesel engines of 25 – 40 Hp while 11 ton vessels are 12.2 m in length and powered by 40 - 60 Hp inboard engines (Appendix i).

1.5.5 Management measures

No government intervention or precautionary regulations have been implemented so far in the shrimp fisheries. So they can be categorised as unregulated fisheries. However, there is a well-established community based management strategy in the stake-seine shrimp fishers in Negombo (Amarasinghe *et al*. 1996-1997). Hence implementation of any future management strategy should be linked with the excising managerial system of the community.

1.6 Estimation of growth, mortality and related aspects of crustaceans

In contrast to fish the growth of shrimps is very difficult to estimate reliably because there are no calcareous structures on their body as there is periodic shedding of exoskeleton (Pauly 1984). There is a substantial amount of literature on techniques and methodologies used for estimation of growth, mortality and related aspects of crustaceans. Use of length frequency analysis for determination of growth parameters has been used successfully in temperate species of malacostraca. But there are some limitations when it applies for tropical penaeid shrimps, due to extended and fluctuating recruitment and mixing of brood stock. Further, it is often difficult to follow a selected brood through its life cycle (Pauly and Munro 1984). Several alternative methods have been discussed in these estimates and these are:

- The use of calibrated growth curves obtained from shrimps grown in captivity (Forster 1970)
- Growth increment studies of tagged and recaptured shrimps (Berry 1967)
- Growth increments based on sizes at sizes at successive moults (Forster 1970)

But none of these methods approaches the degree of reliability obtained in aging fish by means of their otoliths, scales or bones (Brothers 1980). According to Gulland (1984), basic assessment of shrimp stocks could be done with a length – structured version of analytical models.

The instantaneous rate of natural mortality (M) is an important but poorly quantified parameter in most mathematical models. Vetter (1988) reviewed the methods used to estimate M for fish stocks. According to him sensitivity of the common fishery models greatly depends upon M. Natural mortality is likely to be varied in accordance with the seasonality and the size of individuals. The seasonal changes may affect the feeding habits and the size preferences of the populations of predators. Very little information is available on this aspect at present and the natural mortality is always considered as constant (Pauly 1984).

1.6.1 Application of population dynamics models for resource evaluation

When the age composition of commercial and survey catches are known, a wealth of methods is available for routing assessments. Age based data are used to estimate the rate of decline in each year class and this provides information on whether the stock is utilised at a sensible level or whether it is utilised in a manner which is not sustainable. In the absence of information on age, the assessments become much harder. But there are some models for stocks such as shrimps, where age reading is hard or impossible. It requires simple data sources such as total catch, length distributions and catch per unit efforts either from a survey or commercial catches to tune the models (TemaNord 1999).

The surplus yield (production) models are still the most widely applied to evaluate resource status but there are still limitations. Reviews presented by Garcia and Le Reste

(1981) and Kirkwood *et al.* (2001), have pointed out some problems and assumptions concerning the determinism of the model which include the equilibrium conditions and the lack of consideration for the age structure, the ‘constant’ catchability, the environmental noise (Garcia 1984). However requirements of a small data set (catch and effort) and mathematical simplicity have been pointed out as the beneficial aspects of the model when it is applied for shrimp fisheries most of the time. The simulation models used for shrimp fisheries are basically analytical models. Their degree of sophistication is variable but may consider the development of cohorts, each with its own seasonally varying population parameters (Grant and Griffin 1979, Willmann and Garcia 1985). Furthermore, their economic components can deal with seasonal patterns in fishing effort, landings and markets.

1.7 Aims and objectives of the present study

Shrimp trawling in the western coast of Sri Lanka is done in the seas off Handala (only with mechanised vessels) and Negombo (only with non-mechanised vessels) by small scale artisanal fishers. Around 20,000 people are directly or indirectly dependent on fisheries in Negombo Lagoon and adjacent coastal water bodies for their living. Unfortunately these regions are rapidly being modified by natural events and man’s exploitation of the coastal region. Rising sea levels, land subsidence, the alteration of fresh-water inflow, dredge and fill activities, and increased channelisation and salt-water intrusion all affect estuarine habitats (Titus 1986). Even the natural catastrophe, the “2004 Tsunami” had an impact on these critical habitats. Further it is believed that the fishing effort in the area has been increased due to donated fleets and boats after the Tsunami which has created adverse impact on different stocks by increased fishing pressure. To minimise the impact of habitat alterations on the shrimp stocks and better manage the resource requires an understanding of growth and survival of the stocks. So now is the right time to initiate a comprehensive study to re-evaluate the stock status of shrimp resources of the western coastal waters of Sri Lanka.

The primary aim of this study is to investigate the present status of the shrimp trawl fishery in the western coast of Sri Lanka giving special emphasis on assessing the maximum sustainable yields and optimum effort levels. Furthermore:

1. To estimate the monthly and annual variations in production (‘total catch’, ‘shrimp catch’ and ‘by-catch’) and fishing effort.

2. To evaluate the relative ratios and variation of two major shrimp species (*P. indicus* and *M. dobsoni*) and shrimp trawl by-catch in mechanised and non-mechanised shrimp trawl fisheries.

3. To estimate the asymptotic length (L_∞), growth constant (K), mortality rates, exploitation rates, recruitment patterns of *P. indicus* and *M. dobsoni* which are caught by mechanised and non-mechanised trawl fisheries.

4. To suggest suitable managerial recommendations for sustainable utilisation of the shrimp resources off the west coast of Sri Lanka.

2 METHODOLOGY

2.1 Data collection

2.1.1 Catch and effort data

The data collection for the shrimp fishery in Sri Lanka dates back to the early 1990s. The Ministry of Fisheries and Aquatic Resources is the major institutes involved in the data collection. Catch and effort data used in this study were obtained from their database.

Apart from the two major landing sites: Negombo (non-mechanised) and Handala (mechanised), two minor landing sites are located on the west coast of Sri Lanka called Poruthota and Lansiyawaththa. These two were also selected together with Handala and Negombo for the regular collection of fisheries statistics (Figure 4).

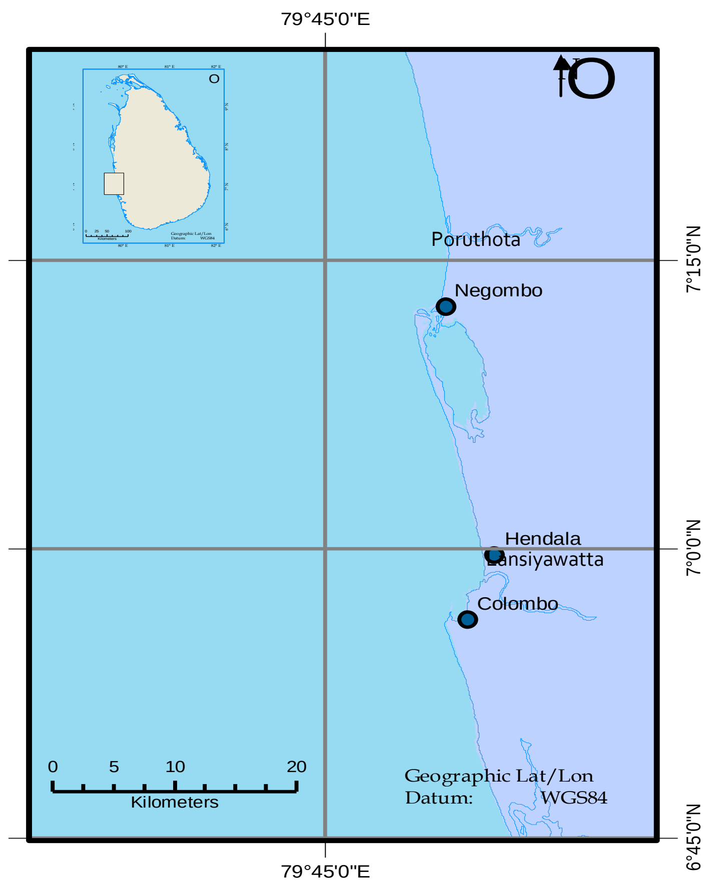


Figure 4: Sampling site (Negombo and Handala on the west coast)

Sampling has been carried out in regular field visits to Negombo and Handala, while effort data had been collected from both major and minor landing sites on a regular basis from 1997 to 2004. On each sampling day more than 30% of the total number of fishing crafts operated at each sampling site were sampled randomly. Other information such as craft and gear specification, details of fishing operation, total catch and species composition of the fishery were also recorded. The total number of fishing crafts operated at each site has been recorded in order to estimate the total effort for the particular month. The number of fishing days in each month has also been recorded separately.

2.1.2 Length frequency data

The length frequency data of *P. indicus* and *M. dobsoni* were collected at weekly intervals from January 2005 to December 2006. Length data were only obtained for *P. indicus* from Handala in 2005. Two to three representative shrimp samples (each around 10% to 20% of the total shrimp catch) were collected on each sampling day, packed in ice and transported to the laboratory. *P. indicus* and *M. dobsoni* were sorted by sex and weighted. The total body length (from the tip of the rostrum to tip of the telson) of each species was measured to the nearest 0.1 cm.

FAO species identification sheets were used to identify the main shrimp species and by-catch species (mainly finfish) in the samples. The species composition was analysed each month separately to evaluate the variation in abundance. Values are given as a percentage of the total catch.

2.2 Data analysis

2.2.1 Analysis of catch and effort statistics

The fishing effort was expressed as the mean number of fishing crafts operated per day with respect to two major craft types (mechanised and non-mechanised). The catch per unit effort (CPUE) is the mean catch in kg per craft-day with respect to each craft type based on the assumptions that:

- The same number of hauls (frequently 4 – 6) were conducted during the study period
- The true fishing time is constant throughout the study period
- A constant number of fishermen were involved in fishing operations
- Only one operation was conducted per day

2.2.2 Monthly total production

Monthly total production for each craft type was estimated as the product of mean catch in kg per craft–day (CPUE), mean number of fishing crafts operated per day (N) and mean number of fishing days for that particular month (D)

$$\text{Monthly Total Production (MTP)} = CPUE * N * D$$

Three shrimp species (*P. indicus, M. dobsoni* and *P. coromandelica*) which contribute most for the total production and the economical value were treated separately by raising the percentage compositions obtained for the samples by monthly production estimates. All the other ‘minor’ shrimp species (*Penaeus merguiensis*, *Penaeus semisulcatus* and *Penaeus monodon*) were grouped together as “others” in estimating the annual shrimp composition. Further, estimated monthly shrimp production was plotted together with respective by-catch in order to highlight the variation in monthly and annual total trawl production. Non-targeted finfish and crabs were considered as by-catch.

2.2.3 Annual total production

Monthly total production was summed to obtain the annual total catch, shrimp catch and by-catch. Annual total catch was also calculated separately for the three major shrimp species: *P. indicus, M. dobsoni* and *P. coromondalica*.

2.2.4 Effect of monsoonal periods on shrimp fishery production

Catch and effort data were used to investigate the effect of monsoonal patterns on the landings. For this purpose, catch per unit effort (CPUE) values expressed as kg/haul were ln (X+1) form formed in order to reduce non-normality. Gulland (1983) has indicated that catch per unit effort in most fisheries are known to be log normally distributed. The CPUE data were grouped into three monsoonal phases, i.e., southwest monsoon (May-September), northeast monsoon (December - February). The CPUE values of months before the southwest monsoon and northeast monsoon were pooled and treated as the CPUE in the inter-monsoon phase with respect to the sampled years (from 1997-2004). The ln (CPUE + 1) data of the three monsoonal phases were subjected to one way Analysis of Variance (ANOVA) to investigate whether the mean CPUE values in different monsoonal phases and yearly periods are significantly different ($\alpha = 0.05$).

2.2.5 Analysis of monthly length frequency data to estimate important population parameters (L_∞, K, M, Z, F and E)

2.2.5.1 Growth

FAO-ICLARM Stock Assessment Tools (FiSAT II, FAO packages 2002, Gayanilo and Pauly 1997) were used to process the length data of *P. indicus* and *M. dobsoni*. As these species are short lived the length data was grouped into monthly intervals. The initial value for asymptotic length (L_α) was estimated using the Powell – Wetherall method in FiSAT. To obtain preliminary estimates for the growth constant (K) and the asymptotic length (L_∞) the best growth curve was fitted with ELEFAN in the same program package. This is done by allowing the curve to pass through the maximum number of peaks of the length frequency distribution.

It was assumed that the growth of shrimps (*P. indicus* and *M. dobsoni*) conforms to the von Bertalanffy growth model (Parrack 1979, Garcia and Le Reste 1981).

Growth parameters L_∞ and K were used in fitting the von Bertalanffy growth equation:

$$L_{(t)} = L_\infty [1- \exp(-k (t-t_0))]$$

Where; $L_{(t)}$ - the length of the fish at time *t*

t_0 - the "age" of the fish when *L* is equal to zero

L_∞ - the asymptotic length

K - the rate at which the $L_{(t)}$ approaches L_∞ (Munro and Pauly 1983).

The approximate estimates for the theoretical age at length zero (t_0), were obtained by using the following equation described by Pauly (1979):

$$\mathrm{Log}_{10} (-t_0) = -0.392 – 0.275\ \mathrm{Log}_{10} L_\infty – 1.038\ K$$

Growth performance index (ø') was estimated for *M. dobsoni* and *P. indicus* in order to compare the standard growth rate of the species (Munro and Pauly 1983).

$$Ø' = \mathrm{Log}_{10} K + 2\ \mathrm{Log}_{10} L_\infty$$

2.2.5.2 Mortality and exploitation rates

The total mortality coefficient, Z ($year^{-1}$), was estimated using the length-converted catch curve method incorporated in FiSAT, using the final estimates of L_∞ and K and the length distribution data of the species (Gayanilo and Pauly 1997). When recruitment and mortality were assumed to be constant, the length converted catch curves were represented by:

$$\ln [N_{i/}dt_i] = a + Z_i$$

Where:

N-the number of fish in length class *i*

dt^i -the time needed for the fish to grow through length class *i*

t^i -age of the mid-length of length class *i* corresponding to the mid length of class *i*

Z -total mortality with sign changed

The natural mortality M ($year^{-1}$), for each species was estimated using Pauly's (1980) empirical equation relating M, t_0, L_∞, K and mean environmental temperature (T) where T = 28^oC as this is the value recorded for water temperature in the sampling area by Anon (1978).

$$\mathrm{Log}_{10} M = - 0.0066 - 0.279\ \mathrm{Log}_{10} L_\infty + 0.6543\ \mathrm{Log}_{10} K + 0.4634\ \mathrm{Log}_{10} T$$

The exploitation rate, E, was calculated by dividing F by Z (F/Z). The parameter E describes the proportion of a given cohort/population that ultimately dies due to fishing given existing exploitation pressure (Beverton and Holt 1966). The length-based methods within ELEFAN are similar to "non-parametric" statistical methods and therefore do not provide measures of confidence intervals or uncertainties (Silvestre *et al*. 2004).

2.2.5.3 The probabilities of capture

The probabilities of capture were estimated by extrapolating the points of the ascending part of the length converted catch curve, a method incorporated into the FiSAT software programme. These extrapolated points were then used for the estimation of selection parameters. In here probability of capture was plotted using the running average technique to estimate selection parameters of the gears.

2.2.5.4 Recruitment pattern

Seasonal changes in recruitment patterns (in terms of the percentage of recruitment by months) were calculated in graphical form using ELEFAN.

Estimated growth parameters of L_∞ and K and t^0 were used as inputs in calculating. The seasonal recruitment pattern of the fish was reconstructed using the time series length-frequency data set and sliced into normal distributed recruitment pulses. This was done by projecting backward along a trajectory described by the computed von Bertalanffy growth formula, all restructured length-frequency data onto a 1-year time scale (Pauly 1987). These tabulated individual male and female recruitment percentage values were plotted on one graph using R for the easiness of comparison.

2.2.5.5 Relative yield per recruit (Y´/R) and biomass per recruit (B´/R)

Estimation of von Bertalanffy growth parameters is important to perform the stock assessment using the yield-per-recruit (Y´/R) and biomass per-recruit models (Beverton and Holt 1966).

Y´/R and B´/R analysis was conduct to obtain reference points and evaluate the exploitation status of *P. indicus* and *M. dobsoni* targeted by the Handala and Negombo fisheries separately. The Y´/R model is the principal steady state model that describes the state of stocks and the yield when the fishing pattern has been the same for a long time so that all fish are vulnerable to capture after recruitment (Sparre *et al*. 1989). The model of Beverton and Holt (1966), as modified by Pauly and Soriano (1986), was used to predict the relative yield per recruit (Y´/R) of the species to the fisheries:

$$Y'/R = EU^{M/K} \; [\, 1- \{3U/(1+m)\} + \{3U^2/(1+2m)\} + \{3U^3/(1+3m)\} \,]$$

Where E = F/Z is the current exploitation rate, i.e. the fraction of mortality caused by fishing activity, *F* is the instantaneous fishing mortality coefficient

U = 1- (Lc/L∞) is the fraction of growth to be completed by the fish after entry into the exploitation phase

m = (1 - E)/ (M/K) = K/Z

The relative biomass per recruit (B'/R) was estimated as:

$B/R = \{(Y'/R)/F\}$

Then, E_{max} - exploitation rate producing maximum yield)

$E_{0.1}$ - exploitation rate at which the marginal increase of Y′/R is 1/10 of its virgin stock

$E_{0.5}$ - the exploitation rate under which the stock is reduced to half its virgin biomass

Computations of Y′/R and B′/R were made using the equations given by Pauly and Soriano (1986), as implemented in FISAT II (Gayanilo and Pauly 1997), knife-edge selection was assumed in the Y′/R and B'/R calculations.

The reference points estimated were:

E_{max} - the value of the exploitation ratio (E) associated with the highest Y/R value that is possible with a given value of length at first capture (L^c).

$E_{0.1}$ - value of the exploitation ratio at which the slope of the Y/R is one tenth of its value at the origin

$E_{0.5}$ - value of the exploitation ratio associated with a 50% reduction of the spawning biomass (per recruit) in the unexploited stock.

2.2.6 Dynamic production model

Dynamic production models are based on the idea that the biomass in a given year (B_{y+1}) depends on the biomass of the previous year (B_y) plus growth and recruitment, minus catch and natural mortality. The usual dynamic production models are described by the equation (King 2007):

$$B^{y+1} = B^y + rB^y(1 - B^y / K) - Y^y$$

Where
$Y = qfB_y$
Y_y = Catch
B_y = biomass at year y
K = carrying capacity of the system or maximum population size
r = intrinsic rate of production or rate of increase of the population
q = catchability coefficient
f = Effort

The term $rB_y(1 - B_y / K)$ is called the production function (surplus production). If the production function is greater than the catch, the population size increases and if catch equals or is close to the surplus production when a fishery is operating at the MSY the population size is expect to be remain constant.

For this analysis the model was fitted with yield and CPUE time series data collected from 1997 to 2004, separately from Negombo and Handala using R package. The model is fitted by using maximum likelihood or non-linear least squares minimisation. Estimates of the initial biomass and model parameters are generated, catch data are incorporated into the production model to predict the whole biomass series, a measure of difference between observed and predicted values is identified and then the differences are minimised to fit the models (Hilborn and Walters 1992, Haddon 2001, Schnute and Richards 2002).

If $\hat{I}_y$ is an index of abundance in year y and B_y is the model based biomass in year y, then we can use $\hat{I}_y = qB_y$ as a predicted index through a catchability q. The index of stock abundance can be constructed by effort data corresponding to the time series of catches hence, $CPUE_y=qB_y$. Using the production model, each point in the entire time series of data was predicted. This model has four parameters B_y, r, q and K which were estimated by minimising the SSE (S) between the observed CPUE and the predicted CPUE by the model, where:

$$S = (CPUE_{pred} - CPUE_{obs})^2$$

And where:

$$CPUE_{pred} = qB_{pred}$$

So, if observed CPUE = Y_y/f, then predicted $CPUE_{pred} = qB_t$.

These primary unknown parameters (B_y, K, r and q), the first three were taken as starting guesses, with q fixed. Then r and q were estimated. After successive estimations K, B_y, r and q were estimated at the same time. These will be used to estimate MSY, f_{MSY}, B_{MSY} and F_{MSY}.

$$MSY = rK / 4$$
$$B_{MSY} = K / 2$$
$$F_{MSY} = r / 2$$
$$f_{MSY} = r / 2q$$

The estimation procedure was separated into a few steps: initialisation of parameters, projection based on those parameters, evaluation of the fit to observed data, and search for the parameters gives the best fit to the data (TemaNord 1999).

Fishing effort, total landing and length frequency data are the only parameters recorded from the governmental data collecting body. Main bottlenecks associated with the raw data which prevent in-depth analysis will be highlighted and recommendations suggested for an in-depth analysis with more appropriate additional parameters and sampling design.

3 RESULTS

3.1 Shrimp trawl fishery off the north-western coast of Sri Lanka

3.1.1 Fishing season

Almost all non-mechanised trawling boats are operated throughout the year in Negombo while in Handala only around one third of trawls are operated year-round. The fishing operation of most trawling boats at Handala are confined to 4-5 months centred June/July while two thirds of the boats are idle or operated for an alternative fishery in the rest of the year.

3.1.2 Fishing crafts, gear and operation

The use of non-mechanised trawls occurs outside the Negombo Lagoon, to a distance of around 10–15 km north of the entrance and trawl to the depth of 12 m during daytimes. Trawling is exclusively done by sail power with outrigger wooden canoes. The crew row when wind power is insufficient.

The trawl net used in the non-mechanised trawling has a relatively shorter cod end and a body than the mechanised trawling net (Table 3). No floats are used for the head rope but lead sinkers placed at intervals along the foot rope and heavy stones of 25 – 35 kg attached at each end. The trawl net is connected to the towing ropes at each side by bridles of about 4.5 m. After around one hour of towing the net is hauled manually. After hauling the net is returned to the water for another trawl towards the opposite direction reversing the craft.

Off the coastal waters of Handala the mechanised trawls are operated on fishing grounds located about 15 – 20 km south of the entrance of Negombo Lagoon in average trawling depths of 15 – 18 m. The overlapping of mechanised and non-mechanised trawling grounds is prevented by regulations. The mechanised trawling crafts are 3.5 tonnes in weight. Thick bamboo poles are extended as booms on either side of the craft from which the net is towed. The fishing operations and net design are similar to those used in the non-mechanised trawls.

The total number of crafts operated from Negombo and Handala are more or less constant and the craft, gear and operational information are summarised in Table 3.

Table 3: Fishing craft, gear and operational information collected from Negombo (non-mechanised) and Handala (mechanised) during the period 2005-2006.

		Dugout canoes (non-mechanised)	**3.5 tonnes wooden boats (mechanised)**
Craft	Number of crafts	168	153
	Length	12 m	10.4 m
	Width	0.5	2.7
	Power	Sail driven	25 – 40 Hp engine
Gear	Cod end length	1 m	2.5 m
	Net body length	7 m	12-15 m
	Cod end mesh size	15 mm	15 mm
	Body mesh size	20 mm	20 mm
	Horizontal opening	5.6 m	15 m
Operation	Number of hauls per day	4 - 6	4 - 6
	Net hauling	manual	manual
	Number of crew members	3 - 4	3 - 4
	Season	Year round	Mostly May-Sept

3.2 Catch and effort variation in the shrimp trawl fishery

3.2.1 Variation of CPUE

Monthly fluctuations of CPUE (kg/ boat-day) of ‘shrimp catch’, ‘by-catch’ and ‘total trawl catch’ (shrimp + by-catch) from Negombo and Handala shrimp trawl fisheries from 1997-2004 are shown in Figures 5 and 6 respectively. There have not been any drastic improvements in fishing effort during the last 10-20 yrs.

In both Negombo and Handala considerable variation in total CPUE values were influenced by the CPUE of shrimps to a greater extent and CPUE of by-catch were more or less steady from both fishing grounds from 1997-2004. In Negombo, CPUE of shrimps increased beyond the by-catch from May-June and reached a peak in August, followed by a gradual decline until September. Further, high CPUEs were again evident in the months around November throughout the study period from 1997-2004. Comparatively less monthly fluctuations in CPUE were observed from Handala and the CPUE values of shrimp were observed to increase gradually beyond the CPUE of by-catch from May. The highest shrimp CPUEs were reported around July followed by a gradual decline until September (Figure 6).

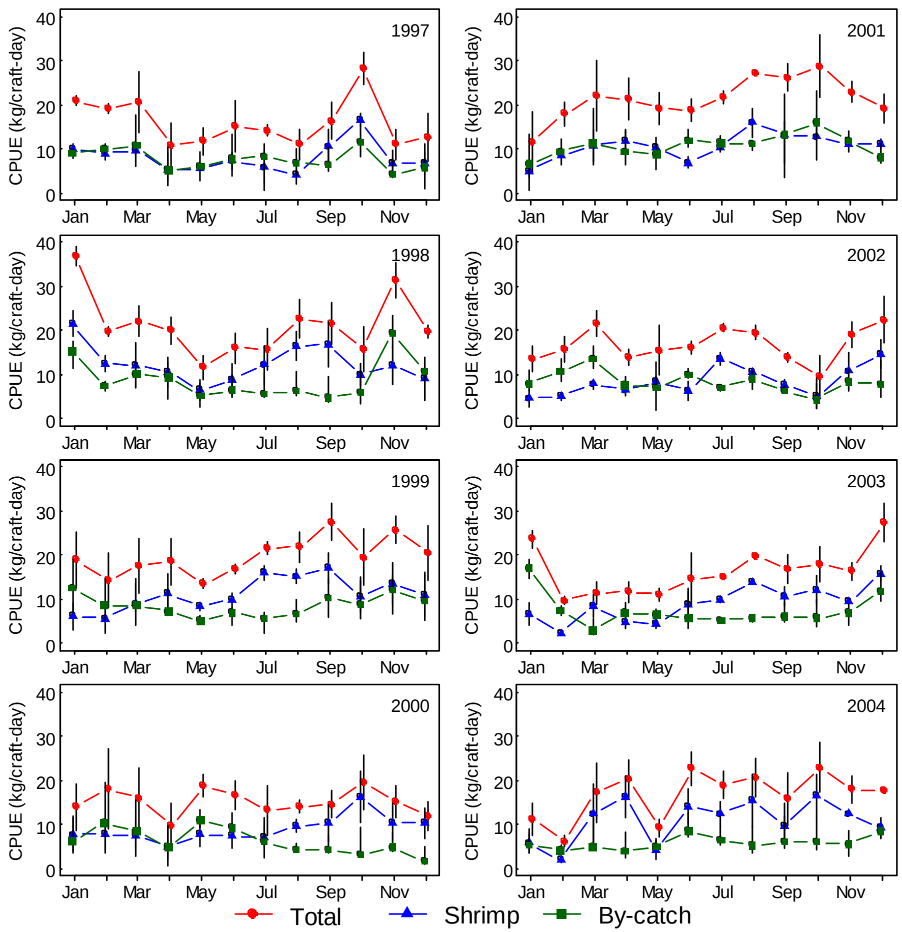


Figure 5: Average daily CPUE (kg per craft-day) from the Negombo trawl fishery.

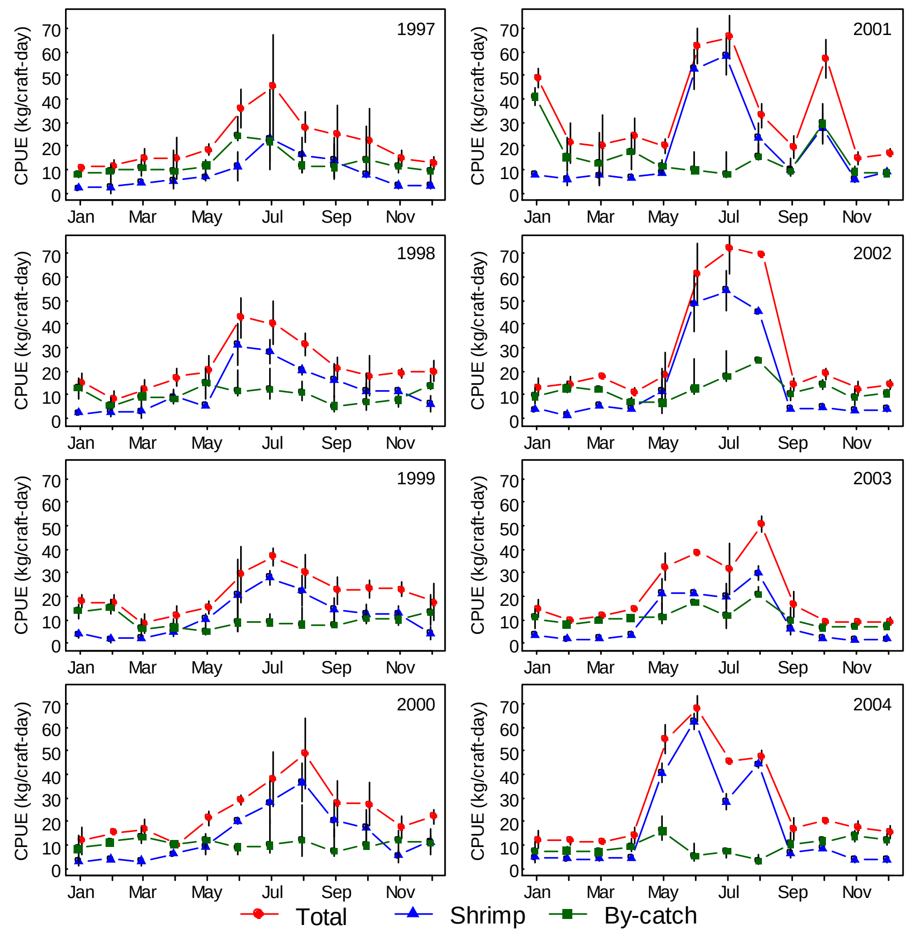


Figure 6: Average daily CPUE (kg per craft-day) from the Handala trawl fishery.

Though the monthly CPUE values of shrimp and total catches in Negombo were observed to be more or less steady throughout the months from 1997 to 2004, an increasing trend in shrimp and total CPUE were evident in Handala from May-September. Considerably high increasing trends in monthly CPUEs of shrimp and total catches were evident in Handala from 2001 to 2004 as opposed to 1997 to 2000.

During the eight years of the study period, monthly mean CPUEs of shrimp ranged from 1.51±0.22 kg/boat-day to 62.5±3.71 kg/boat-day from Handala. Meanwhile from Negombo the mean shrimp CPUEs ranged from 2.01±0.51 kg/boat-day to 21.46±3.02 kg/boat-day.

Consequently the highest "total CPUE" ranged in Negombo from 6.20±1.24 kg/boat-day to 36.65±2.16 kg/boat-day while in Handala it ranged from 8.09±3.4 kg/boat-day to 72.07±10.6kg/boat-day.

3.2.2 Variations in total fishing effort and total shrimp production

Figures 7 and 8 show the monthly variation in total fishing effort and shrimp production of Negombo and Handala trawl fisheries. Monthly fluctuations of total production and fishing effort are evident from these fisheries, especially in Handala.

The Handala fishery has a clearly demarcated high production from May to September. This coincides with the southwest monsoon. Higher monthly production was evident from Negombo in both the southwest monsoonal period and the latter part of the southwest monsoonal periods around August to November. Throughout the study period very low fishing efforts were reported from Handala from January to May resulting in low shrimp production. In Negombo, fishing effort was relatively high throughout the year though there are slight fluctuations with the southwest monsoon from May to September. Very low fishing effort was reported in Handala in 2002 resulting in low monthly production.

The monthly shrimp production in Negombo has ranged from 0.86 to 31.25 t while the fishing effort had been from 240 to 2400 fishing boats-day (Appendix ii).

The monthly shrimp production in Handala ranged from 0.38 to 62.73 t during the study period. At the same time, fishing effort in Handala has ranged from 72 to 1968 fishing boats-day.

Mean annual fishing effort for the period 1997-2004 at Negombo was 16,129 ± 3,496 fishing boat-days and in Handala for the same period estimated average annual fishing effort was 7,612 ± 2041 fishing boat-days.

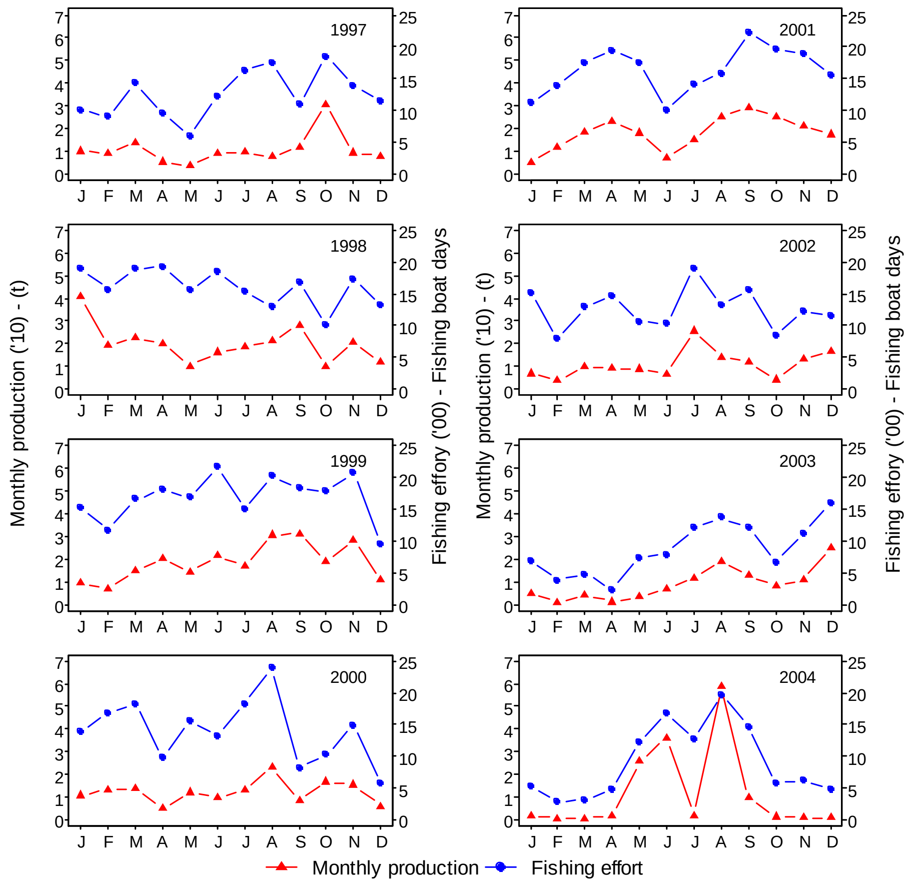


Figure 7: Variations in total shrimp production (left y-axis) and total fishing effort (right y-axis) in the Negombo trawl fishery

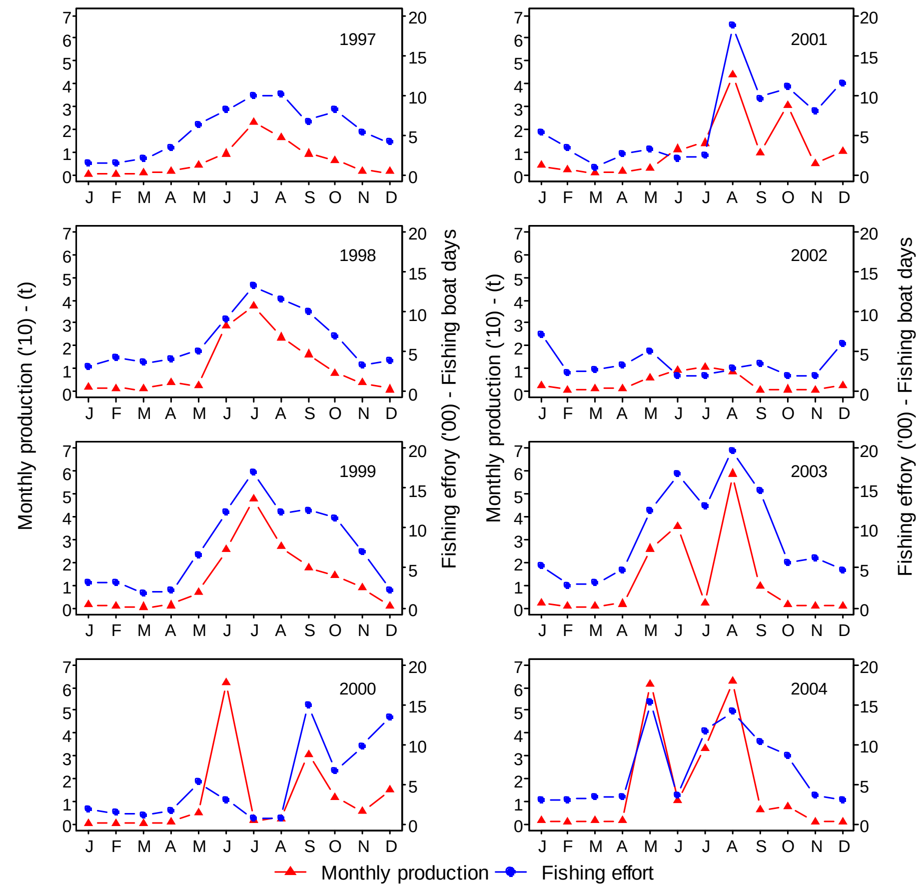


Figure 8: Variations in total shrimp catch (left y-axis) and total fishing effort (right y-axis) in the Handala trawl fishery

Figure 9 shows the deviation of annual total shrimp production and total fishing effort from the mean during this period. The mean shrimp production in Negombo for the period was 164,591 kg while in Handala it was 125,699 kg.

The catches were comparatively low in the years 1997 and 2002 in both fisheries but in the following years Handala has been able to obtain higher catches in both occasions. Meanwhile in Negombo, the recovery is not prominent after the drop in 2002. In both fishing grounds the production seems to fluctuate with fishing effort but in 2004 the production increased by 49912 kg though there had been a reduction in the effort by 2542 fishing boat-days.

Mean annual fishing effort for the period 1997-2004 at Negombo was 16,129 ± 3,496 fishing boat-days (ranging from 10,488 fishing boat-days to 20,112 fishing boat-days) and in Handala for the same period the estimated average annual fishing effort was 7,612 ± 2041 fishing boat-days (ranging from 4082 fishing boat-days to 10,896 fishing boat-days).

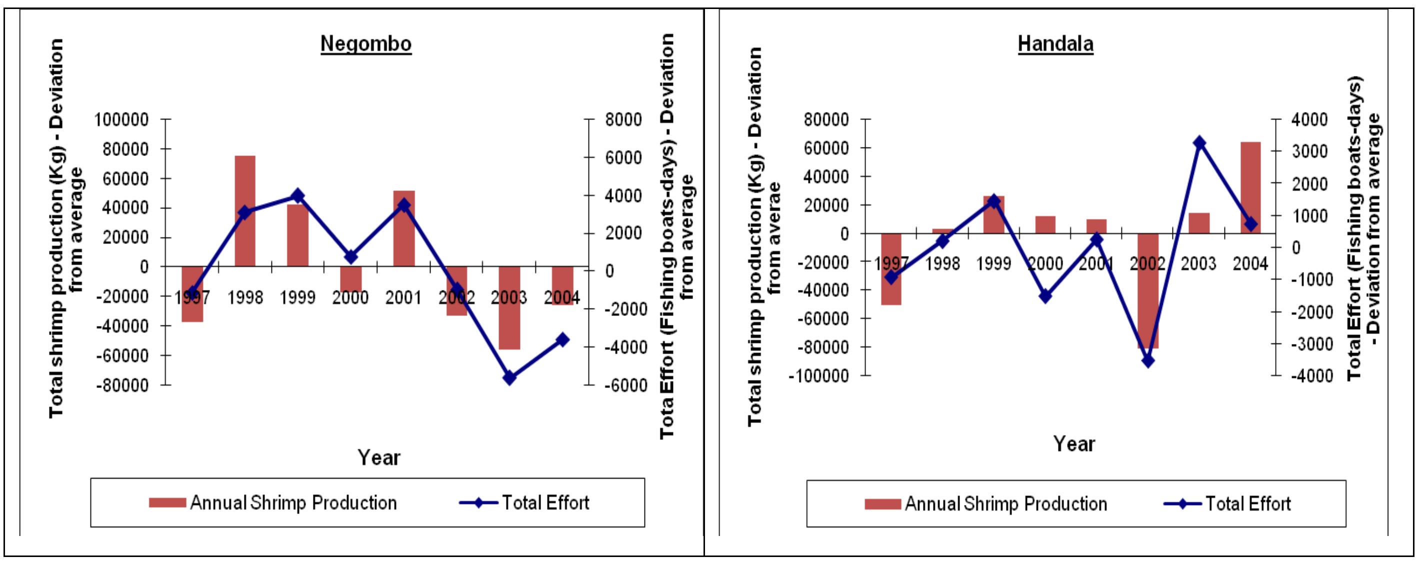


Figure 9: Deviation of annual total shrimp production (left y-axis) and total fishing effort (right y-axis) from the mean calculated for 1997-2004 for the Negombo and Handala trawl fisheries.

Shrimp production fluctuations are shown in Figure 10a and it shows that there are no inter-associated fluctuation patterns in shrimp production. Further, Figure 10b confirms very poor correlation (r^2=0.101) between the total monthly shrimps production, suggesting that these two fisheries are functioning independently.

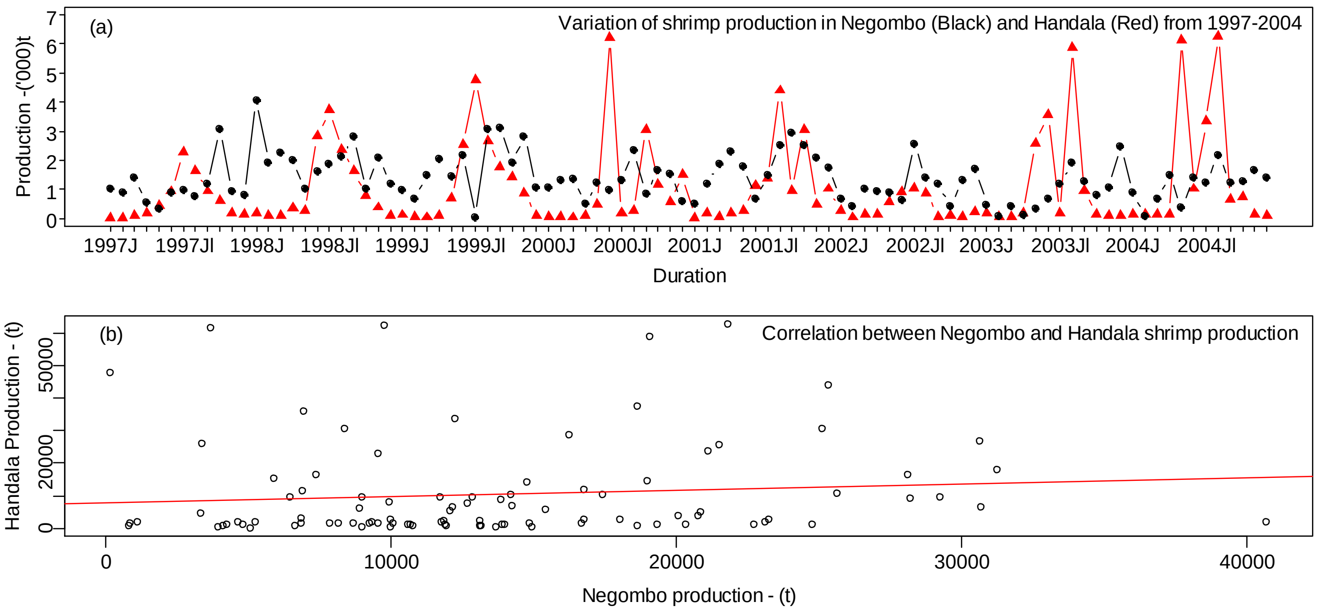


Figure 10: (a) Monthly fluctuation patterns of shrimp production in Negombo and Handala. (b) Correlation between Negombo and Handala shrimp production from 1997-2004.

There is a strong positive correlation in both Handala (r^2= 0.736) and Negombo (r^2=0.756) in terms of production and effort (Figure 11). Except for a few occasions, there were not many records of very high fishing efforts from both fisheries. Even from Handala, where mechanised boats are operated, the monthly effort has not exceeded beyond 1500 fishing boat-days, except 5-6 times for the eight year study period. This might be due to the high seasonality of the catch abundance or perhaps market generated forces due to lower prices during the periods having high CPUEs might have prevented very high fishing.

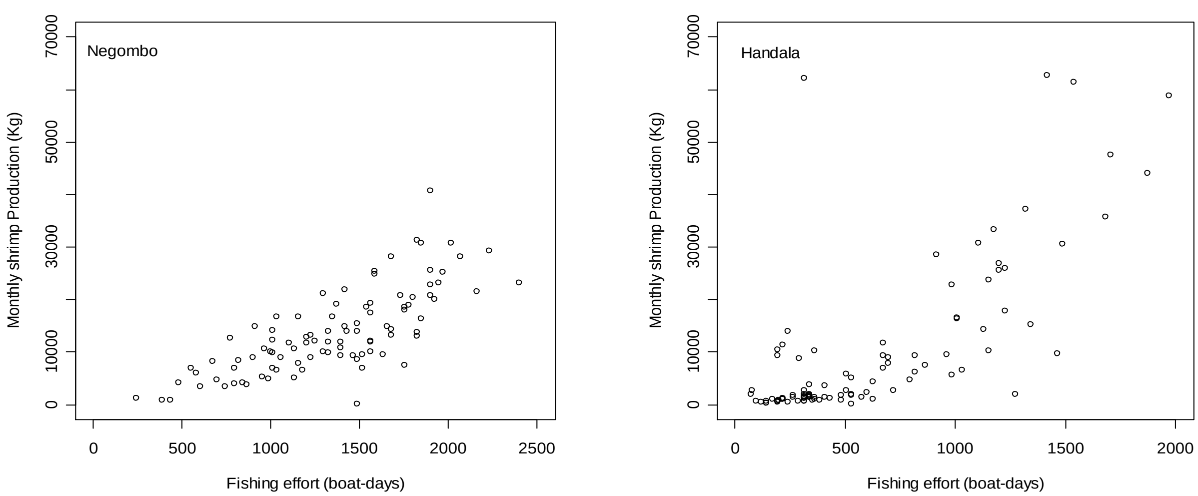


Figure 11: Relationship between monthly fishing effort vs. monthly shrimp production in Negombo and Handala from 1997-2004.

3.2.3 Effects of monsoonal patterns on shrimp production

Figures 12 and 13 show the estimated ln (CPUE +1) in different monsoonal periods in Negombo and Handala from 1997 to 2004. Comparison of means of CPUE (kg/haul) at different monsoonal periods from ANOVA confirms that there is a significant difference in the mean CPUE in Handala ($P<0.05$). Turkeys HSD multiple comparison (Zar 1984) indicated that CPUE during the southwest monsoon was significantly higher than those of other monsoonal periods.

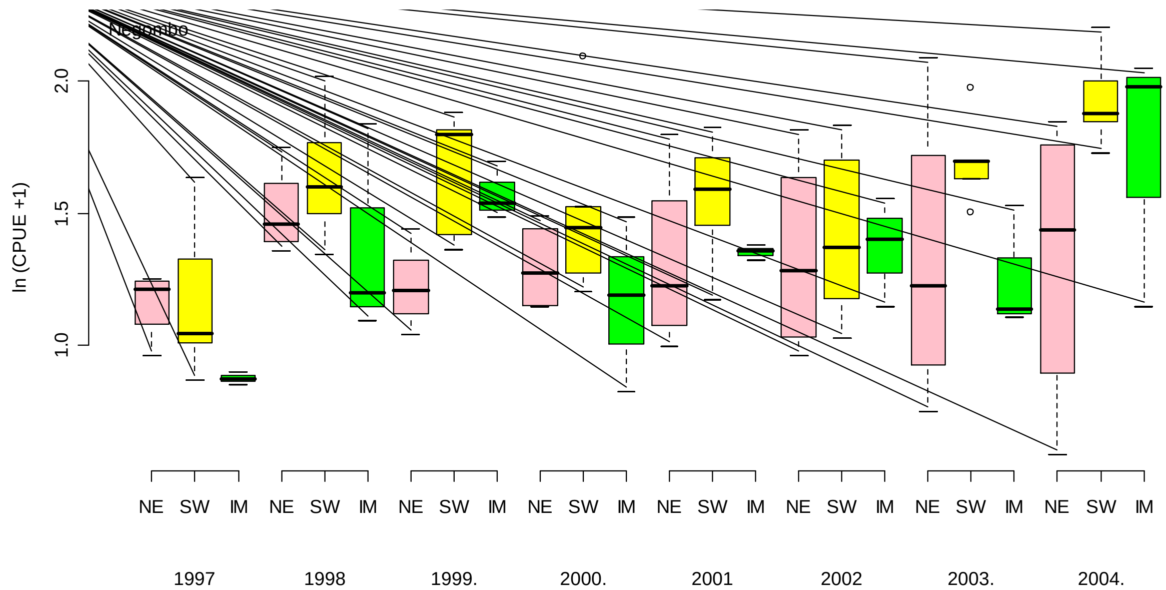


Figure 12: Box plot of ln (CPUE +1) in different monsoonal periods (NE- northeast, SW- southwest, IM- intermediate) in Negombo from 1997- 2004.

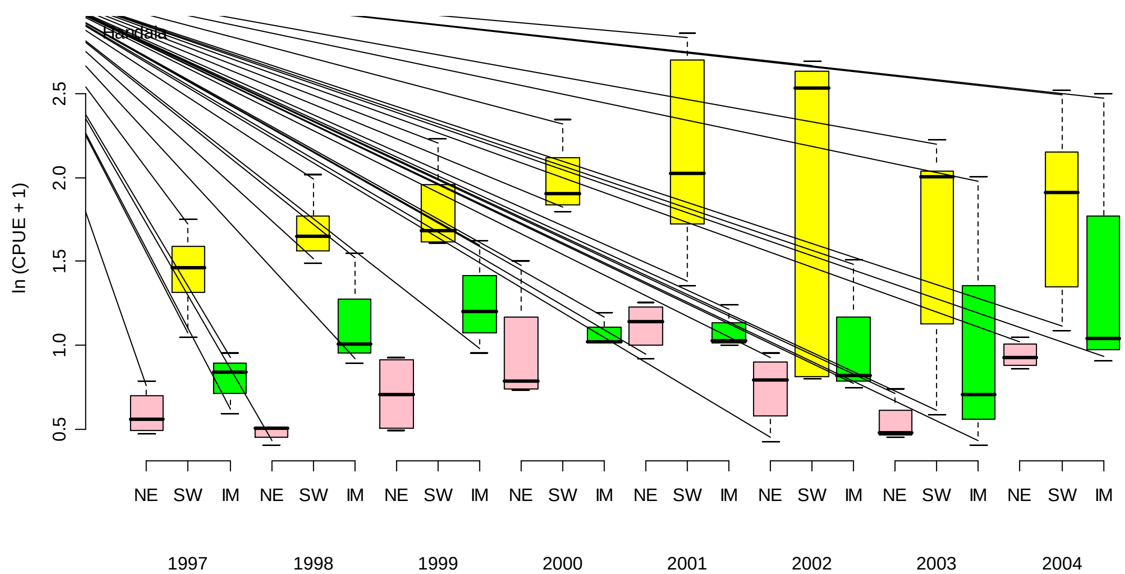


Figure 13: Box plot of ln (CPUE + 1) in different monsoonal periods (NE- northeast, SW- southwest, IM- intermediate) in Handala from 1997- 2004

The estimated mean catches for the period of 1997 to 2004 from Negombo during northeast, southwest and inter-monsoons were 2.90, 4.06 and 3.24 kg/haul respectively while in Handala the mean catches were 1.22, 5.94 and 2.32 kg/haul respectively for the same monsoonal periods.

3.2.4 The species composition of the trawl catches

3.2.4.1 An overview of total catch statistics

A total of six shrimp species and 28 commercially important non-targeted species (by-catch) which belong to 11 orders and 13 families were recorded during the study and results are summarised in Table 4.

Table 4: Major shrimp species and by-catch species recorded from 1997 to 2004 from the Negombo and Handala fishing grounds.

	Order	Family	Species
Shrimp species	Penaeoidea	Penaeidae	*Penaeus monodon* *Penaeus semisulcatus* *Penaeus indicus* *Penaeus merguiensis* *Metapenaeus dobsoni* *Parapenaeopis coromondalica*
By-catch species	Perciformes (Percoidei)	Carangidae	*Carangoides armatus*
	Perciformes (Percoidei)	Drepanidae	*Drepane punctata*
	Perciformes (Percoidei)	Seranidae	*Epinephelus longispinis* *Epinephelus truvina*
	Perciformes (Percoidei)	Gerreidae	*Gerres filamentosus*
	Clupeiformes	Clupeidae	*Hilsa kelee* *Sardinella gibbosa* *Sardinella longiceps* *Sardinella albella* *Nematalosa nasus*
		Engraulididae	*Stelephorus commersonii* *Stelephorus indicus* *Thryssa dussumieri* *Thryssa mystax*
	Perciformes (Sphyraenoidei)	Sphyraenidae	*Sphyraena jello*
	Perciformes (Percoidei)	Lethrinidae	*Lethrinus lentjan* *Lethrinus nebulosus* *Lethrinus argentimaculatus*
	Perciformes (Percoidei)	Leiognathidae	*Leiognathus brevirostris* *Leiognathus dussumieri* *Leiognathus splendes* *Secutor roconius* *Secutor insidiator*
	Perciformes (Mugiloidei)	Mugilidae	*Mugil cephalus*
	Perciformes (Percoidei)	Centropomidae	*Lates calcarifer*
	Myliobatiformes	Dasyatididae	*Dasyatis kuhlii*
		Portunidae	*Portunus pelagicus* *Portunus sanguinolentus*

Among shrimps, *P. indicus* and *P. merguiensis* are much larger and have higher commercial value than the relatively small *M. dobsoni* and *P. coromondalica.* Contributions of *P. monodon* from Handala and Negombo were reported to be less than 1%.

The percentage contribution of shrimp has remained at more or less steady state since 1997 to 2004 for both Handala and Negombo fishing sites (Figure 14). Negombo has a higher shrimp percentage of 55% but Handala is 44.55%.

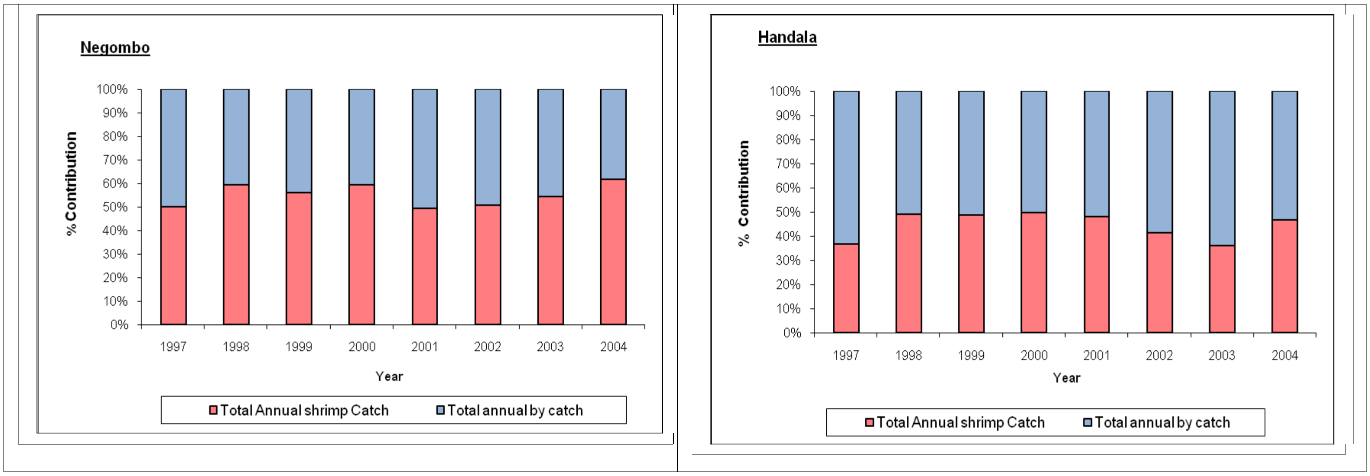


Figure 14: Percentage contribution of total shrimp production and total by-catch from Handala and Negombo trawl fisheries during the period 1997-2004.

3.2.4.2 Contribution of major shrimp species to the trawl catches

The shrimp production in Handala shows a demarcated contribution during May to September (southwest monsoonal period) throughout the study duration (Figures 15 and 16). But *P. indicus* shows more stability than the *M. dobsoni*.

In both Negombo and Handala the highest contribution to the catch was by *M. dobsoni*. In Handala, *M. dobsoni* percentage contribution for the total catch ranged from 7% (February 2002) to 58% (January 2001) meanwhile in Negombo it ranged from 18% (January 2003) to 58% (December 2000).

The lowest contribution was by *P. indicus* for both fisheries. The contribution of *P. indicus* ranged from 0.4% (January 1998) to 4% (in November 1997) in Negombo while in Handala it ranged from 0% (December 2004) to 18% (May 2002).

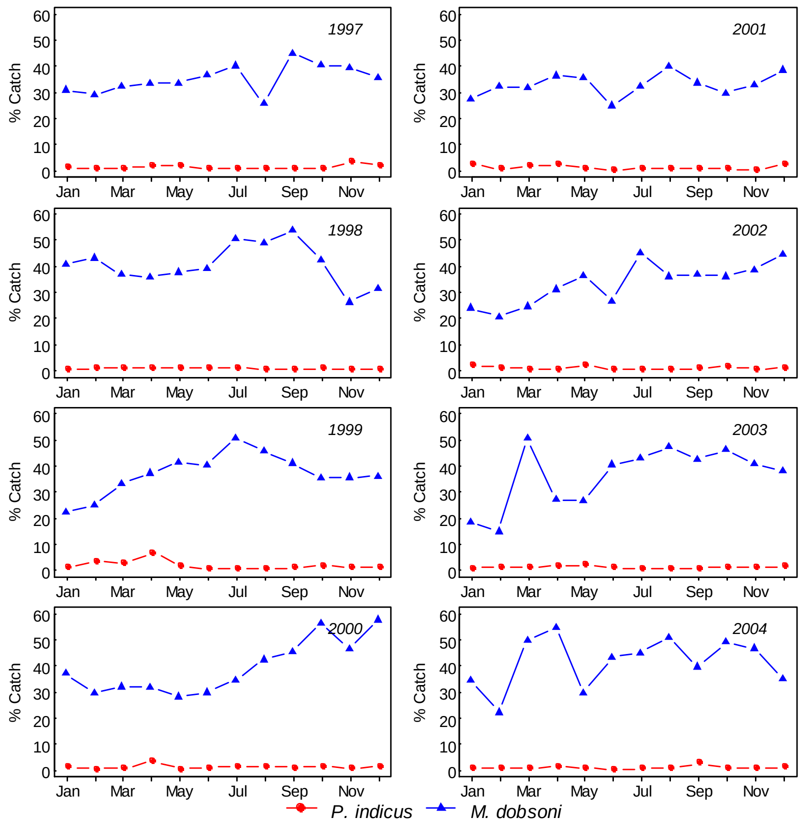


Figure 15: Monthly percentage composition of *P. indicus*, *M. dobsoni* from the Negombo trawl fishery from 1997 to 2004.

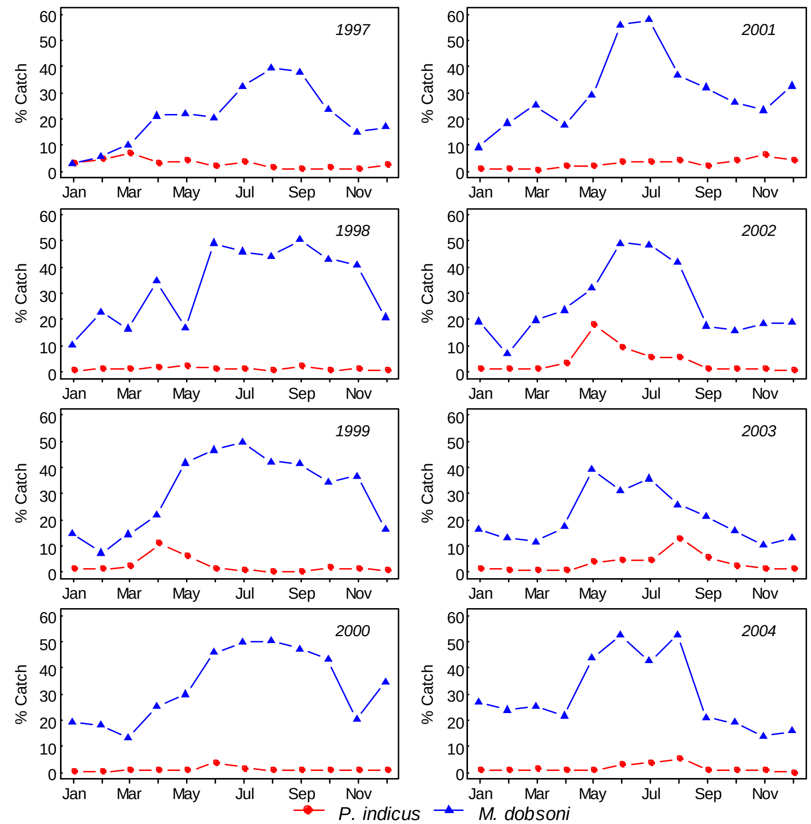


Figure 16: Monthly percentage composition of *P. indicus*, *M. dobsoni* from the Handala trawl fishery from 1997 to 2004**.**

Figure 17 compares the annual percentage contributions of three major shrimp species to the total catch. The contributions of *P. monodon, P. semisulcatus* and *P. merguiensis* are collectively represented as “others”. The highest percentage contribution was provided by *M. dobsoni* throughout the study period in both fisheries and this is more or less in similar range. The annual percentage contribution of *M. dobsoni* was 62%±3.2 and 66.5%±0.5 in Handala and Negombo respectively. Meanwhile the lowest annual percentage contribution was evident by *P. indicus* as 5.4%±2.3 and 2.5% ±0.6 from Handala and Negombo respectively.

The contribution of *P. coromandelica* was 27.5% ±2.9 (Handala) and 28.5%±0.3 (Negombo) by being the second highest contributor for the total shrimp production in both sites during the period 1997-2004.

The average annual production calculated for *M. dobsoni* for the period 1997-2004 from Handala and Negombo was 74 t and 109 t respectively. Meanwhile in the same period 32 t and 43 t of average productions were produced by *P. coromandelica* from Handala and Negombo respectively. Commercially highly valuable *P. indicus* have produced the lowest mean production from Handala and Negombo as 6.6 t and 4.5 t.

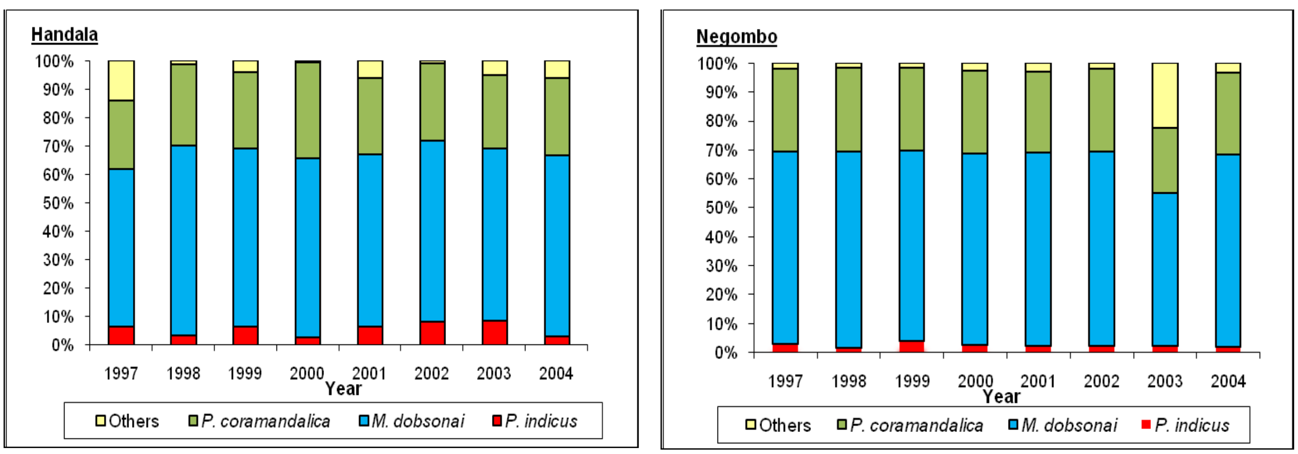


Figure 17: Annual fluctuations of percentage contributions of different shrimp species to the total shrimp production in the Handala and Negombo trawl fisheries during 1997-2004.

3.2.5 Length frequency distribution of P. indicus and M. dobsoni

3.2.5.1 Length frequency analysis of *P. indicus*

Monthly length distributions of *P. indicus* are shown in Figures 18 and 19 for 2005 and 2006 from the non-mechanised (Negombo) trawlers. When length distribution of *P. indicus* is analysed the length range for females for the trawl nets in Negombo was 7-18 cm while for males it was reported to be 6-18 cm. The highest length value was reported from males in the month of October while for females it was in July. Generally when considering both 2005 and 2006 together, the mode of length frequency of males was around 13 cm while for females it was 14.4 cm.

Catch samples reflects the increased abundance of male and female individuals in the coastal fishing grounds from May to September and this can be attributed to the fact of their migration linked with the southwest monsoonal rains. The emergence of new peaks can also be observed from May to June and this may be due to the shifting of older individuals due to newly recruited individuals.

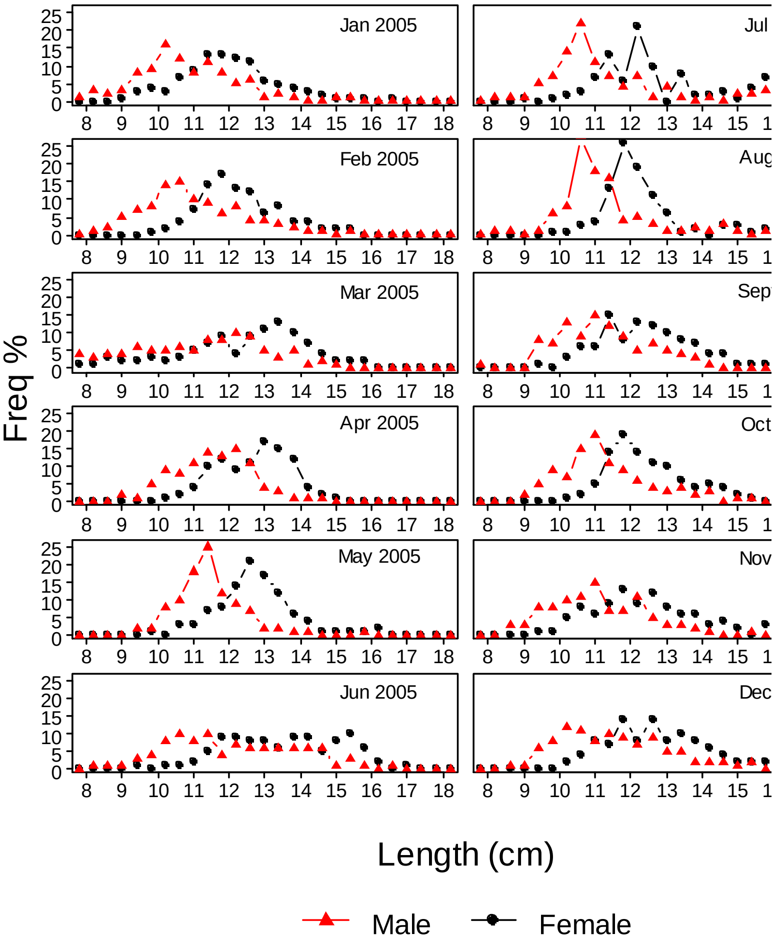


Figure 18: Monthly fluctuation of length frequency distribution of *P. indicus* males (n=3752) and females (n=3386) from coastal waters off Negombo during 2005. Collection months are shown on the right of each graph.

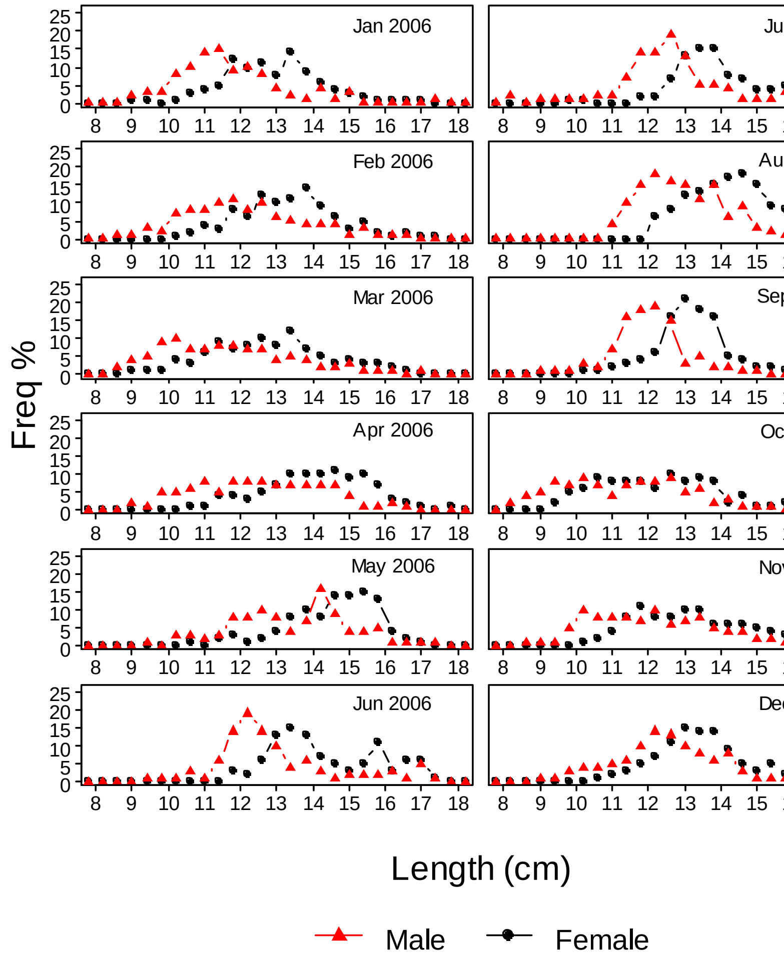


Figure 19: Monthly fluctuation of length frequency distribution of *P. indicus* males (n=4676) and females (n=3901) from coastal waters off Negombo during 2006. Collection months are shown on the right of each graph

When the length distribution of *P. indicus* is analysed the length range for females for the trawl nets in Handala was 7-18 cm while for males it was reported to be 9-18.5 cm. Minimum lengths in both males and females were recorded in the months of July/August. The highest female length was recorded in July and the highest male length was reported in September.

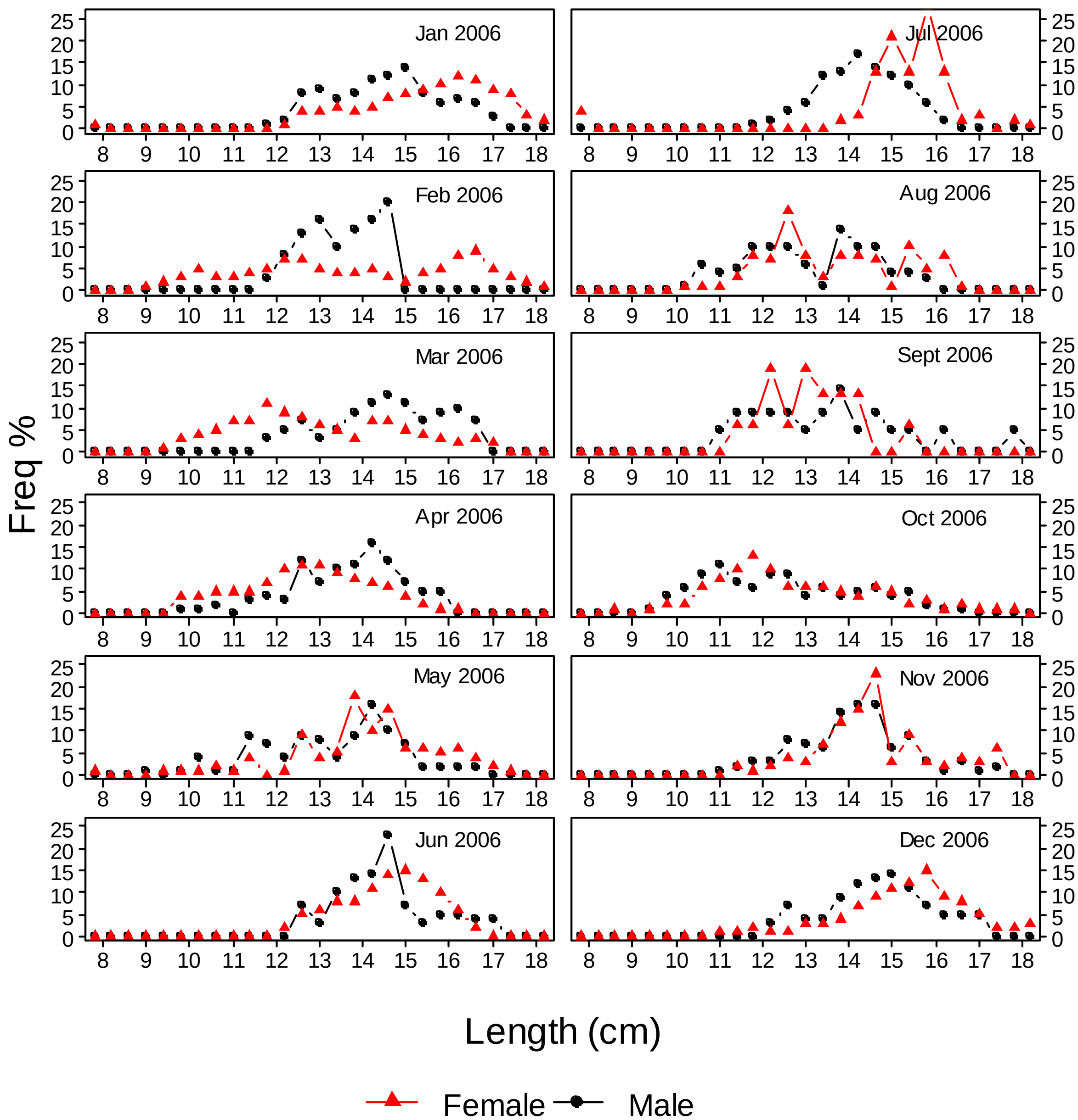


Figure 20: Monthly fluctuation of length frequency distribution of *P. indicus* males (n=1402) and females (n=1186) from Handala in 2006. Collection months are shown on the right of each graph.

The modes of males and females were 12 cm and 14 cm respectively for the entire fishing year. Even in Handala emergence of new length classes of *P. indicus* can be observed in April to May as in the case of Negombo and this is also due to the newly entered young individuals to the coastal area with the effect of monsoonal rains. Several peaks emerged in female length frequency distribution in the months of August and September which may be due to the inadequate individuals due to low sample size.

3.2.5.2 Length frequency analysis of *M. dobsoni*

Monthly fluctuations of the length frequency distributions of *M. dobsoni* caught by non-mechanised trawlers from coastal waters off Negombo are shown below in Figures 21 and 22 for the years 2005 and 2006 respectively. Females in Negombo were in the range of 3.5 – 11.5 cm wile males ranged from 3.5 – 10 cm. The minimum length range of females was observed in the month of October while the smallest length range in males was observed in March. Same as for *P. indicus* even the length frequency distribution pattern of *M. dobsoni* showed newly emerging new recruits during April-June in coastal fishing areas. Further, gradual shifting of the newly emerged peaks towards the higher length class is more prominent. *M. dobsoni* recruitment took place from May to September in both consecutive years. Monsoonal rains are probably influencing the recruitment of *M. dobsoni* towards the coastal areas where the trawl nets are operating.

Figures 23 and 24 shows the length frequency distribution of *M. dobsoni* caught by mechanised trawls in Handala in the years 2005 and 2006 respectively. When length distribution of *P. indicus* is analysed the length range for females for the trawl nets in Handala was 4-12 cm while for males it was reported to be 4 – 10 cm. Same as in Negombo, the minimum male length of *M. dobsoni* was observed in March at Handala. In Handala the minimum female length was recorded in October. The highest length recorded for females and males was observed in July and March respectively. According to the length frequency distribution analysis *M. dobsoni* enter to the coastal area in the month of March and this is just before the onset of the southwest monsoonal rains. This pattern was observed in both consecutive years in the fishery in Handala.

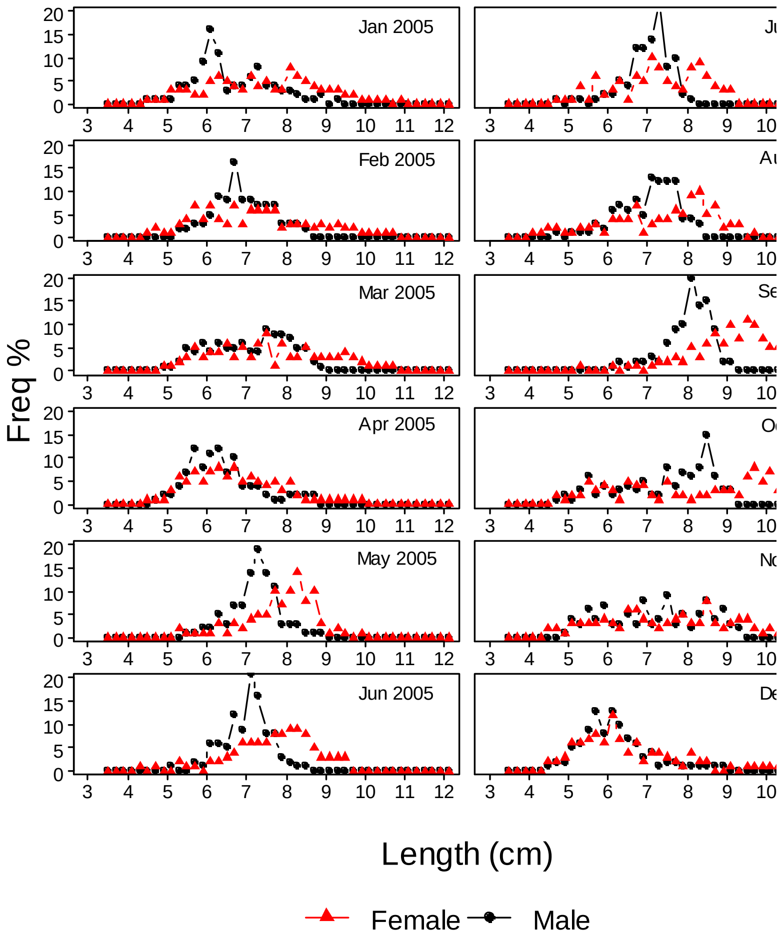


Figure 21: Monthly fluctuation of length frequency distribution of *M. dobsoni* males (n=6148) and females (n=5496) from Negombo during 2005. Collection months are shown on the right of each graph.

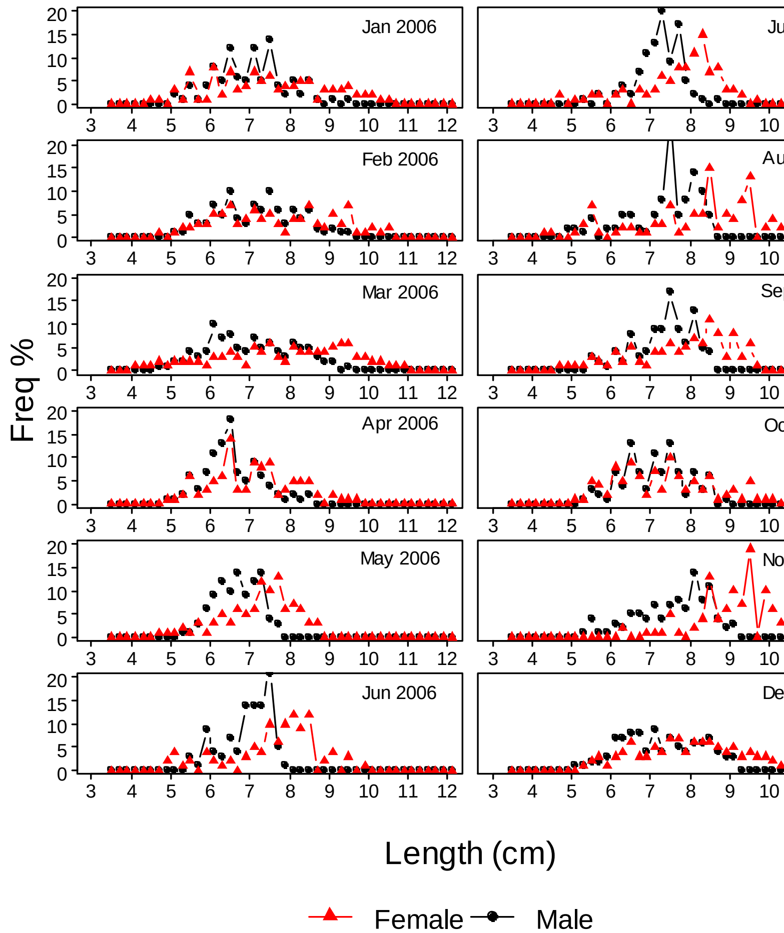


Figure 22: Monthly fluctuation of length frequency distribution of *M. dobsoni* males (n=7724) and females (n=5264) from Negombo during 2006. Collection months are shown on the right of each graph

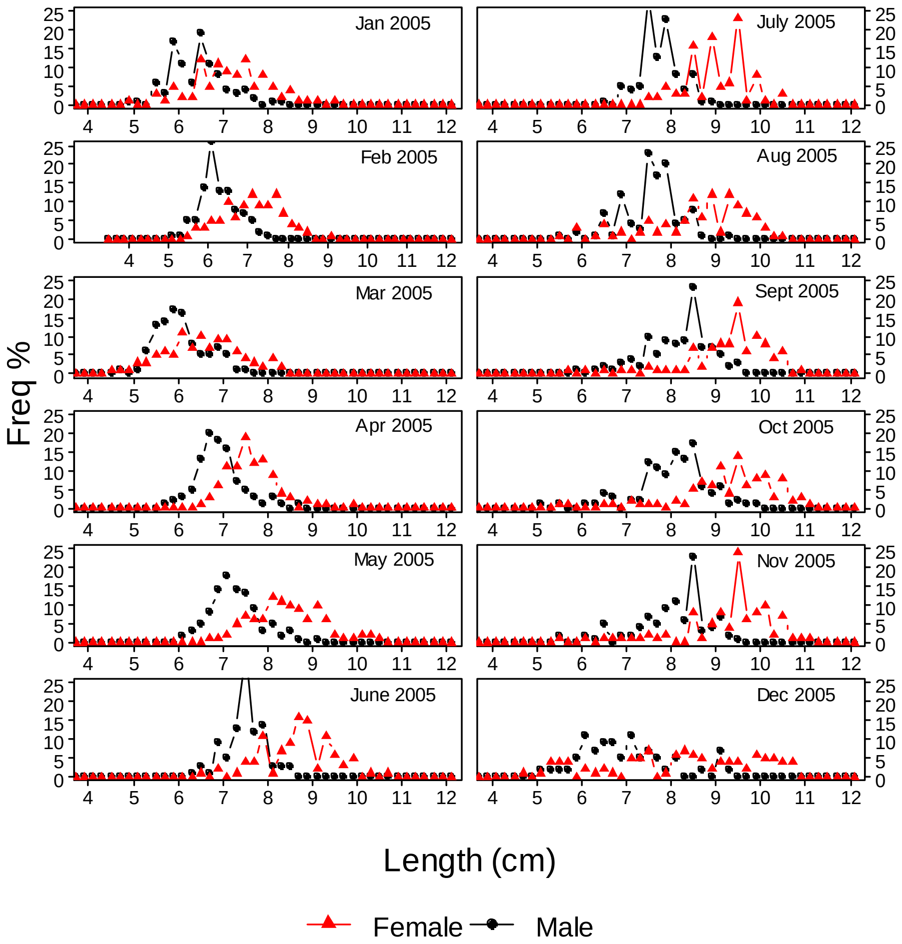


Figure 23: Monthly fluctuation of length frequency distribution of *M. dobsoni* males (n = 4014) and females (n = 8610) from Handala in 2005. Collection months are shown on the right of each graph.

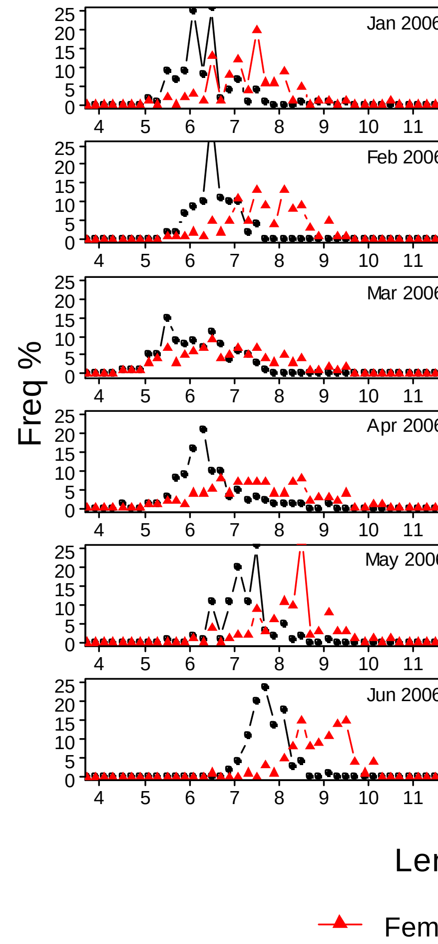


Figure 14: Monthly fluctuation of l
dobsoni males (n = 4038) and fema
2006. Collection months are shown

3.3 Population characteristics

3.3.1 Growth parameters (L_∞ and K)

The estimated asymptotic length (L_∞) and the growth constant (K) for *M. dobsoni* and *P. indicus* are summarised separately for both sexes and also combined in Table 5 (Appendix iii shows the stimulated growth curves). Asymptotic length (L_∞) estimated for *M. dobsoni* males and females from both sites were in similar rages while the growth constant (K) recorded for both sexes from Handala were higher compared to the values recorded from Negombo. Higher L_∞ and K values were observed for both female species from Handala and Negombo. Though there is a marked difference in K values reported from the two sites for *M. dobsoni* such a difference in K is not prominent in *P. indicus* for the two sites. But the difference evident in K values in *M. dobsoni* for the two sites cannot be seen in the pooled sex data. Growth performance index were in a similar rage for both sexes. The t_0 reported to be in a similar range of all species with small negative values.

Table 5: Asymptotic length (L_∞), growth constant (K), growth performance index (Ǿ) and age at which the length of the fish is zero (t_0), of *M. dobsoni* and *P. indicus* caught from Negombo and Handala fisheries.

Species	Site	Sex	L_∞ (cm)	K (yr^{-1})	Rn / r^2	Ǿ	t_0
M. dobsoni	Handala	Male	11.80	0.68	0.381	1.97	-0.040
		Female	12.01	1.30	0.185	2.27	-0.009
		Pooled data (male+female)	**11.73**	**0.78**	**0.144**	**2.03**	**-0.028**
	Negombo	Male	11.75	0.60	0.101	1.92	-0.049
		Female	11. 95	0.84	0.410	2.08	-0.027
		Pooled data (male+female)	**11.65**	**0.73**	**0.151**	**1.99**	**-0.036**
P. indicus	Handala	Male	19.2	1.0	0.146	2.56	-0.016
		Female	20.02	1.2	0.144	2.68	-0.010
		Pooled data (male+female)	**19.80**	**1.03**	**0.144**	**2.61**	**-0.015**
	Negombo	Male	19.10	1.1	0.146	2.60	-0.013
		Female	20.08	1.26	0.131	2.73	-0.008
		Pooled data (male+female)	**19.90**	**1.10**	**0.101**	**2.64**	**-0.012**

3.3.2 Mortality parameters

Instantaneous total mortality (Z), natural mortality (M), fishing mortality (F) and exploitation rate ($E_{current}$) for males, females and pooled sex data of *M. dobsoni* and *P. indicus* are summarised in Table 6. Appendix iv shows the corresponding length converted catch curves.

Estimated values from both Handala and Negombo indicate that female *M. dobsoni* and *P. indicus* have higher natural morality rates (M) than males. Fishing mortality (F) recorded from Handala mechanised trawling is higher in both species of males and females than in Negombo. But this higher F is masked in Handala when pooled sex data are considered.

The exploitation rates of both species are within the range of 0.50 to 0.55 in both sites when pooled sex data are considered. But when considering two sexes separately *M. dobsoni* males have higher exploitation rates than females in both sites but *P. indicus* females have high exploitation rates in both sites.

Almost all shrimps are well below the optimal exploitation rate.

Table 6: Instantaneous total mortality (Z), natural mortality (M) and fishing mortality (F) coefficient and present exploitation rate ($E_{current}$) of *M. dobsoni* and *P. indicus* caught from the Negombo and Handala trawl fisheries.

Species	**Site**	**Sex**	**Z**	**M**	**F**	**$E_{current}$**
M. dobsoni	Handala	Male	4.48	1.79	2.68	0.60
		Female	6.06	2.74	3.32	0.55
		Pooled data (male+female)	**4.73**	**2.15**	**2.58**	**0.55**
	Negombo	Male	3.91	1.66	2.25	0.58
		Female	3.74	2.06	1.68	0.45
		Pooled data (male+female)	**5.06**	**2.48**	**2.59**	**0.51**
P. indicus	Handala	Male	3.96	2.02	1.94	0.49
		Female	5.21	2.25	2.96	0.57
		Pooled data (male+female)	**4.32**	**2.05**	**2.28**	**0.53**
	Negombo	Male	3.80	2.03	1.77	0.47
		Female	5.08	2.32	2.76	0.54
		Pooled data (male+female)	**4.27**	**2.13**	**2.14**	**0.50**

3.3.3 Probabilities of capture

The estimated probabilities of capture values at L_{25}, L_{50} and L_{75} are summarised in Table 7 for males and females and pooled sex data of *M. dobsoni* and *P. indicus*. Respective curves of probability of capture are given in Appendix v.

Generally lower L_{50} values were reported for *M. dobsoni* and *P. indicus* caught from Negombo trawl nets than Handala. All females of *M. dobsoni* and *P. indicus* had lower L_{50} values than males except the *P. indicus* females reported from Negombo.

Table 7: Estimated sizes at probabilities of capture of *M. dobsoni* and *P. indicus* from Negombo and Handala trawl nets.

Species	**Site**	**Sex**	L_{25} (cm)	L_{50}(cm)	L_{75}(cm)	L_{opt}
M. dobsoni	Handala	Male	4.47	5.11	5.79	9.00
		Female	4.37	5.07	7.44	8.18
		Pooled data (male+female)	**4.26**	**4.89**	**6.34**	**8.91**
	Negombo	Male	4.35	4.84	5.79	8.74
		Female	3.90	4.45	6.07	8.42
		Pooled data (male+female)	**3.86**	**4.33**	**5.22**	**7.92**
P. indicus	Handala	Male	9.05	9.84	11.71	15.55
		Female	8.63	9.41	11.57	14.51
		Pooled data (male+female)	**8.62**	**9.38**	**11.34**	**14.64**
	Negombo	Male	6.62	7.84	8.91	12.26
		Female	7.82	8.81	10.35	13.63
		Pooled data (male+female)	**6.65**	**7.64**	**9.26**	**12.14**

$L_{opt} = E_{Max} * L_{\infty}$ (cm)

3.3.4 Recruitment patterns

Figure 25 shows the percentage recruitments for males and females of *M. dobsoni* and *P. indicus* from Handala and Negombo. FiSAT routine reconstructs the recruitment pulses from a time series of length-frequency data to determine the number of pulses per year and the relative strength of each pulse in percentages.

Both male and female *M. dobsoni* show prominent recruitment pulses during May-August. In Handala females produce a pulse with the magnitude of 21% during May which is followed by males in June with the 20.7% recruitment. But in Negombo the peak period of the two recruitment pluses of *M. dobsoni* males and females were separated by two months, initially males produced initial recruitment towards coastal areas in May with 18.8% recruitment followed by females with peak recruitment in July with the magnitude of 16.7% recruitment.

In *P. indicus* a scattered recruitment pattern was observed with 2-3 distinguishable peaks especially in males. Initially in both habitats, *P. indicus* females result initial recruitment pulse during March-April followed by the second recruitment pulse in July-August with relatively higher magnitudes. Even females were resulted two similarly prominent pluses with lower percentages of recruitment followed by higher percentages of recruitment in March-April and September- August.

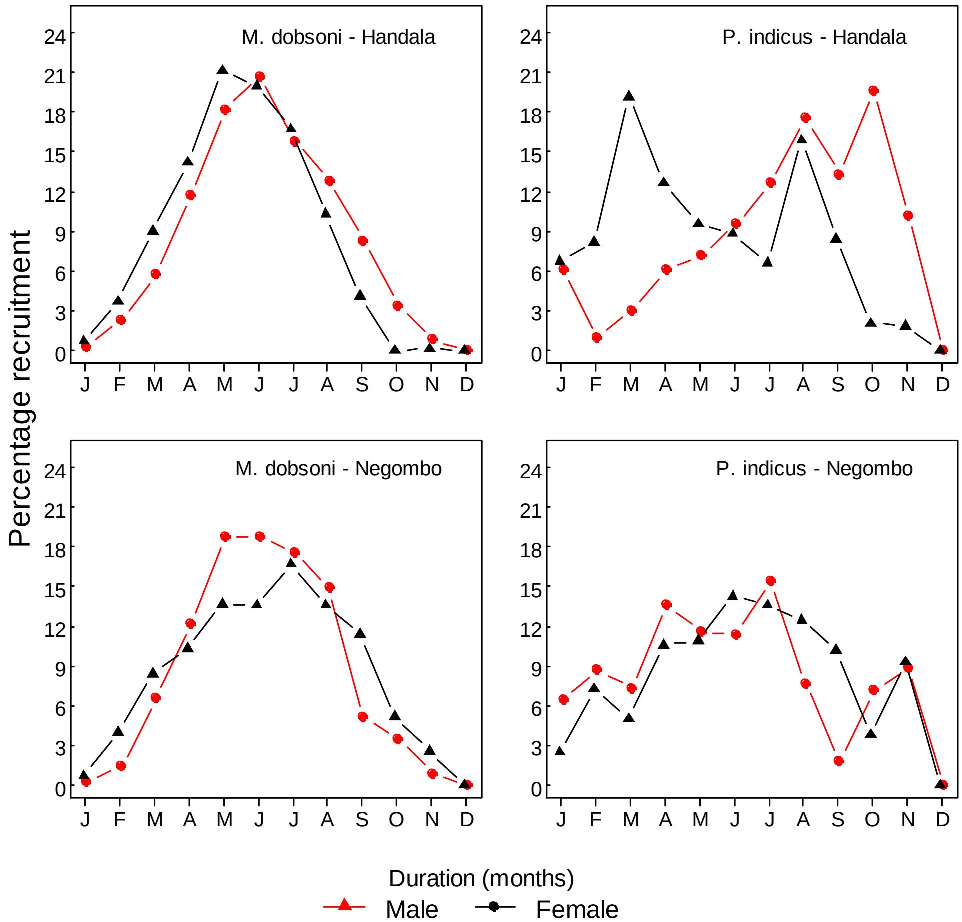


Figure 25: Percentage recruitment of *P. indicus* and *M. dobsoni* (males and females) from Handala and Negombo

3.3.5 Relative yield per recruit (Y´/R) and biomass per recruit (B´/R) model

The estimates of the yield per recruit model for both fisheries (Handala and Negobmo) have been summarised in Table 8 for both species (*M. dobsoni* and *P. indicus*) with respect to their sex and location (Negombo and Handala) together with pooled sex data. Inputs of the model M/K and L_c/L_∞ are also given with the estimates E_{max} (exploitation rate which produces maximum yield), $E_{0.1}$ (exploitation rate at which the marginal increase of relative yield-per-recruit is 1/10th of its value at E=0 / biologically optimum limit) and $E_{0.5}$ (value of E under which the stock has been reduced to 50% of its unexploited biomass). Figures 26 and 27 show the relative Y´/R and B´/R curves obtained for *M. dobsoni* and *P. indicus* pooled sex data. Similarly Y´/R and B´/R curves obtained for *P. indicus* and *M. dobsoni* with respect to their sexes are given in Appendices vii and ix respectively. The respective yield isopleths diagrams are also given in Appendices vi and viii for both species with respect to their sex.

The current exploitation rates ($E_{current}$) (calculated for both individual sexes and pooled sex data) of *M. dobsoni* and *P. indicus* from Handala and Negombo were well below the respective maximum acceptable limit (E_{max}) predicted by the Y´/R model (Table 8). In both species in Negombo, present exploitation levels are well below the biological optimum limit ($E_{0.1}$). Hence, the present result levels in both locations are being operated for both species under the maximum sustainable limit. Exploitation of the relative spawning stock biomass seems to be in a more or less similar range (0.33 to 0.36) in both habitats for both species under the current rate of exploitation.

Table 8: Y'/R and B'/R model input data (M/K / L_c / L_∞) and estimated values of $E_{0.1}$, $E_{0.5}$ and E_{Max} for *M. dobsoni* and *P. indicus* caught from Negombo and Handala trawl fisheries.

Species	**Site**	**Sex**	**M/K**	**L_c / L_∞**	$E_{0.1}$	$E_{0.5}$	**E_{Max}**	**$E_{current}$**
M. dobsoni	Handala	Male	2.36	0.43	0.60	0.35	0.76	0.60
		Female	2.11	0.42	0.56	0.34	0.68	0.55
		Pooled data (male+female)	**2.76**	**0.24**	**0.60**	**0.35**	**0.76**	**0.55**
	Negombo	Male	2.77	0.41	0.62	0.34	0.74	0.58
		Female	2.45	0.37	0.60	0.34	0.71	0.45
		Pooled data (male+female)	**2.84**	**0.27**	**0.57**	**0.33**	**0.68**	**0.51**
P. indicus	Handala	Male	2.02	0.51	0.71	0.37	0.81	0.49
		Female	1.87	0.47	0.60	0.35	0.72	0.57
		Pooled data (male+female)	**1.99**	**0.47**	**0.61**	**0.36**	**0.74**	**0.53**
	Negombo	Male	1.85	0.41	0.55	0.34	0.64	0.47
		Female	1.84	0.44	0.56	0.35	0.68	0.54
		Pooled data (male+female)	**1.94**	**0.38**	**0.52**	**0.33**	**0.61**	**0.50**

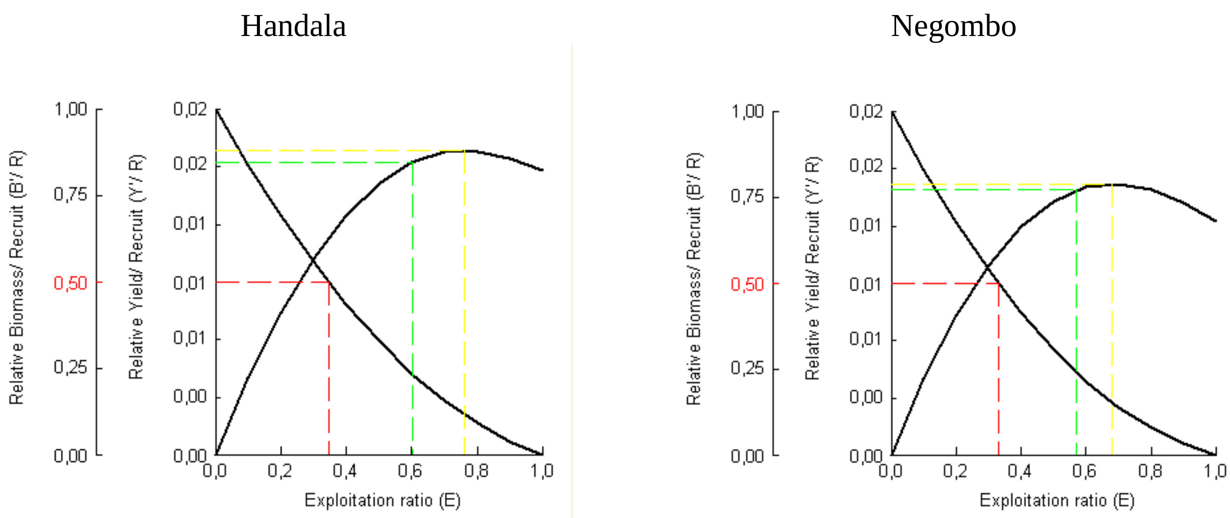


Figure 26: Y'/R and B'/R curves for *M. dobsoni* pooled sex data of Handal and Negombo from 2005-2006. $E_{0.5,}$ $E_{0.1}$ and E_{max} are represented by red, green and yellow colours.

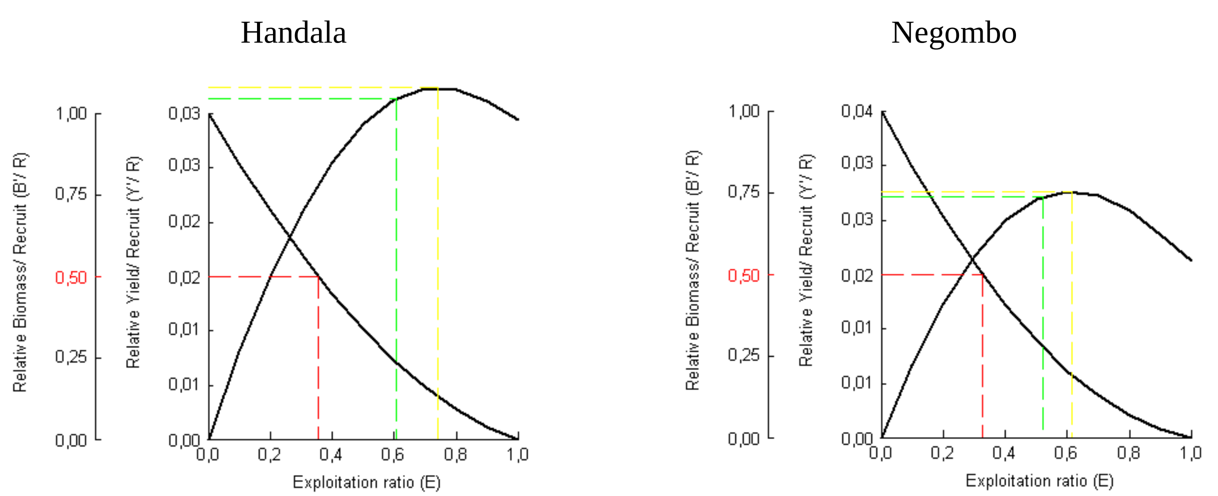


Figure 27: Y'/R and B'/R curves for *P. indicus* pooled sex data of Handal and Negombo from 2005-2006. $E_{0.5,}$ $E_{0.1}$ and E_{max} are represented by red, green and yellow colours

3.4 Dynamic production modelling

Summarised results of the dynamic production model are given in Table 9. The correlation between observed CPUE and predicted CPUE were positive for *M. dobsoni* as well as for the entire shrimp populations in both Handala and Negombo. For *M. dobsoni* correlation between observed and predicted CPUE were 0.578 and 0.795 at Handala and Negombo respectively (Figures 28 and 29) while it was 0.944 and 0.605 respectively for entire shrimp fisheries at Handala and Negombo (Figures 30 and 31).

Table 9: Estimated parameters of *M. dobsoni* and total shrimps, using the non-equilibrium dynamic biomass production model in R.

Species	Site	MSY	f_{MSY}	B_t	F_{MSY}	K	r	q
M. dobsoni	Handala	103.97	16,734	130	0.89	232	1.78	5.3 e^{-5}
	Negombo	151.63	35,637	194.5	1.17	259.4	2.34	3.2 e^{-5}
Entire shrimps	Handala	150.43	12,575	210.4	0.76	395.7	1.52	6.0 e^{-5}
	Negombo	247.69	37,712	371. 6	1.07	462.2	2.14	2.8 e^{-5}

In both fishing locations different maximum yields are sustained at different biomass levels. The maximum sustainable yield of 104 t and 152 t of *M. dobsoni* were obtained from Handala and Negombo respectively. To obtain respective MSY of *M. dobsoni* from Handala and Negombo required fishing effort of 16734 and 35637 fishing-boat days respectively. The MSY of 150 t and 248 t for the entire shrimp fishery were given from Handala and Negombo levels respectively. For the MSY for total shrimp production required 12,575 and 37,712 fishing-boat-days respectively from Handala and Negombo.

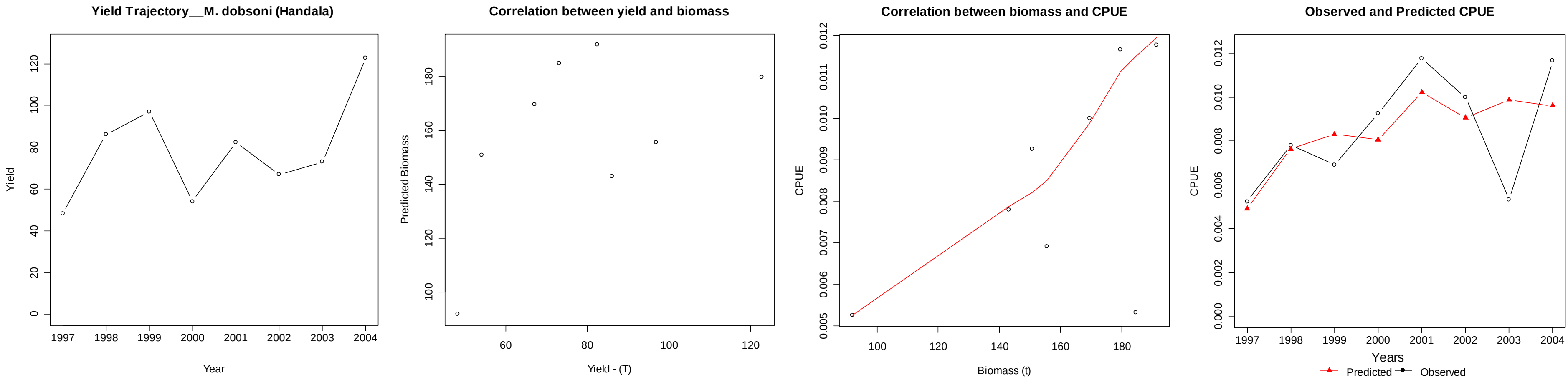


Figure 28: Yield trajectory, correlation between yield and biomass (r^2=0.529), biomass and CPUE and observed and predicted biomass (r^2=0.578) determined by the dynamic production model for *M. dobsoni* in Handala

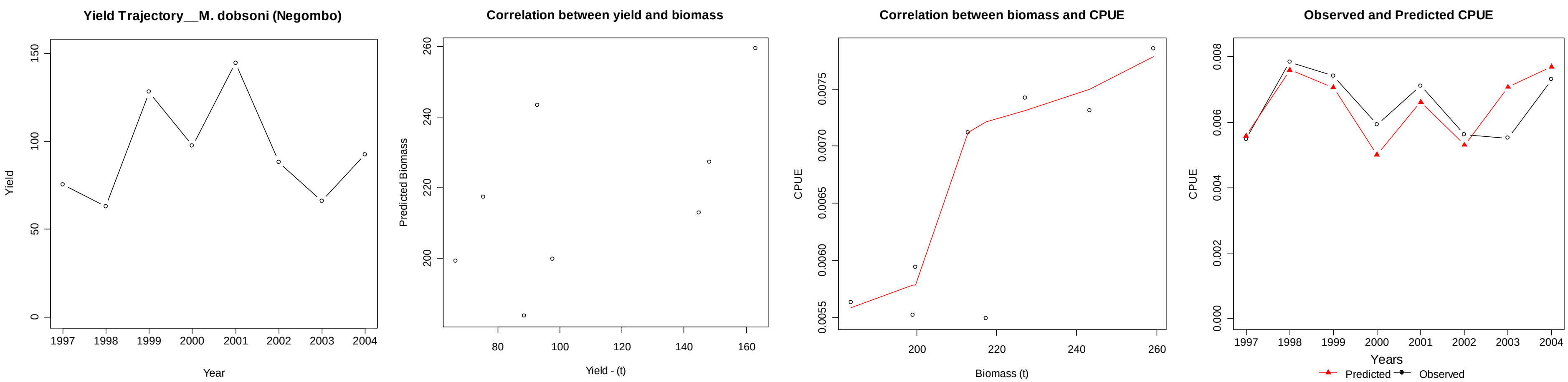


Figure 29: Yield trajectory, correlation between yield and biomass (r^2=0.583), biomass and CPUE and observed and predicted biomass (r^2=0.823) determined by the dynamic production model for *M. dobsoni* in Negombo

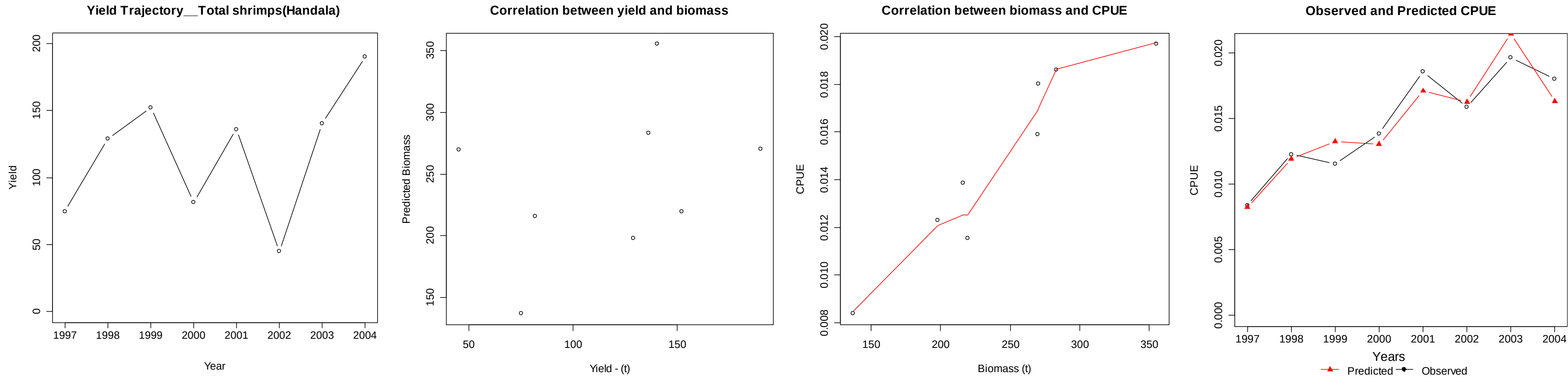


Figure 30: Yield trajectory, correlation between yield and biomass (r^2=0.343), biomass and CPUE and observed and predicted biomass (r^2=0.945) determined by the dynamic production model for all shrimps in Handala

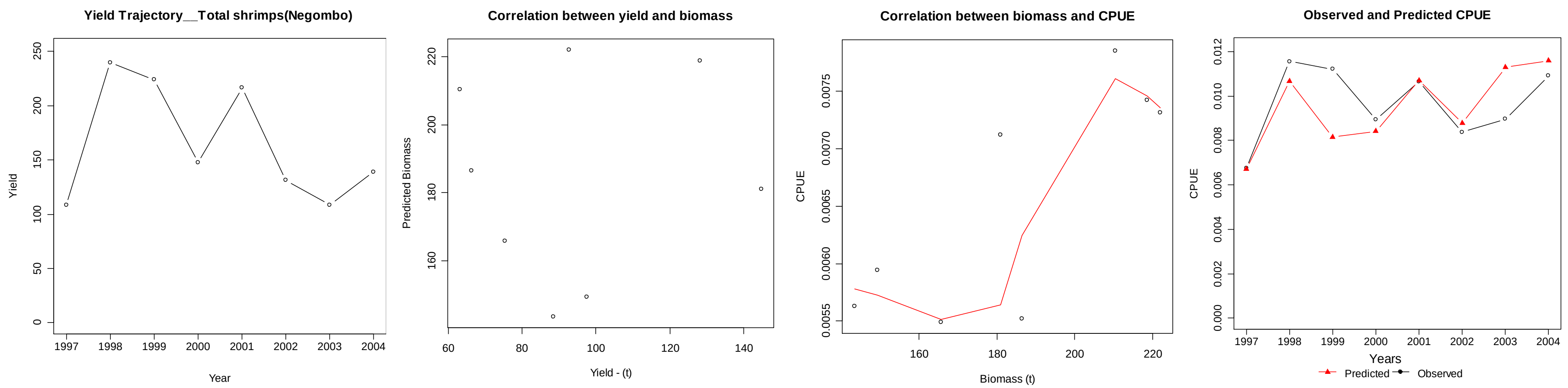


Figure 31: Yield trajectory, correlation between yield and biomass (r^2=0.174), biomass and CPUE and observed and predicted biomass (r^2=0.795) determined by the dynamic production model for all shrimps in Negombo.

Figures 32 and 33 show yield trajectories in relation to the predicted biomass from 1997 to 2004. The model reveals that the yield trajectories are on the right descending portion of the predicted biomass indicating the biomass was greater than B_{MSY}. As the model indicated both *M. dobsoni* and 'total' yield in Handala were well below the MSY except slight increased experienced in 2004. Also in 1999 entire shrimp yields were close to the MSY in Handala.

In Negombo both *M. dobsoni* and 'total' yields were well below the MSY throughout the

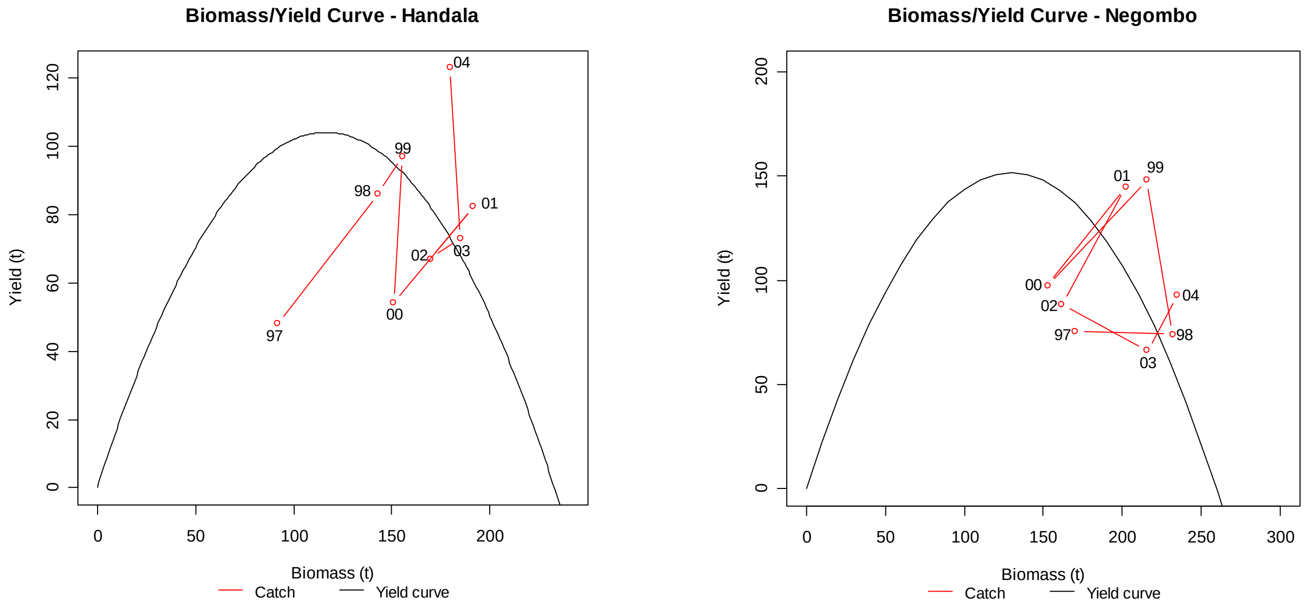


Figure 32: Biomass and yield curve of *M. dobsoni* in Handala and Negombo showing observed catch and predicted yield trajectory from 1997 to 2004.

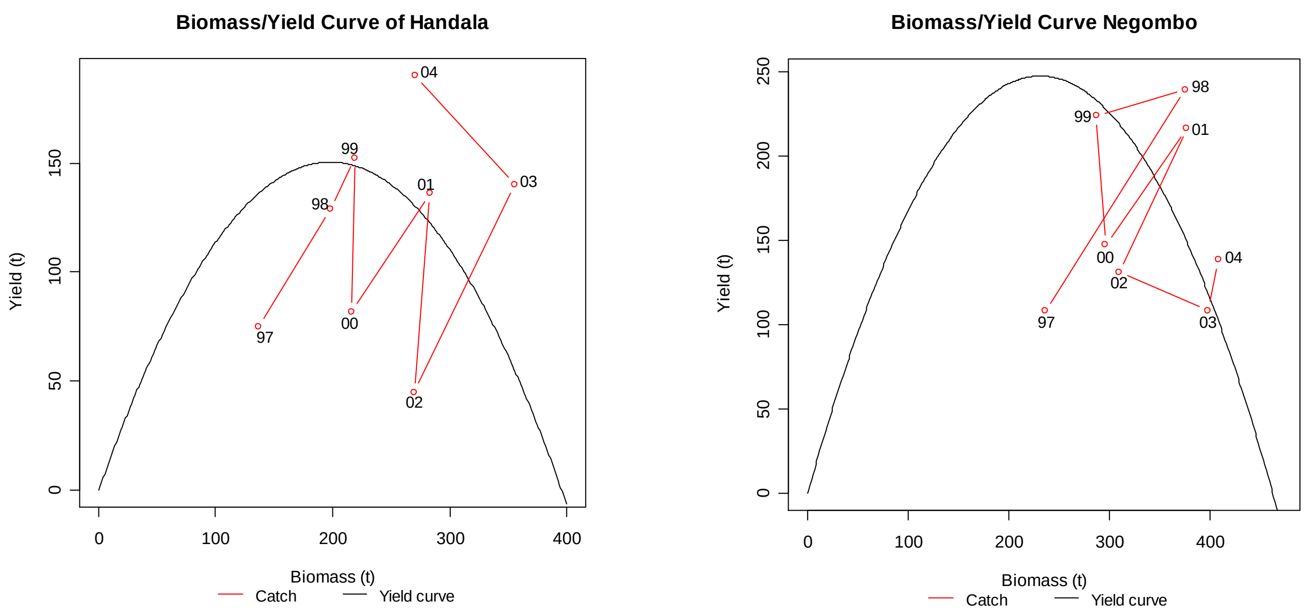


Figure 33: Biomass and yield curve of entire shrimps in Handala and Negombo showing observed catch and predicted yield trajectory from 1997 to 2004.

study period, while in 1999 yields are closer to MSY. Though the entire shrimp yield from Negombo in 1998 was closer to MSY, the entire *M. dobsoni* yield was well below.

Though there is a slight production increase recorded from Handala in 2004, it should be noted here that almost all marine fisheries in Sri Lanka were not operated for 3-4 months after the 'Tsunami' in December 2004.

4 DISCUSSION

4.1 Catch and effort

The production of shrimp trawling off the western coastal waters of Sri Lanka shows high monthly variations. The highest maximum CPUEs were evident from May to August. From May to September shrimp catch became higher than the by-catch in both fishing grounds indicating that this is the most suitable season for shrimp trawling. This is in line with the findings of Jayawardana *et al.* (2004) and De Bruin *et al.* (1994), who have also reported the same season for the shrimp fishery off the western coast of Sri Lanka. This coincides within the southwest monsoonal period in Sri Lanka.

The present analysis therefore confirms that this is significantly higher than those recorded during the northeast and inter monsoonal periods. According to the findings of Lhomme and Garcia (1984) and Garcia and Le Reste (1981), mass migration of shrimp towards the spawning grounds in coastal waters from estuarine areas is influenced by the osmotic stress occurred due to various climatic and physiochemical factors such as rainfall, water level, currents, salinity and temperature fluctuations. Hence, it is reasonable to assume that adult shrimps migrate towards the spawning grounds with the onset of the southwest monsoon (May – September) due to the osmotic stress occurred as a result of low salinity waters with the monsoonal rainfall. This results in high shrimp production and relative abundance in the shrimp trawling waters in the western coast of Sri Lanka.

According to the previous studies conducted by Jayawardena *et al.* in 2004 and Jayakodi in 1984 (Jayawardena *et al.* 2004) 'catch rates' (kg/hour) have been used as an index for comparing the stock abundance of the non-mechanised shrimp trawl fishery in Negombo. But the area which can be trawled by the sailing trawls is totally dependent on the strength of wind velocity. Hence, use of 'catch rates' as an index for comparison of stock abundance or gear efficiency is doubtful unless the wind velocity has been taken into consideration for gear efficiency standardisation. On the other hand, the trawling areas for both Negombo and Handala are well defined by regulations to avoid the overlapping of trawling grounds (Jayawardena *et al*. 2004). Therefore, fishermen used to trawl more or less a similar area each day within the boundaries. After completing a haul, direction of the vessel will be reversed and trawled towards the starting point. After each hauling trawl catch will be taken in before reversing the vessel. Hence, it is reasonable to assume that the trawlers cover a constant trawling area despite the wind velocity. Furthermore, the trawling efficiency can also be considered as more or less equal in Negombo as all the coastal trawling areas around Sri Lanka have similar topographic characteristics as smooth muddy bottoms described by Jayawardena *et al.* (2004). Owing to the above facts, in this study, abundance of shrimp was compared in terms of kg/haul in determining the monsoonal effects.

The estimated mean CPUE for the period of 1997 to 2004 from Negombo during the northeast, southwest and inter-monsoons were 2.90, 4.06 and 3.24 kg/haul respectively while in Handala mean catches were 1.22, 5.94 and 2.32 kg/haul respectively for the same monsoonal periods. Disregarding the monsoonal effect average catch rates reported by Jayawardena *et al.* (2004) for the period 1998 - 1999 were 3.8 and 3.93 kg/haul from Negombo and Handala fisheries respectively. In 1984 Jayakodi has reported (Jayawardena *et al.* 2004) catch rates for Negombo non-mechanised fishery as 2.6 kg/hour and 2.9 kg/hour for the period 1979-80 and 1981-81 respectively.

For the purpose of production calculation, CPUE was considered as kg/fishing-days as described in the methodology. Further, slightly high CPUE can be identified from Negombo during March and November indicating relatively high abundance of shrimp. Perhaps this might be due to closeness of Negombo trawling grounds to the estuary mouth where shrimps migrate towards and outwards of the estuary during the onset and later of the southwest monsoon.

Estimated annual shrimp production was higher throughout the study period in Negombo than in Handala except 2003 and 2004. This might be attributed to the fact that in Handala fishermen have a tendency to shift to alternative fisheries during the non-monsoonal period where low catches are experienced, but in Negombo traditional non-mechanised boats are operated throughout the year with more or less similar efficiency resulting in higher annual shrimp production than the mechanised trawl fishery in Handala.

Total annual shrimp production in this study for the year 1998, for Negombo (239 t) and Handala (128 t) was in similarity with the values reported by Jayawardena *et al.* (2004) as 245 t and 129 t respectively. A clear drop in production was evident from Handala in 2002. The factors which could be assumed to be responsible for the sudden decline in total shrimp production at Handala in 2002 have not been documented. Interestingly CPUE values for 2002 were high and there were no observations of low shrimp CPUEs from 2000 until 2004 during this study from Handala. As the present analysis reveals the sudden drop in total shrimp production at Handala in 2002 must be attributed to the low fishing effort implemented specifically during the most productive fishing period (May-September). But the reason for this low fishing effort has not been documented. Even this drop in fishing effort during 2002 was evident from Negombo resulting in low shrimp production, though the production drop is not as prominent as in Handala. Further, the present study confirms that both fisheries are recovering after the sudden drop in 2002, although the recovery rate in Negombo seems relatively lower than Handala. The analysis of the shrimp production patterns and the correlation between the shrimp production in the two sites have confirmed that so far the two fisheries are functioning independently without influencing the production of each other.

Though there is a high positive correlation between monthly shrimp production and monthly fishing effort, the declining production trends expected at higher fishing efforts were not evident from both fisheries during the eight years studied. Perhaps this must be mainly due to non-implementation of higher fishing effort where the production decline could be experienced. The observed low fishing effort levels might be due to the suppressing influence generated by local shrimp markets where there is a higher demand only for the newly caught fresh shrimps. On the other hand even the implemented higher fishing efforts might not have a significant effect on these short-lived shrimps but this aspect has not been discussed much in the literature.

Of total trawl catches, the percentage mean annual shrimp contribution estimated for the period 1997-2004 was 55% (non-mechanised) and 44% (mechanised trawling) and these values were completely different from the mean values reported for the period 1998-99 by Jayawardena *et al*. (2004) as 60% (non-mechanised) and 64% (mechanised trawling). Even from this study, the mean percentage contribution of mechanised trawls estimated only for the period 1998-99 (48.5%) for the purpose of comparison, did also differ a lot from the values reported by Jayawadena *et al.* (2004) but the estimated non-mechnised shrimp trawling value for 1998-99 period (5 %) was closer. According to Jayawardena *et al.* (2004) a higher mean percentage shrimp contribution resulted in mechanised trawling but according to the present study the mean percentage contribution calculated for 1997-2004 and even 1998-1999 emphasised the high percentage contribution of shrimp resulting from non-mechanised trawling.

In this study, there are six shrimp species and 28 by-catch finfish species in the catches. Four shrimp species out of six have also been reported by Jayawardana *et al.* (2004) but no report on *Penaeus monodon* or *Penaeus semisulcatus.* On the other hand, findings of this study reveal that the percentage contribution of *P. monodon* and *P. semisulcatus* is less than 1%. The mean percentage contribution of *M. dobsoni* and *Parapenaeopis coromondalica* to the total catch were 66 and 28% respectively from non-mechanised trawling while Jayawardena *et al.* (2004) reported their contribution together as 58% from non-mechanised trawling for the period 1997-98. Similarly the combined value reported by Jayawardena *et al.* (2004) for *M. dobsoni* and *P. coromondalica*, for mechanised trawling was 59% but this study estimates 62% and 28% separately for *M. dobsoni* and *P. coromondalica.* Though the percentage contribution of *P. indicus* is less than 3% it is considered an important species due to its higher commercial value.

4.2 Population dynamics

The length frequency plots constructed for both *P. indicus* and *M. dobsoni* from coastal trawl samples also confirm the abundance and new recruitments observed in coastal areas from May to September in both Negombo and Handala fisheries.

The use of modal progression in length-frequency plots of sequentially sampled fish populations is a well-established method of determining growth rates. But as described by Pauly and Morgan (1987), accurate ages can only be determined, if the cohort of length frequency distribution plots is followed from first hatching. Analysis of monthly or weekly time interval sampling has been suggested by Garcia (1988) for tropical shrimps with high growth rates and seasonality within their short lifespan. Further, monthly time series analysis has been presents by Pauly and Palomares (1989) in determining the population dynamics of short-lived anchoveta species (*Engraulis ringens*). Hence use of monthly sequential data is more appropriate for this study as the tropical shrimps have short lifespans and seasonality (Garcia 1988).

Though the actual growth curve of individual crustaceans shows a stepwise pattern which is influenced by their moulting, Sparre and Veneman (1992) have shown that average growth curves of cohorts becomes smoother with conformity with the von Bertalanffy model as individuals in a cohort moult at different times. Further, Parrack (1979), Garcia and Le Reste (1981), and Frechette and Parsons (1983) have confirmed that the average body growth of crustacean is in conformity with the von Bertalanffy model. So the use of the von Bertalanffy model to calculate growth parameters in shrimps is a common practice.

The growth parameters (L_α and K) were estimated based on the approximation of L_∞ values by the Wetherall method (Wetherall 1986, Wetherall *et al.* 1987). However, Pauly (1986) has discussed the risk of using the Wetherall method with a limited number of data sets which could lead to unreliable results, but the present investigation is based on randomly selected large samples with a proper sampling design.

The estimates of asymptotic lengths and growth constant values of this study are in the range of values reported by Jayawardena *et al.* (2002) for the west coast (both Negombo and Handala) for *P. indicus* males (19.2 cm and $1.51y^{-1}$ respectively) and females (19.1 cm and 1.8 y^{-1} respectively). Also the asymptotic lengths recorded for *M. dobsoni* in the present study were not much different when compared to the values reported by Jayawardana *et al.* (2003) as 11.49 cm and 12.8 cm for males and females respectively but growth constant values recorded for *M. dobsoni* in present study were slightly lower than the values reported for males (1.02 y^{-1}) and females (1.73 y^{-1}) in the period 1998-2000 by the same authors through the same study. According to Sparre and Venema (1992), the high growth rate constant is evident especially for the short lived species. So high K vales for *P. indicus* and *M. dobsoni* can be obvious because K is a curvature parameter of the growth-curve which determines how fast the shrimp approaches its asymptotic length. Out of the coastal waters of Sri Lanka, a similar range of asymptotic lengths and growth constants for *P. indicus* has been reported in the coastal waters of Bangladesh by Khan and Latif (1995) as 22.83 cm and 0.5 y^{-1} respectively. From Indian waters the asymptotic lengths and growth constants of *P. indicus* have been reported by Devi (1986) as 21.84 cm and 2 y^{-1} while Agasen and Mundo (1988) have reported 20.6 cm and 1.2 y^{-1} for south India.

Generally the growth index (ø´) is used to evaluate the reliability of the L_∞ and K estimates. As suggested by Moreau *et al.* (1986) in open water environmental conditions, fish either grow rapidly towards a small size (high K, low L_∞), or slowly towards a large size (low *K*, high L_∞). Hence, according to Pauly (1991) the (ø´) remains more or less constant among different populations of the same species. Therefore, species belonging to the same family are supposed to have similar ø´ values, as ø´values are normally distributed. Hence, the growth index (ø') estimated for *P. indicus* and *M. dobsoni* from Handala and Negombo were compared and the values are in the similar range. Furthermore, the growth index (ø′) reported for *P. indicus* males (2.74) and females (2.84) by Jayawarena *et al.* (2002) was close to the preset estimated values but ø′ reported for *M. dobsoni* males (2.16) and females (2.44) by Jayawarena *et al.* (2003) were slightly higher than the values obtain from the present study. Also the present study is in conformity with the finding of growth index (ø′) values reported for *M. dobsoni* in the region by Benerji and George (1967), Ramamurthy *et al*. (1978), Achuthankutty and Parulekar (1986) in India. As the estimated growth index (ø′) of *P. indicus* and *M. dobsoni* are within the range of values reported from the region, can rely on accuracy of estimates of present study as suggested by Moreau *et al*. (1986).

Mortality (fishing and natural mortality) rates are important for understanding the rate of population decay and present estimates of Z, M and F of *P. indicus* and *M. dobsoni* from both Negombo and Handala were relatively higher. Both *P. indicus* and *M. dobsoni* are fast-growing species with short lifespans and high rates of reproduction which are features typically associated with r-selected species. Comparatively both *P. indicus* and *M. dobsoni* females have high F and Z rates compared to males in both habitats except the slightly lower values recoded for the *P. indicus* females in Negombo. Perhaps higher F rates in females can be attributed to the fact that they are more vulnerable to fishing gear during the time of spawning due to their biological conditions and physiological lethargic conditions. Garcia (1988) has found fishing mortality to be around 1.6 ± 0.3 per year in fairly well-developed fisheries where catch and effort have been stable for a long time after an initial period of rapid increase.

Further, calculated M rates of female *P. indicus* and *M. dobsoni* in Negombo and Handala were higher than for the males. According to this study, estimated natural mortality rates (M) of *M. dobsoni* using Pauly's (1980) empirical equation were reasonably close to the M values calculated by Jayawardena *et al.* (2003) for males (1.72 yr^{-1}) and females (2.51 yr^{-1}) by Rikhter and Efanov's formula (Rikhter and Efanov 1976). Similarly the M value calculated for *P. indicus* by Jayawardena *et al.* (2002) using the same method for both male and female pooled data (1.73 yr^{-1}) were slightly lower than vales obtained for this study by Pauly's (1980) empirical equation. Usually M is a difficult parameter to estimate in an exploited resource (FAO 1993). According to Sparre *et al*. (1989) most of the procedures rank no higher than 'qualified' guesses.

The probability of capture for trawl nets was estimated by extropalating length-converted catch curve analysis through backward projection of the numbers expecting no selectivity by the gear. These extropalated points were then used for the estimation of selection parameters (Gayanilo and Pauly 1997). This selectivity pattern was used in the Y′/R analysis as it was assumed to have knife-edge type of gear selectivity.

The estimated sizes at 25, 50 and 75% probability of capture of males and females of *M. dobsoni* and were comparatively lower than the values reported for the period 1998-1999 by Jayawardanae *et al*. (2003) for mechanised trawling in Handala by around 2-3 cm. Similarly the estimates of Jayawardanae *et al*. (2002) for probabilities of capture at 25, 50 and 75% of *P. indicus* males and females from non-mechanised and mechanised trawling for the years 1998-1999 were also higher by 2 - 3 cm than the present estimated values. No documentary evidence, reports or witness on mechanised and non-mechanised trawl net modification during the past decades from Handala and Negombo for the observed comparatively lower probability of capture values from this study than Jayawardena's reports on 1998-99 period. Nevertheless, according to the estimated values, it is reasonable to assume that both trawl nets have approximate knife-edge selection, hence it can be used in Y´/R and B´/R model as the knife-edge type of gear selectivity is required by the model.

Traditional fisheries advice has always been based on size at sexual maturity to fix minimum L_{50}. As only the matured spawners are migrated towards the coastal area, the chances are lower for immature individuals to become vulnerable for the coastal trawling at Negombo and Handala. However, it is essential to estimate the length at first maturity in order to determine whether the fishing gear adversely affects shrimps before they are matured. Though female individuals have relatively higher mean length values, almost all females except *P. indicus* from Negombo were reported to have lower L_{50} values compared to males. The relatively lower L_{50} values observed in many female shrimps can be attributed to their biological and behavioural characteristics, gained during the egg bearing stages.

The estimated shrimp recruitment patterns in the present study conform to estimated shrimp productions. The high contribution of *M. dobsoni* to the total shrimp catches during May-August from Handala and Negombo must be due to the higher percentage of recruitment occurring in the same period. The highest percentage contribution (around 62%) of *M. dobsoni* to the total shrimp catch seems to be masking the elevated *P. indicus* production resulted by two distinguishable high recruitment peaks.

4.3 Relative yield per recruit (Y´/R), biomass per recruit (Y´/R) and dynamic production modelling

The current exploitation rates of both *P. indicus* and *M. dobsoni* reported from Handala and Negombo are well below the E_{max} calculated by the yield per recruit (Y´/R) model, hence one can assume that there is no threat of over-exploitation at the moment. But the Y´/R model works best when applied to species with low mortality rates (when natural mortality is less than 0.6) in which case yield per recruit curves reach a maximum at relatively low levels of fishing mortality. From a practical viewpoint, yield per recruit is maximised at low values of E only in the case of large, long lived, low mortality fishes (Silvestre *et al*. 2004). But in the case of tropical species with high values of M, a yield per recruit curve may not reach a maximum within a reasonable range of maximum mortality values (Silvestre *et al*. 2004). Hence, the results of yield per recruit analysis might be misleading, often suggesting that an extremely high fishing mortality F (or E) is required to secure the maximum yield (Gulland 1983, Pauly and Munro 1984). As a result an agreement emerged to generally limit fishing mortality to the point where the slope of the yield-per-recruit curve has one tenth of its value at the origin of the curve ($E_{0.1}$). Therefore, consideration of $E_{0.1}$ as the target reference point is reliable. Even the calculated present exploitation rates of *P. indicus* and *M. dobsoni* in Handala and Negombo are lower than the target reference point. Furthermore, the exploitation rates estimated separately for males and females of *P. indicus* and *M. dobsoni* resulted in lower values than $E_{0.1}$ emphasising that there is no threat of over-exploitation of the stock at the moment. As described by Gulland and Boerema (1973) and Gulland (1983) there is no biological reason for selecting $E_{0.1}$ as a reference point, but as this level of fishing mortality is lower than that required to obtain the maximum yield it is believed to provide greater profitability and a buffer against recruitment over-fishing.

Dynamic production models rely on having a time series of accurate catch effort data and it assumes that catch rates are reliable indices of biomass. Though it has been suggested that the results from fishery-independent research surveys are preferred as an index of abundance, it can be used with commercial fishery data collected on properly planned randomised sampling strategy for this sort of analysis for some extent (Cooke and Beddington 1984, Quinn and Deriso 1999). Further, TemaNord (1999) has also suggested the possibility of using CPUE and effort data of commercial fisheries for this analysis. Hence, in the present study CPUE data were obtained from commercial fisheries as an index of abundance in analysing the dynamic biomass models. Independent estimates of population parameters calculated through FiSAT were helped in determining the starting guesses when fitting the model to catch data. Maximum sustainable yield of *M. dobsoni* estimated through the non-linear minimisation technique for Negombo (158.3 t) and Handala (103.97 t) were relatively closer to the values reported by Jayawarden *et al.* (2003) by the Thompson and Bell yield and stock prediction model (Thompson and Bell 1934) for Negombo (128.95 t) and Handala (109.8 t) for the period of 1998-1999. The present estimate of *M. dobsoni* MSY is above the mean current production calculated for the period 1997-2004 for Negombo (109 t, ranging 66 to 148 t) and Handala (73 t ranging from 46 to 122 t). Though the dynamic production model describes the changes in biomass considering the mortality (F, M) and L_∞ and K values of species, an attempt was taken to estimate the MSY of whole shrimp biomass as all major shrimps (62% contribution from *M. dobsoni*), are having a more or less similar range of population parameters. Even these estimated MSY for ‘total shrimps’ were well above the currently exploited values of Negombo (average 164 t ranging from 108 to 239 t) and Handala (125 t ranging from 44 to 190 t). Existing mean annual fishing effort calculated in this study for the period 1997-2004 for Negombo (average 16129 fishing-boat-days ranging from 15144 to 20112 fishing boat-days) and Handala (average 7612 fishing boat-days ranging from 4082 and 10896 fishing boat-days) were below than the estimated respective f_{MSY}.

Estimates of MSY through yield per recruit (considering the length frequency data) and dynamic production models with non-linear least squares regression (considering the catch and effort data) shows that shrimp trawl fisheries in Negombo and Hadala are not facing a potential threat of being over-exploited with current fishing efforts as they operate well below the f_{MSY}. Though the MSY and f_{MSY} calculated in this study were within the range of reported values by Jayawardena *et al*. (2003) for the period of 1998-99, their estimated exploited production quantities are higher than the estimates of this study. Hence, the conclusion of Jayawardena *et al*. (2003) was to reduce the fishing effort by 20-30% in 1998-1999. The present study deals with the latest data for a period of eight years. But discrepancy in estimated productions in these two subsequent studies emphasis the continuation of the assessment and monitoring of the shrimp trawl fishery off the western coast of Sri Lanka with a comprehensive study. The findings of the present investigation will be a basis for such a study.

Study of seasonal patterns/population dynamics and the use of dynamic models is important in assessing the present stock status and potential yield. Ultimately, estimates of potential yields and future predictions and forecasting should lead to managerial recommendations, strategies and regulations. Though both Y´/R and dynamic biomass models suggested that there is no threat of over-exploitation at Handala and Negombo fisheries, it is important to implement managerial strategies to utilise the resource sustainably as there had been a slight increase in production in Handala compared to the MSY in 2004. The management in both the commercial as well as the biological point of view, emphasises the importance of identifying the exact time period which maximised the profitability and ensured the survival of a minimum spawning stock. As described by Hill and Agnew (2002) optimal harvesting times depend on natural mortality and growth rates. Many of the tropical shrimp species are short-lived (Garcia 1988). Hence, the exploited portion of the population often consists of a single, short-lived generation. On top of that, their short distance migratory behaviour with respect to the environmental changes (as monsoonal effects) makes them available for different gears in a short period of the year. Hence, changes in their population structure need to be analysed considering their single cohort generation. Recently published literature is available on the management of single cohort squid populations considering depletion estimates of recruitment relations to cumulative catch (Royer *et al.* 2002), variation of spawning stock size with respect to sea surface temperature (Agnew *et al.* 2000) and relatively high spawning mortalites (Hendrickson and Hart 2006). But novel approaches for the development of forecasting models considering unique characteristics of tropical shrimp species are scanty except few stock recruitment relationships evaluations by Pauly (1982). A further level of uncertainty is generated due to highly fluctuating environmental factors and tropical relationships need to be considered when taking approaches to develop forecasting models for short-lived shrimp species considering all the life cycle stages of shrimp.

5 CONCLUSIONS AND RECOMMENDATIONS

With the findings of this study it is clear that there is a potential to maximise the utilisation of highly valuable shrimp resources, which sustain large numbers of fishers in the western coast of Sri Lanka, if managed in an effective way. Further, both Y´/R analysis and dynamic production models conclude that there is no danger of over-exploitation of shrimp stocks. Hence, both the Handala and Negombo shrimp trawl fisheries have the potential to be expanded further up to the MSY. But it is advisable not to increase the existing fishing potential as the implemented models are not specifically developed to address the unique biological and behavioural features of short-lived shrimp species. The study confirmed the significant effect of the southwest monsoonal rain on the short distance spawning migration of shrimps towards the coastal waters. So modification of stock assessment models considering the characteristic features associated with the short lifespan of shrimps and also the level of uncertainty associated with predictions due to so-called environmental and ecological fluctuates is an inevitable immediate requirement for the evaluation of population structures and future forecasting of short-lived tropical shrimp species in a more precise way.

Any initiative towards the management of the shrimp fishery in Negombo and Handala should be an integrated approach as the lagoon and the associated coastal waters are multi species fisheries. Therefore, it is vital to initiate a comprehensive study to investigate the population structure and the ecology of shrimps including the dynamics of recruitment thorough novel approaches of analysis considering the short lifespan of shrimps. So owing to the above factors further study/ or existing sampling programmes can be expanded addressing the following issues:

1) Identification of the boundaries of the shrimp stock/s utilised by Handala and Negombo is the preliminary requirement, as such an approach has not been investigated yet. Molecular biological analysis or tagging approaches can be implemented.
2) The exploitation of the population structure (abundance and size) of the lagoon shrimp fishery through various gears has to be evaluated together with the costal trawling as knowledge of the dynamics of the entire population structure is essential in projecting the stock status. Furthermore, independent fishery surveys should be conducted to evaluate the abundance and distribution of all stages.
3) Collection of monthly sequential physio-chemical measurements of environmental parameters (salinity, rainfall, sea surface temperature, turbidity, current patterns and velocity, wind velocity) will lead to scientific justification of the effects of environmental changes on shrimp migratory patterns. And further, based on these fluctuating environmental parameters, predictions can be made on the uncertainty associated with future forecasting.
4) The knowledge of a fishery's capacity is crucial to its management. The exact number of fishers either directly or indirectly supported by the shrimp stock needs to be estimated and any implementation of a novel strategy should be linked together with the existing community based management systems of the shrimp fishery to make it effective.
5) Detailed information on shrimp trawl by-catch species and their life history because shrimps might be capturing young fish which might have been exploitable by other gears. Also, collection of maturity data in order to analyse the length at 50% maturity will also be useful in determining the impact of the gears.
6) Considering all above information, analysis of the entire stock structure through a novel unique approach giving special emphasis to the biological and physiological characteristics of the shrimps' short lifespan.

ACKNOWLEDGEMENTS

I wish to thank my supervisor Hreiðar Þór Valtýsson (University of Akureyri, Iceland/Marine Research Institute, Iceland) for his advice and guidance for successfully complete this task.

I am especially thankful to the United Nations University for granting me a fellowship to participate this Fisheries Training Programme, which is a remarkable milestone in my career.

My sincere gratitude to Dr. Tumi Tómasson (Director of the UNU-FTP) and Þór H. Ásgeirsson (Deputy Director) and Professor Gunnar Stefansson (University of Iceland/Marine Research Institute, Iceland) for their enlightening comments and suggestions in the preparation of this report.

I wish to thank Dr. Guðmundur Þórðarson (Marine Research Institute, Iceland) for his valuable guidance, help and support for broadening my understanding on the R package.

I acknowledge the help of Sigríður Kr. Ingvarsdóttir and Guðni Magnús Eiríksson (Marine Research Institute, Iceland) during my stay in Iceland and for their encouraging words.

A note of gratitude is also owed to librarians and the other library staff of the Marine Research Institute, Iceland and University of Akureyri, Iceland.

I cannot forget the support given by Lára Guðmundsdóttir (University of Akureyri) during my stay at the University of Akureyri.

My gratitude is extended to the Director General and remarkable staff of the Marine Research Institute (MRI), Reykjavik, and University of Akureyri for the material and moral assistance extended to us during the six month programme 2007-2008. It is a pleasure to acknowledge the support and cheerfulness of all the fellows of UNU-FTP 2007/8.

LIST OF REFERENCES

Achuthankutty C.T & Parulekar A.H. 1986. Biology of commercially important penaeid prawns of Goa waters. Indian journal of marine sciences. New Delhi. Vol. 15, no. 3, pp. 171-173.

Agasen V.E and Mundo C.M.D. 1988. Growth, mortality and exploitation rates of P. indicus in Manila Bay, Philippines and South India. Contribution to Tropical Fisheries Biology. In: The paper presented by the participants of FAO / DANIDA Fellow up training course Venema, S., Christensen, J.M. and pauly D [eds] FAO Fish Rep. 389, Rome 89 - 100

Agnew D.J., J.R. Beddington, and S.L. Hill. 2002 Renewable Resources Assessment Group, Department of Environmental Science and Technology, Imperial College London, Royal School of Mines, Prince Consort Road, London SW7 2BP,United Kingdom. Can. J. Fish. Aquat. Sci. **59**: 1851–1857

Amarasinghe U.S., Chandrasekara W.U. and Kithsiri H.M.P. 1996-1997. Traditional practices for resource sharing in an artisanal fishery of a Sri Lankan estuary. *Asian Fisheries Science* **9**, 311–323.

Anderson, J.L and J.K King. 2003. - The International Seafood Trade, Woodhead Publishing limited, [Nov 20th 2007] Books.google.com.

Anonymous 1978. A survey of the coastal fish resources of Sri Lanka August September. Report on survey with R/V Fridjot Nansen 1- 29.

Benerji, S.K. and George, M.J. 1967. Size distribution and growth of *Metapenaeus dobsonai* (Miers) and their effect on the trawler catches off Kerala. Proceedings of the Symposium on crustaceans. Marine Biological Association of India part 2: 636 - 648

Berg, S. E (1971). Invstigations on the bottom conditions and the possibilities for marine prawn and fish trawling on the north east coast of Sri Lanka. Bulletine of Fisheries Research station of Sri Lanka 21 (2): 67-73

Berry R.J 1967. Dynamics of the Tortugas (Florida) pink shrimp populations. Ph.D. Thesis University of Rhode Island, University of Microfilms, Michigon 160 p

Beverton, R.J.H., Holt, S.J., 1966. Manual of methods for fish stock assessment. Part 2. FAO Fisheries Technical Paper, vol. 38, Rev. 1, 67 pp.

Broadhurst M.K., P. Suuronen, Petri and A. Hulme 2006. Estimating collateral mortality from towed fishing gear, F I SH and F I SHERI E S , 2006, 7, 180–218

Brothers,E.B.1980. Age and growth studies on tropical fish P 119 – 136 In Saila, S and Roedel P. (Eds) Stock Assessment for small scale fisheries proceedings of an international workshop held in September 19 – 21 1979. Centere for Marine Research Division, University of Rhode Island

Central Bank of Sri Lanka (2004) *Annual Report*. Central Bank of Sri Lanka, Colombo.

Central Bank of Sri Lanka (2005) *Annual Report*. Central Bank of Sri Lanka, Colombo.

Chestnoy, V.N 1970. The adaptive variations in catchability of trawls on the Wedge bank. Bulletin of Fisheries Rsearch Station of Ceylon. 21 (1): 39-47

Cooke, J.G., and Beddington, J.R. 1984. The relationship between catch rates and abundance in fisheries. IMA *Journal of Mathematics Applied in Medicine and Biology* 1: 391–405

Dall, W., B.J. Hill, P.C. Rothlisberg and D.J. Sharples. 1990. *The biology of the penaeidae. In : Advances in Marine Biology* (eds J. H. S. Blaxter and A. J. Southward). **27**. Academic Press London. 489 pp

Dayaratne, P., O. Linden and R. De Silva 1997. The Puttlam / Mundel estuarine System and Associated coastal waters. A report on environmental degradation, resource management issues and options for their solutions PP 1- 70

De Bruin, G.H.P. 1965. Penaeid prawns of Ceylon, Decapoda (Penaeidae). *Zool. Medded.Decl.* **41** (4) : 73-104,

De Bruin G.H.P. 1970. The distribution of penaeid prawns in Ceylon waters. *Bulletin of Fisheries Research station of Sri Lanka* **21**, 67–73.

De Bruin, G.H.P. 1971. Fluctuation in species composition of prawns in estuaries. *Bulletin of Fisheries Research Station of Sri Lanka.* **22** (1/2) : 47-51

De Bruin, G.H.P., B.C. Russell and A. Bogusch 1994. The Marine Fishery Resources of Sri Lanka, FAO species Identification guide for fishery purposes. FAO, Rome

Devenport J, Ekaratne S.U.K., Walgama S.A, Lee D.and Hills J.M. 1999. Sucessful stock enhancement of lagoon prawn fishery at Rekawa , Sri Lanka using cultured post – larvae of penaid shrimp. *Journal of Aquaculture* ***180*** (1 -2): 65 - 78

Devi S.L 1986. Growth and population dynamics of the Indian white prawn Penaeus indicus H M Edwards from Kakinada. Proceeding of Indian academic Science, Animal science. Vol. 95, no. 5, pp. 629-639. 1986.

Dissanayake, DCT 2006. Monitoring and Assessment of offshore Fishery in Sri Lanka. *Final project report submitted for United Nations University Fisheries Training Programme*, Rekjavik, Iceland

Dore I. and Frimodt C. 1987. *An illustrated guide to shrimp of the world*. Osprey books.P.O. Box 965, Huntington, New York 11743, USA and Scandinavian Fishing year book, Hedehausene, Denmark, 229 p.

Eayrs, S. 2007. A Guide to Bycatch Reduction in Tropical Shrimp- Trawl Fisheries, Revised edition. Rome, FAO.

Edwards, R.R.C. 1978. The fisheries and fishery biology of penaeid shrimps on the Pacific coast of Mexico, Oceanogr. Mar. Biol., 16, 145-80.

FAO 2003. Fisheries sector study of the Northeast province of Sri Lanka. FAO, Rome

Fischer W. & Bianchi G. 1984. FAO Species Identification Sheets for Fishery Purposes. Western Indian Ocean Fishing Area 51. Rome: FAO

Forster, J.R.M. 1970. Further studies on the culture of prawns, Pelaemon, *Serratus pennat* with emphasis on the post larval stages. Fish. Invest. Ser 11, **26** (6) 40 p

Frechette, J. and Parsons, D.C. 1983. Report of shrimp ageing workshop held at Ste Foy, Quebec, in May and at Dartmouth, Nova Scotia, in November 1981 , NAFO Sci.Coun. Studies, 6, 79-100.

Funegaard, P. 1986. Shrimp seed-any to sell. Come to Sotkhira, Bangladesh, Bay of Bengal News, 22, 2-6.

Gabriel, K., K. Lange, E., E. Dahm and T. Wendt 2005. Von Brandt’s Fish catching methods of the world (4th edition) Blackwell publishing Limited. UK

Garcia. S. 1984. Environmental aspects of penaeid shrimp biology and dynamics, in Gulland, J.A. and Rothschild, B.J. (Eds), Penaeidshrimps-Their Biology and Management,pp. 268-71, Fishing New Books, Farnham, UK.

Garcia S. 1988. Tropical penaeìd prawns Fish Population Dynamics (Second Edition), Edited by I.A. Culland by John Wiley & Sons Ltd

Garcia, S. and Le Reste, L. 1981. Life cycles, dynamics, exploitation and management of coastal penaeid shrimp stocks, FAO Fish. Tech. Pap., 203, 215.

Gayanilo F.C. Jr. and Pauly D. 1997. The FAO-ICLARM Stock Assessment Tool (FiSAT) Reference manual. FAO Comput. Info. Ser. (Fish.) 8, FAO, Rome. 262 p.

Grant, W. and Grifin, W. 1979. Bioeconomic model of the Gulf of Mexico shrimp resources, Trans. Amer. Fish. Soc., 108, 1-13.

Grey D.L., Dall W. and Baker A. 1983. *A guide to Australian penaid prawns*. Published in Darwin by the Department of Primary production of the Northern Territory national library of Australia. Cataloguing in publication Entry 139 p.

Gulland J.A 1983. Fish Stock Assessment: a manual of basic methods. FAO/Wiley Series on Food and Agriculture. John Wiley and Sons, Chichester.

Gulland J. A. 1984. Introductory guidelines to shrimp management. Some further thoughts. In: Penaid shrimps their biology and Management. Gullanad J.A. and Rothschild, B.J. [eds] 290- 299

Gulland, J.A and Boerema, L. K 1973. Scientific advice on catch levels. National Oceanographic and Atmospheric Administration Fishery Bulleting. U.S 71 (2), 325-35.

Gulland, J.A. and Rothschild, B.J. (Eds) 1984. Penaeid Shrimps-Their Biology and Management, p. 308, Fishing New Books, Farnham, UK. Gutland and Rothschild 1984

Haddon, M. 2001. *Modelling and quantitative methods in fisheries*. Chapman and Hall/CRC. New York .

Hendrickson L. and Hart 2006. An age-based cohort model for estimating the spawning mortality of semelparous cephalopods with an application to per-recruit calculations for the northern shortfin squid, *Illex illecebrosus* Fisheries Research, Volum 78, Issue 1, 4-13

Hilborn, R. and Walters, C. 1992. *Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty*. Chapman and Hall, New York.

Hill S. and Agnew D.J 2002. Optimal harvest strategies for single-cohort squid population. Bulletin of Marine science, 71 (1): 371 -381.

Holthuis, L.B. 1980. FAO species catalogue. Vol. 1 : Shrimp and prawns of the world. An annotated catalogue of species of interest to fisheries, FAO Fish. Synop., 125, 1, 271.

Jaawardene P.A.A.T., D.S. McLusky and P. Tytler 2002. Estimation of Population Parameters and Stock Assessment of *Penaeus indicus* (H. Milne Edwards) in the Western Coastal Waters of Sri Lanka. *Asian Fisheries Science* Asian Fisheries Society, Manila, Philippines. **15** :155-166

Jayawardena P.A.A.T and H. A. R.E Perera 2003. Observations on the artisanal stake net fishery for shrimps in the Negombo Lagoon, Sri Lanka. *Fisheries Management and Ecology*, **10**, 41–50

Jayawardene P.A.A.T., D.S. Mclusky and P. Tytler 2003. Population dynamics of *Metapenaeus dobsoni* from the western coastal waters of Sri Lanka Fisheries Management and Ecology, 10,179–189

Jayawardene P.A.A.T., D.S. Mclusky and P. Tytler 2004. Present status of the shrimp trawl fishery in the seas off Negombo and Hendala on the western coastal waters of Sri Lanka

Jayawickrama, S.J.C. 1992. Comparative study of the prawn trawl fishery of Negombo and Chilaw. M.Sc. thesis University of Colombo. Sri Lanka. 89p.

Joseph B. D. L 1984. Two hundred mile exclusive economic zone and fishery development of Sri Lanka. Jornal of the National aquatic Resource Agency, Sri Lanka 32 (1/2): 25-34.

Joseph, B.D.L. 1999. *Management of shark fisheries in Sri Lanka*. FAO Fisheries Technical paper 378/1. FAO: Rome.

Kennelly S. J. 2007. By-catch Reduction in the World's Fisheries (Reviews: Methods and Technologies in Fish Biology and Fisheries), Springer, Netherland

Khan G. and M.A. Latif 1995. Potentials, constructions and strategies for conservation and management of open brackish water and marine fishery resources, Fisheries and Aquaculture department. National Workshop on Fisheries Resources Development and Management in Bangladesh - Bay of Bengal Programme**.** Project reports (not in a Series) - REP74

King K. 2007. Fisheries biology assessment and management (second edition) Fishing news books. Blackwell Publishing.

Kirkwood, G.P., Aukland, R. and Zara, S.J. 2001. Length Frequency Distribution Analysis –*LFDA version 5*. MRAG Ltd, London, UK.

Leung P. and Engle C 2006. Shrimp Culture: Economics, Market, and Trade, World aquaculture society and Blackwell publishing , USA

Lhomme, F. and Garcia, S. 1984. Biologie et exploitation de la crevette penaeide au Senegal, in Gulland, J.A. and Rothschild, B.J. (Eds), Penaeid Shrimps-Their Biology and Management, pp. 11 1-44, Fishing News Books, Farnham, UK.

Ministry of Fisheries (MOF) Sri Lanka. 2007. [December 2007] <http://www.fisheries.gov.lk/>

Moreau J., Bambino C. & Pauly D. 1986. Indices of Overall Growth Performance of 100 Tilapia (Cichlidae) Populations. In: J.L. Maclean,L.B. Dizon & L.V. Hosillos (eds) The First Asian Fisheries Forum. Manila,Philippines: Asian Fisheries Society,pp. 201–206.

Munro, J.L. and Pauly D. 1983. A simple method for comparing the growth of fishes and invertebrates. ICLARM Fish byte 1(1): 5-6.

NAQDA, 2008. National Aquaculture Development Authority of Sri Lanka, Minitry of Fisheries and Aquaculture Resources, Statictics. [January 15, 2008] http://www.naqda.gov.lk/pages/stats.asp

Parrack, M.L. 1979. Aspects of brown shrimp, Penaeus aztecus, growth in the northern Gulf of Mexico, *US* Fish. Wildl. Serv. Bull., 76, 827-36.

Pauly D. 1979. Theory and Management of Tropical Multispecies Stocks. A Review, with Emphasis on the Southeast Asian Demersal Fisheries. ICLARM Studies and Reviews Vol. 1,Manila: ICLARM,35 pp.

Pauly, D., 1980. On the interrelationship between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. J. Cons. Int. Expl. Mer. 39 (2), 175–179.

Pauly, D. 1982. A method to estimate the stock-recruitment relationships of shrimps. *Transactions of the American Fisheries Society* 111(1): 13-20.

Pauly, D. (1984). The population dynamics of short-lived species with emphasis on squids, Paper presented at the NAFO special session on the biology and ecology of squids, Illex illecebrosus and *Loligo* pelaei in the North East Atlantic.

Pauly D. 1986. On improving operation and use of the ELEFAN programmes. Part IV. Conclusions. Fishbyte 4,14.

Pauly, D. 1987. A review of the ELEFAN system for analysis of length-frequency data in fish and aquatic invertebrates. D. Pauly and G.R. Morgan (Eds.), *Length-based Methods in Fisheries Research*. Vol. 13. ICLARM.

Pauly, D., 1991. Growth performance in fishes: rigorous description of patterns as a basis for understanding causal mechanisms. ICLARM Aquabyte 4 (3), 3–6.

Pauly, D. and Morgan G.R. (eds), 1987. Length-based methods in fisheries research. Manila; ICLARM and Kuwait; KISFR, 468 pp.

Pauly, D., Munro, J.L., 1984. Once more on the comparison of growth in fish and invertebrates. ICLARM Fishbyte 2 (1), 21.

Pauly, D. and M. L. Palomares 1989 . New estimatios of monthly biomass, ecruitment and related statistics of anchoveta (Engraulis ringens) off Peru (4-14 S) 1953-1985, p 189-206. In D Pauly, P. Muck , J. Mendo and I Tsukayama (eds) The Peruvian upwelling ecosystem: dynamics and interactions. ICLARM Conference Proceedingsn 18, 438p.

Pauly, D. and Soriano, M.L., 1986. Some practical extension to the Beverton and Holt's relative yield-per-recruit model. In: MacLean, J.L., Dizon, L.B., Hosillo, L.V. (Eds.), The First Asian Fisheries Forum. Asian Fisheries Society, Manila, Philippines, pp. 491–496.

Quinn, T.J and Deriso, R.B. 1999. *Quantitative Fish Dynamics*. Oxford University Press, Oxford

Ramamurthy, S., Annigen, G.G. and Kurup, N.S 1978. Resource Assessment of the Penaid prawn *Metapenaeus dobsonai* along the Mangalore coast. Indian Journal of Fisheries 25 (1/2) 56 - 66

Rikhter, V.A. and V.N. Efanov. 1976. On one of the approaches of estimation of natural mortality of fish populations ICNAF Research Doccument. 76/VI/8 : 12p

Royer J., P. Pe´rie`s and J. P. Robin 2002. Stock assessments of English Channel loliginid squids: updated depletion methods and new analytical methods ICES Journal of Marine Science, 59: 445–457.

Schnute, J.T and Richards, L. 2002. Surplus production models. In P Hart and J Reynolds (eds). Hand book of Fish biology and Fisheries, Vol II, Blackwell Science, Oxford, p103 -126.

Siddeek M.S.M. 1978. Estimating the population density of prawns by the use of catch per effort data from rawlers at Chilaw. *Bulletin of Fisheries Research Station of Sri Lanka* **28**, 1–26.

Silvestre G. T., Len R. Garces L. R., 2004. Population parameters and exploitation rate of demersal fishes in Brunei Darussalam (1989–1990). In Fisheries Research 69 (2004) 73–90.

Sparre, P., Ursin, E. and Venema, S.C. 1989. Introduction to Tropical Fish Stock Assessment.Part 1- Manual. FAO, Fisheries Technical Paper No. 306/1, 337 pp.

Sparre, P., Ursin, E. and Venema, S.C. 1992. Introduction to Tropical Fish Stock Assessment.Part 1- Manual. FAO, Fisheries Technical Paper No. 306/1, 337 pp.

Subramaniam S.P. 1990. Chwaka Bay (Zanzibar, East Africa) as nursery ground for penaeid prawns. Hydrobiologia **208**, 111–122.

Sydnes,A.K. and Normann, A.K 2003. Desk study on the fisheries sector in Sri Lanka. Norwegian College of Fishery Science. Tromso

TemaNord 1999. Assessment methods for shrimp stocks in the North-Eastern Atlantic, Nordic Council of Ministers Copenhagen.

Thompson, W.F. and F.H. Bell. 1934. Biological statistics of the Pacific halibut fishery. 2. Effect of changes in intensity upon total yield and yield per unit of gear. Rep.Int.Fish. (Pacific Halibut) Comm., 8 : 49p

Titus, J. G. 1986. Greenhouse effect, sea level rise, and coastal zone management. *Coastal Zone Management*
14(3):147-171.

Turner S. J., S. F. Thrush, J. E. Hewitt, V. J. Cummings, G. Funnell 1999. Fishing impacts and the degradation or loss of habitat structure. Fisheries Management and Ecology 6 (5), 401–420.

Vetter E.F. 1988. Estimation of natural mortality in fish stocks. A review. *Fisheries Bulletin* **86**(11) 25 - 43

Weerasooriya, K.T., 1977. Trawl nets presently used in the coastal waters of Sri Lanka. *Bull. Fisheries Res. Stn. Sri Lanka* **27**, 19–27.

Wijerathne, B. 2001. Coastal fisheries in Sri Lanka: Some recommendations for future Management. Final project report submitted for United Nations University Fisheries Training Programme, Rekjavik, Iceland

Wetherall J.A. 1986. A new method for estimating growth and mortality parameters from length-frequency data. Fishbyte 4, 12–14.

Wetherall J.A.,Polovina J.J. & Ralston S. 1987. Estimating growth and mortality in steady-state fish stocks from length-frequency data. ICLARM Conference Proceedings 13, 53–74.

Willmann, R. and Garcia, S. 1985. A bio-economic model for the analysis of sequential artisanal and industrial fisheries for tropical shrimp (with a case study of Suriname shrimp fisheries), FAO Fish. Tech. Pap., 270, 49.

Zar, J.H. 1984. Biostatistical Analysis. Prentice-Hall Inc. England. Wood Cliffs, N.J

Traditional sail driven large dugout canoe (non-mechanize craft) operated in coastal waters off Negombo

Wooden boat with outrigger engine (mechanize craft) operated in coastal waters off Handala

A trawl catch of Negombo showing variety of species included in a catch

Summarized monthly production and fishing effort in Handala and Negombo

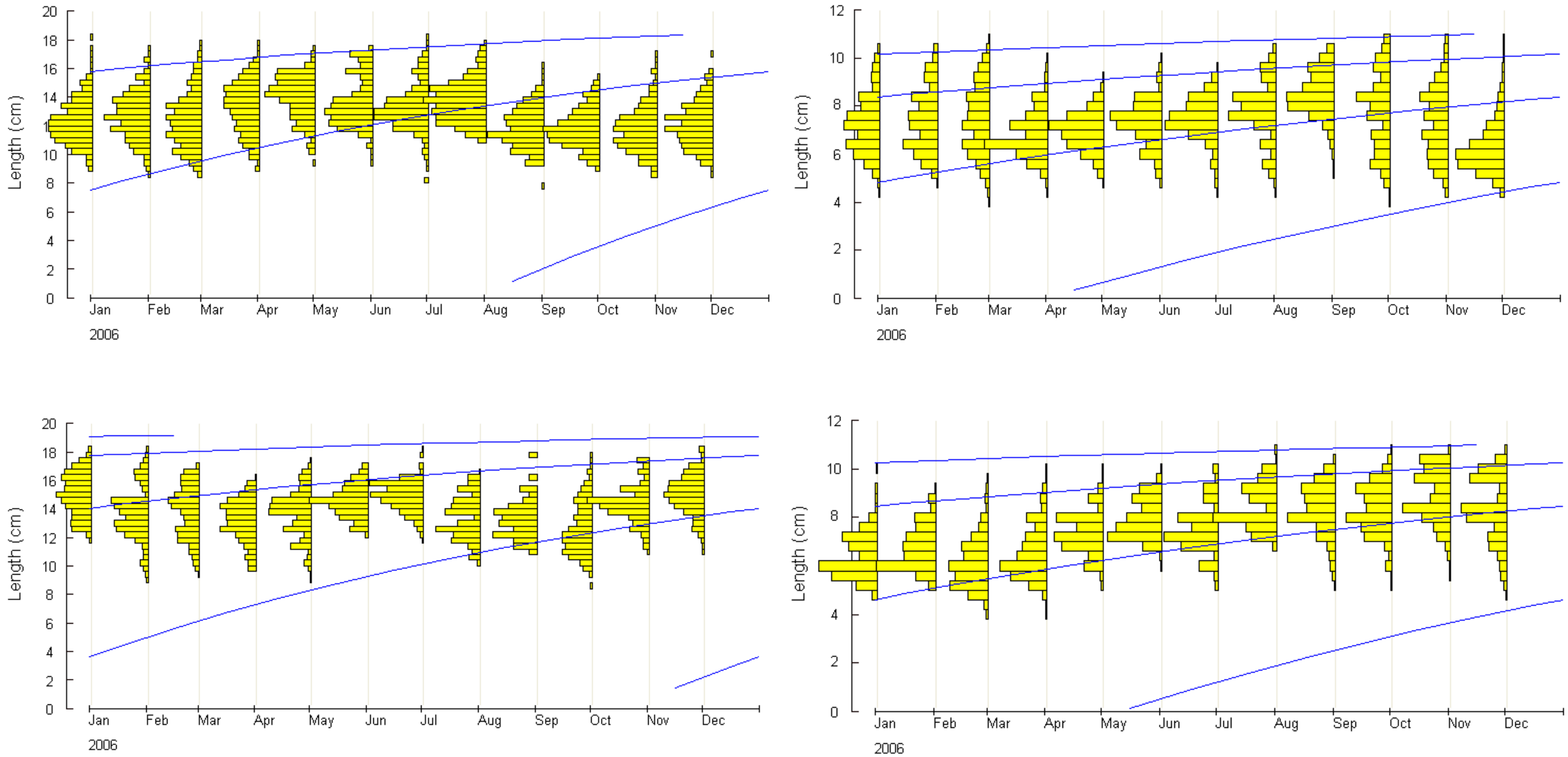
		Handala								Negombo							
		1997	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Jan	P	338	890	1240	635	4165	2752	1958	1518	10000	40691	18990	10767	5086	6865	4657	8684
	E	144	312	312	192	528	720	528	312	998	1896	1512	1392	1128	1512	696	1488
Feb	P	338	1156	629	587	2032	384	564	1310	9000	19337	10181	13169	11881	3965	856	868
	E	144	432	312	144	336	240	288	312	899	1560	1176	1680	1392	792	384	432
Mar	P	938	1057	391	401	727	1408	638	1457	13903	22745	14373	13714	18638	10088	4122	6855
	E	216	360	192	120	96	264	312	336	1428	1896	1656	1824	1752	1296	480	552
Apr	P	1763	3681	1115	1061	1743	1390	1785	154	5278	20093	13031	4839	23114	9284	1158	14882
	E	336	408	216	168	264	336	480	336	948	1920	1800	984	1944	1464	240	912
May	P	4312	2700	6935	5049	2719	5872	25948	61440	3369	10010	8544	12096	18057	8898	3405	3707
	E	624	504	672	528	312	504	1224	1536	600	1560	1680	1560	1752	1056	744	864
June	P	9386	28465	25510	6229	11386	9345	35707	10224	9016	16269	14968	9808	6934	6471	6050	14210
	E	816	912	1200	312	216	192	1680	360	1224	1848	2160	1320	1008	1032	792	1008
July	P	22896	37306	47576	2023	13976	10430	1941	33398	9567	18636	8459	13115	14802	25654	11799	12297
	E	984	1320	1704	72	240	192	1272	1176	1632	1536	1488	1824	1416	1896	1200	1008
Aug	P	16487	23669	26793	2644	44013	8693	58893	62728	7417	21145	13360	23265	25326	13873	19107	21833
	E	1008	1152	1200	72	1872	192	1968	1416	1752	1296	2016	2400	1584	1320	1368	1416
Sep	P	9377	16324	17808	30532	9597	770	9628	6563	11729	28112	18914	8407	29271	11976	12874	12162
	E	672	1008	1224	1488	960	192	1464	1032	1104	1680	1824	816	2232	1560	1200	1248
Oct	P	6271	7920	14300	11745	30691	873	1357	7508	30668	9970	15707	16773	25144	4249	8171	12689
	E	816	696	1128	672	1104	192	576	864	1848	1008	1776	1032	1968	840	672	768
Nov	P	1781	3843	8903	5570	4752	674	939	1317	9354	20791	24905	15455	20871	13118	10687	16710
	E	528	336	696	984	792	192	624	360	1392	1728	2064	1488	1896	1224	1128	1344
Dec	P	1380	890	952	15330	10245	2367	888	1149	7889	11911	9178	5930	17430	16789	24786	14001
	E	408	384	216	1344	1152	600	480	312	1152	1320	960	576	1560	1152	1584	1488

P = Production (kg), **E** = effort (boat-days)

Penaeus indicus ***Metapenaeus dobsoni***

Neg omb o

Han dala



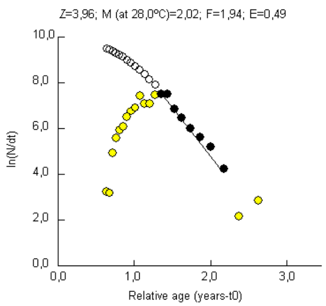
Monthly length frequency distributions of *Penaeus indicus and Metapenaeus dobsoni* for pooled sex data form Negombo and Handal

6

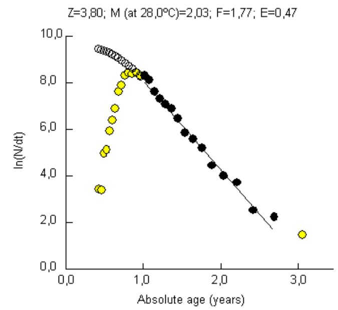
Penaeus indicus / *Metapenaeus dobsoni*

Male

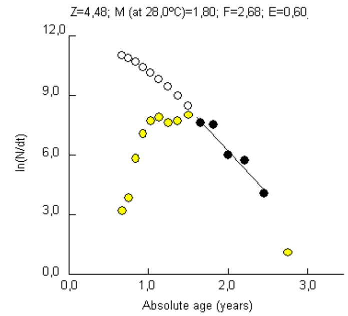
Penaeus indicus – Handala



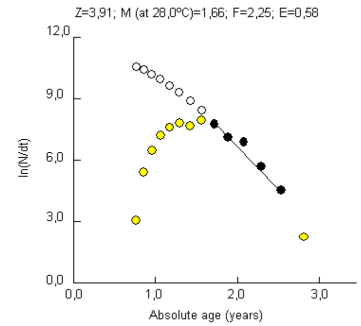
Penaeus indicus – Negombo



Metapenaeus dobsoni – Handala

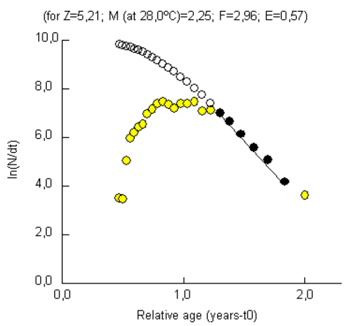


Metapenaeus dobsoni – Negombo

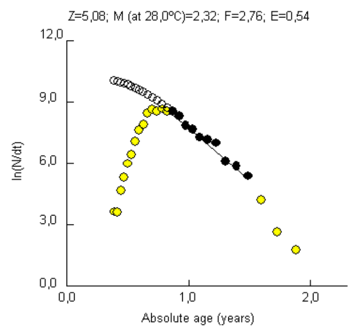


Female

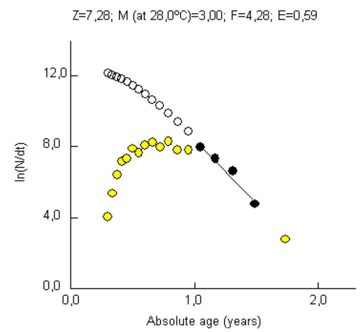
Penaeus indicus – Handala



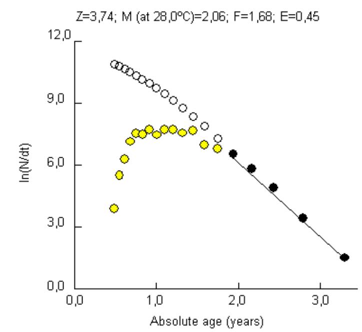
Penaeus indicus – Negombo



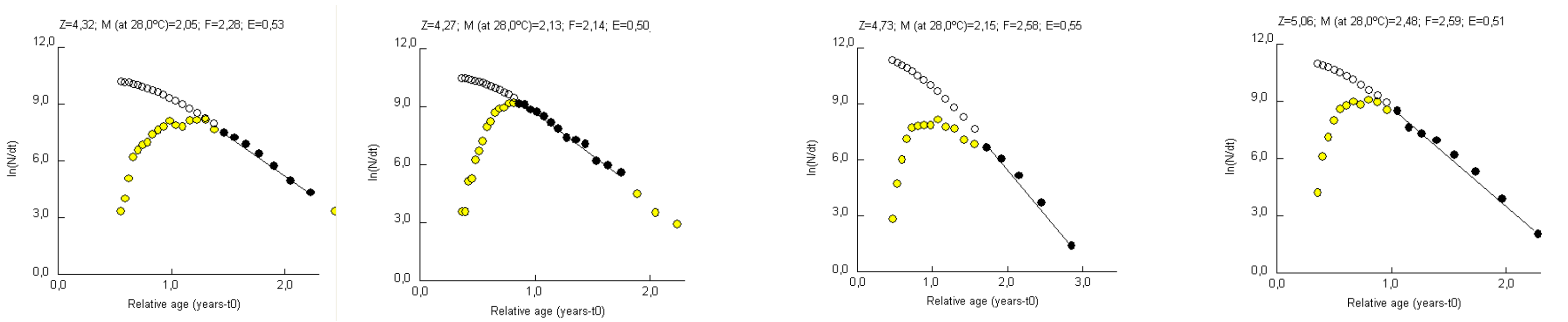
Metapenaeus dobsoni – Handala



Metapenaeus dobsoni – Negombo



Pooled data



APPENDIX - v

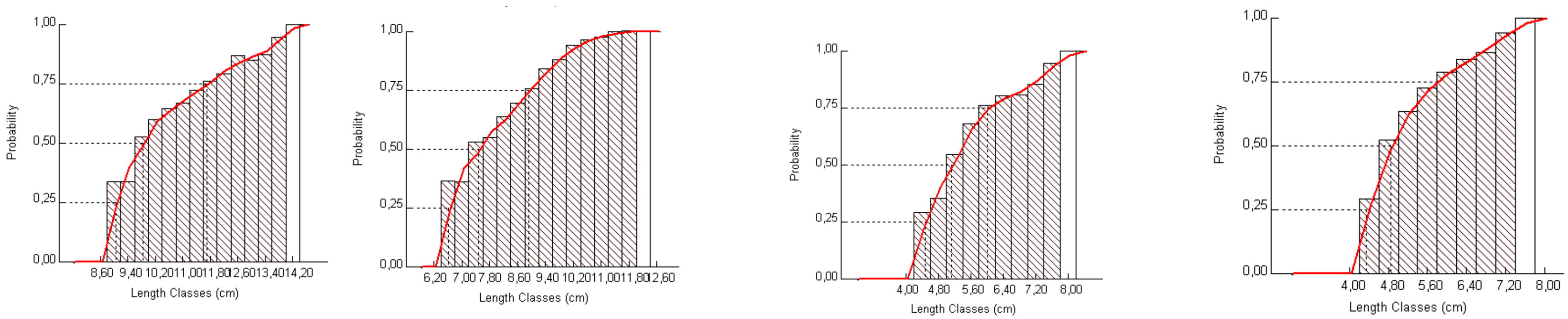
Length converted catch curves for *Penaeus indicus and Metapenaeus dobsoni* from Handala and Negombo fisheries with respect to their sexes

.

Penaeus indicus | ***Metapenaeus dobsoni***

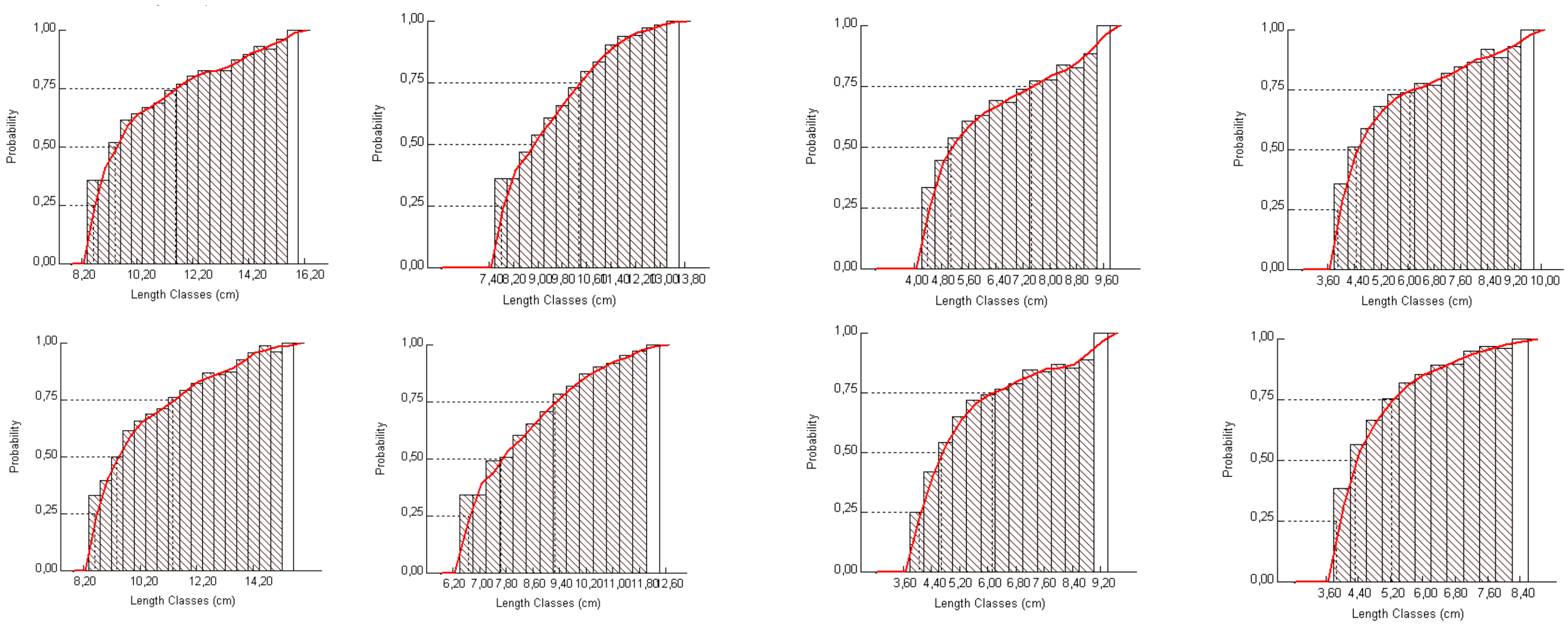
Handala | **Negombo** | **Handala** | **Negombo**

Male



Female

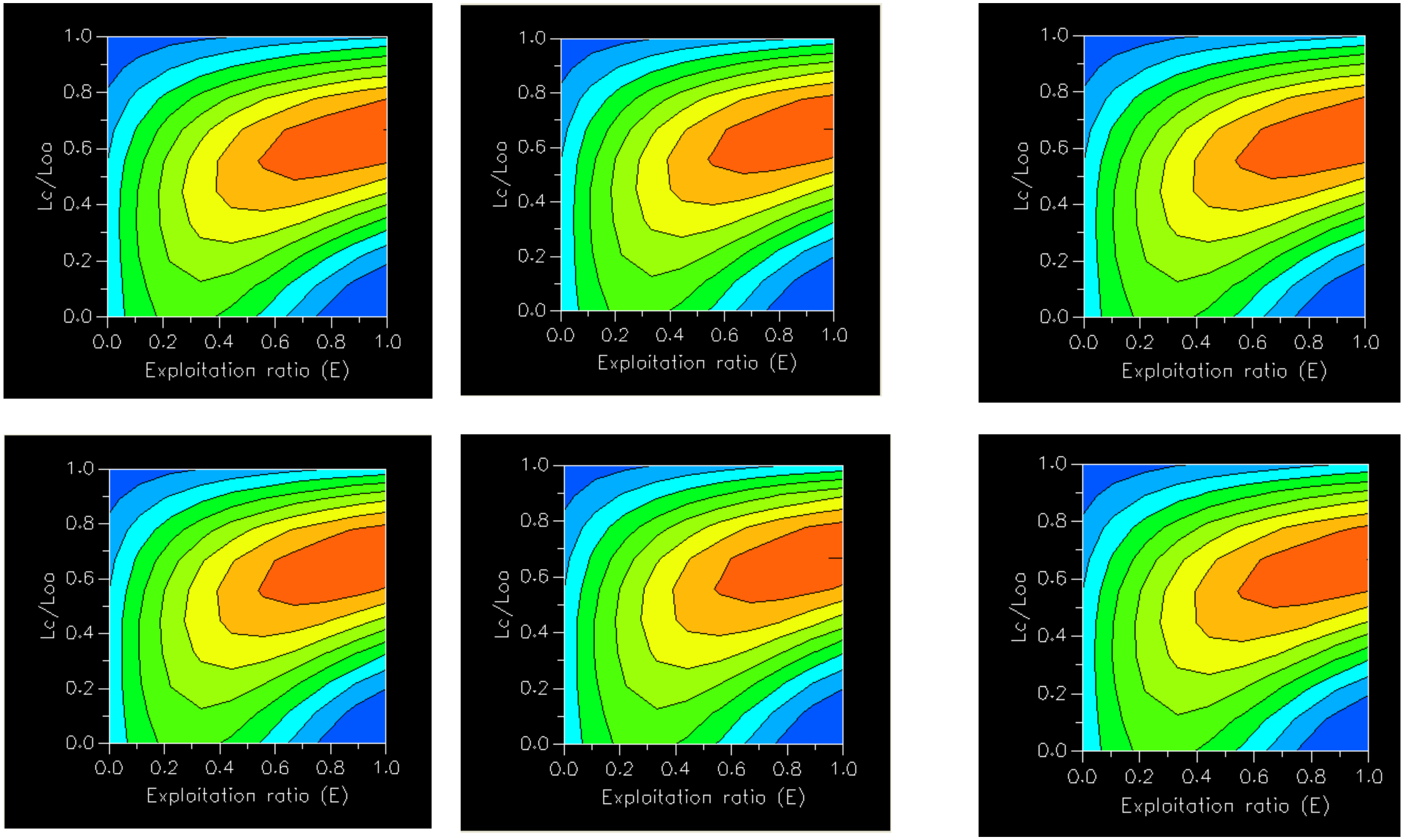
Pooled data



Probability of capture curves for *Penaeus indicus and Metapenaeus dobsoni* from Handala and Negombo fisheries with respect to their sex

Yield Isopleth curves of *Penaeus indicus*

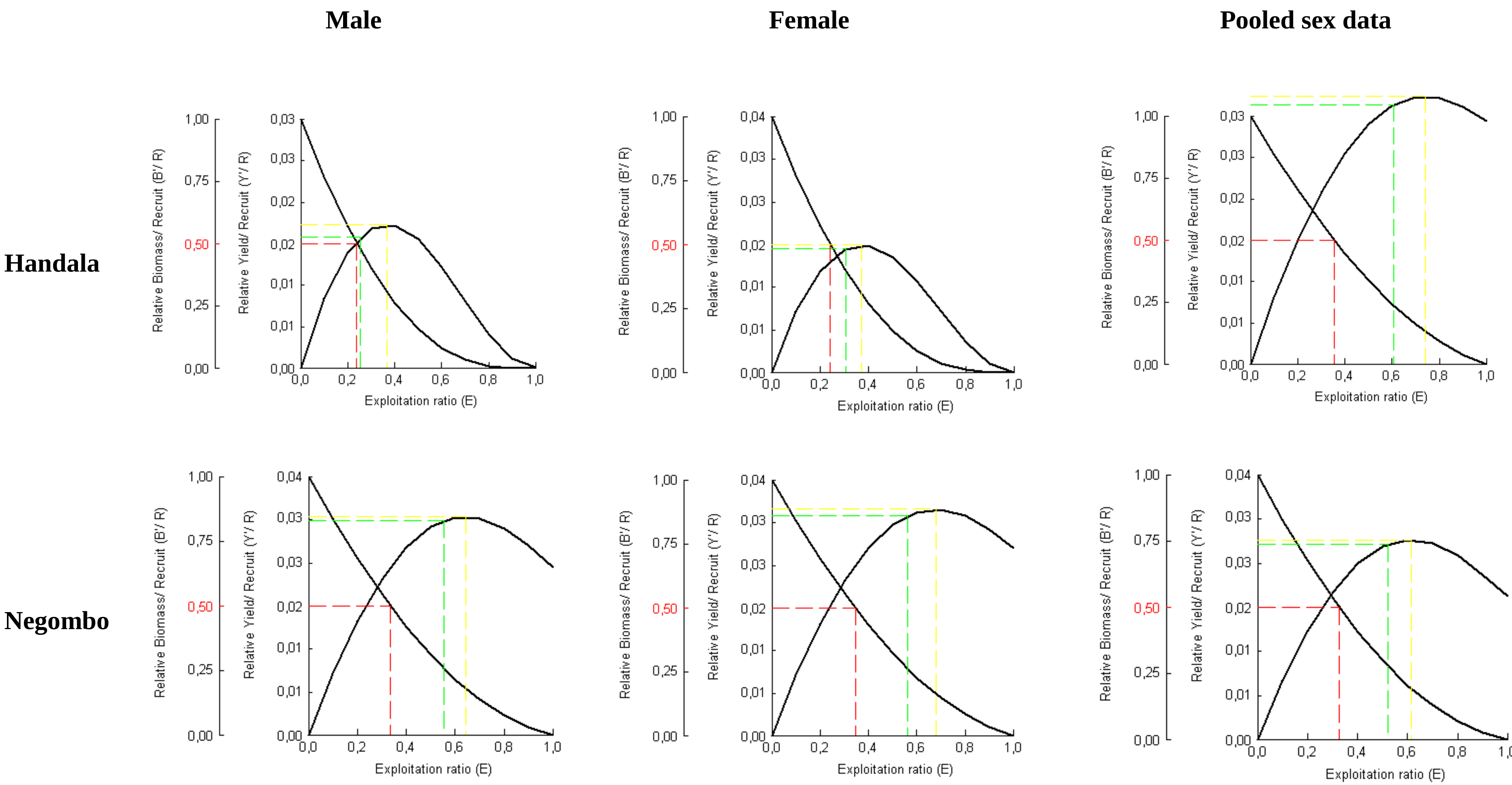
	Male	Female	Pooled sex data
Handala			
Negombo			



Y'/R isopleths diagram for *Penaeus indicus*

APPENDIX - vii

Penaeus indicus



Y'/R and B'/R curves for ***Penaeus indicus*** from Handala and Negombo with respect to their sexes and poled sex data from 2005-2006. $E_{0.5,}$ $E_{0.1}$ and E_{max} are represent by red, green and yellow colours.

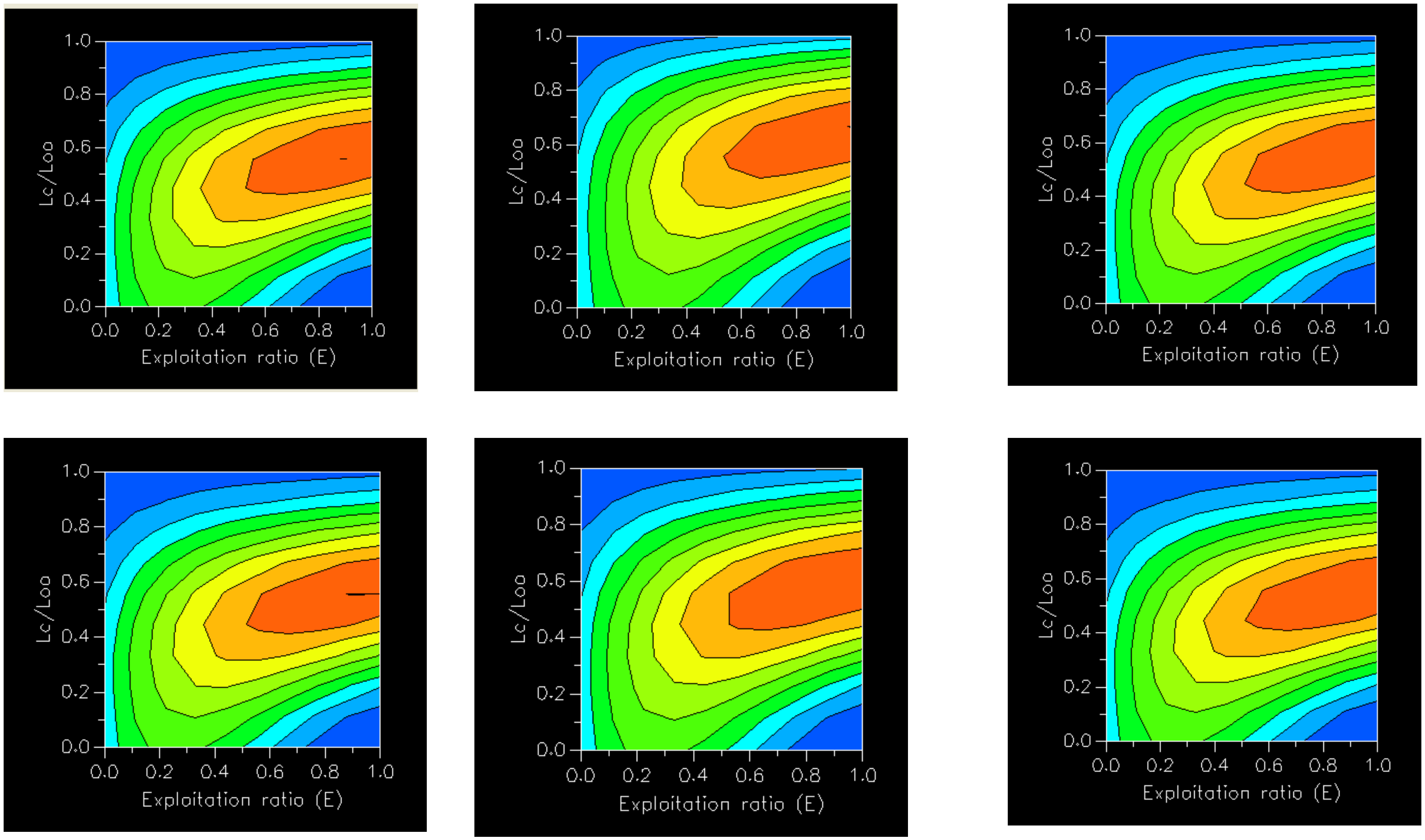
APPENDIX - viii

Yield Isopleth curves of *Metapenaeus dobsoni*

Male **Female** **Pooled sex data**

Handala

Negombo



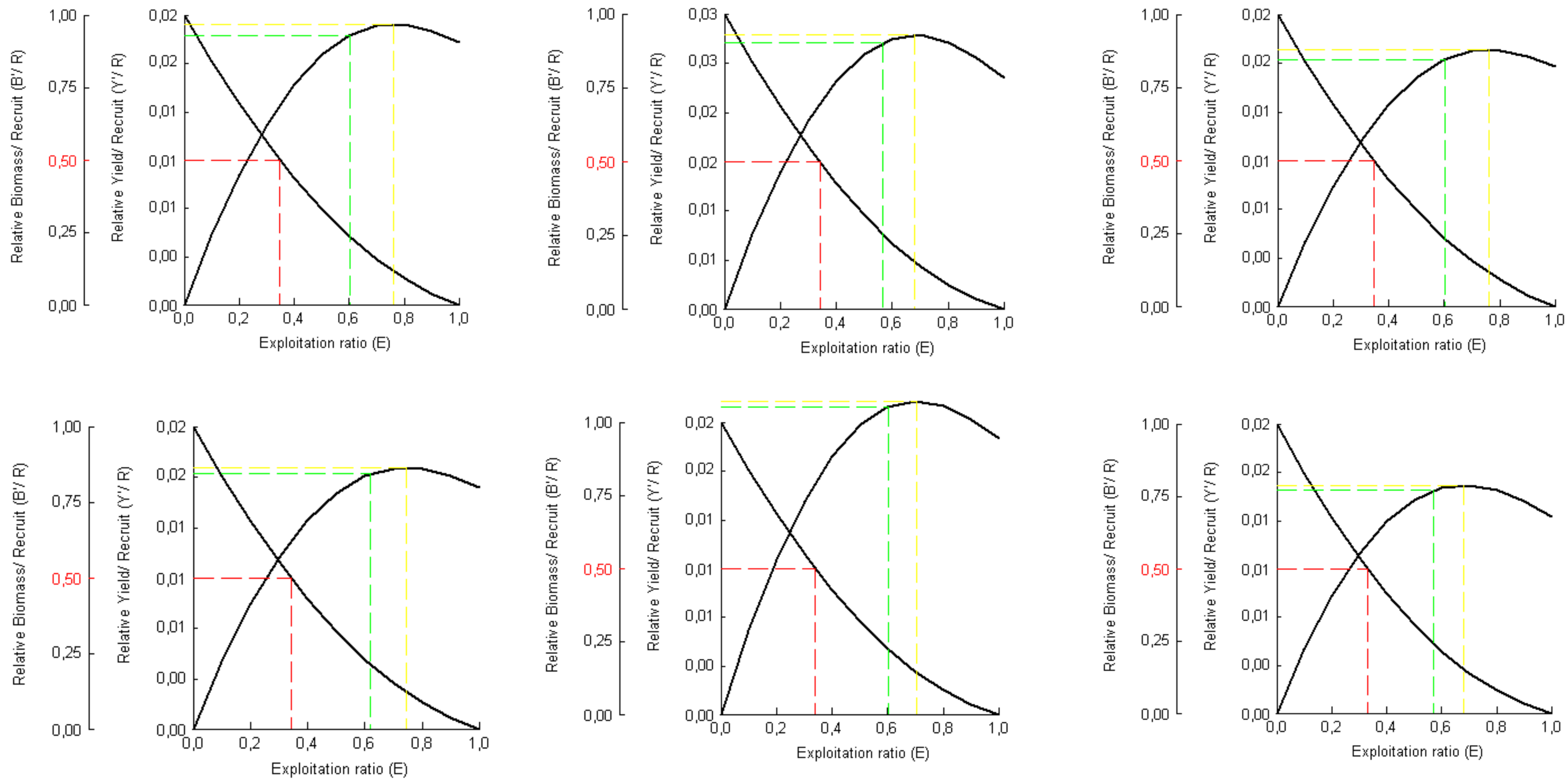
Y'/R isopleths diagram for *Metapenaeus dobsoni*

Metapenaeus dobsoni

Male **Female** **Pooled sex data**

Handala

Negombo



Y'/R and B'/R curves for ***Metapenaeus dobsoni*** from Handala and Negombo with respect to their sexes and poled sex data from 2005-2006 . $E_{0.5,}$ $E_{0.1}$ and E_{max} are represent by red, green and yellow colours.