Combining insights into reproduction and gear selectivity to enhance management advice for *Encrasicholina heteroloba* (Engraulidae) in the west coast of Sri Lanka

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Abstract *Encrasicholina heteroloba* belonging to the family Engraulidae is a commercially important fish species in the small-scale artisanal fisheries in Sri Lanka. Fishery, reproductive biology and gillnet selectivity pattern of *E. heteroloba* were assessed using the data collected from the Negombo fish landing site on the west coast of Sri Lanka from January to December 2015 in order to provide baseline information such as catch rate, total production, reproductive seasonality, size at first sexual maturity (L_{50}) and gear selectivity pattern of this data poor fishery. *E. heteroloba* are mainly exploited using drift gillnets of 1.1 cm, 1.2 cm and 1.8 cm stretched mesh sizes. Females spawn throughout the year reporting a peak spawning in July. The sizes at first sexual maturity of *E. heteroloba* male and female are 7.40 cm and 7.45 cm, respectively. The gillnet selectivity study revealed that the optimum length (L_{opt}) and selection range of *E. heteroloba* varied with mesh sizes and estimated L_{opt} for 1.0 cm, 1.2 cm and 1.8 cm mesh sizes were 5.6 cm, 6.4 cm and 9.2 cm, respectively. We suggest to promote use of 1.8 cm mesh gill nets as a higher percentages of immature individuals are landed when smaller mesh (<1.2 cm) gill nets are used. The findings of this study will be useful to manage *E. heteroloba* stocks on the west coast of Sri Lanka.

Key words: Gillnet selectivity, Mean size at sexual maturity, optimum length, selection range

INTRODUCTION

Anchovies belonging to the family Engraulidae are small pelagic fish that often forms large shoals (Santaclara 2006). Globally, there are around 140 species of anchovies belonging to 17 genera and they are widely distributed in the Indian, Atlantic and Pacific Oceans and Mediterranean Sea (Lavoue *et al.* 2010). Anchovies are relatively short-lived species (Chayakul, 1990) and are considered as ecologically and economically important components of many marine ecosystems, particularly in upwelling regions (Barange *et al.* 2009).

Anchovies make a notable contribution to the world marine capture fisheries production (~10 %) and its contribution in 2016 was 6.5 million tonnes. Peruvian anchovy (*Engraulis ringens*), Japanese anchovy (*Engraulis japonicus*) and European anchovy (*Engraulis encrasicolus*) are the most dominant species in the global anchovy catches (FAO 2018).

Anchovy is one of the dominant species in the coastal capture fishery in Sri Lanka. Although accurate catch statistics of anchovies are not available, it is reported that their contribution to the total coastal marine fishery production is being around 15 to 20% (MFAR, 2015). Anchovies are mainly exploited in the coastal waters around Sri Lanka using small mesh gill nets and beach seines. Although, the catching of anchovy is a highly seasonal activity in many parts of the country, there is a year around fishery on the west coast of Sri Lanka. However, up to now there has not been a routine monitoring or any management measures in this fishery. Therefore, baseline information such as catch rates, total landings and the seasonal pattern of the fishery is yet to be known.

Insights into fishing activities, stock status and biology, more specifically reproductive biology of fishes are essential to implement evidence based fisheries management plan (Anger, 2006). Further, there is considerable attention to improve the size and species selectivity of commercial fishing gear as a measure of sustaining exploited fish stock

(Stewart, 2001). However, no information related to such aspects is available for the anchovy fishery in Sri Lanka. Therefore, this study was aimed at to evaluate the catch rates, reproductive seasonality, size at first sexual maturity and gear selectivity pattern of *Encrasicholina heteroloba*, the widely exploited anchovy species on the west coast of Sri Lanka, in order to fill the knowledge gap of this data poor fishery.

MATERIALS AND METHODS

Study site and fishery data collection

Catch and the fishing effort data (active number of boats) of *E. heteroloba* were collected at the Negombo fish landing site (7°12'37.22" N, 79° 49'51.39" E), which is the main anchovy fish landing site on the west coast of Sri Lanka. Data were collected bi-weekly from January to December 2015. On each sampling day, 50–60% of boats operated for the anchovy fishery were sampled randomly. Boats to be sampled were selected using a random number table and the total catch of *E. heteroloba*, gear information such as mesh size, number of net pieces used, were collected from each boat. Total length (TL) of *E. heteroloba* (n = 2147) was measured to the nearest 0.1 cm using a measuring board and recorded with respect to the mesh size. Three samples of *E. heteroloba* each with ~1kg were collected randomly from the sampled boats to carry out reproductive biological studies.

Collected catch and effort data were used to calculate the catch rates (CPUE ± SD in kg boat^{-1} day^{-1}). Monthly total catch (MTP in tonnes) was estimated using the following equation.

MTP = CPUE x NFO x MRD   (1)
where,
MTP   - Monthly total catch of *E. heteroloba*
CPUE   - Mean catch rate of *E. heteroloba*
NFO   - Average number of boats operated for the *E. heteroloba* fishery per day
MRD   - Total number of fishing days for that particular month

Reproductive biology

In the laboratory, total length (TL), standard length (SD) and the total body weight (TW) of each individual (n =4340) were measured. Sex and gonad development stages were identified by dissecting and observing the gonads macroscopically (Ferreri *et al*., 2009). Monthly variation in sex ratio was estimated. Gonad weight and somatic weight of each dissected individual were measured separately and Gonado Somatic Index (GSI) was calculated using the following equation.

$$GSI \{(Gonad\ weight)/(Somatic\ weight)\} \times 100$$
(2)

Percentage mature (Stage III and above) males and females in each length class were determined and from the plots of percentage maturity against length mean sizes at maturity or lengths at 50% maturity (L_{50}) of *E. heteroloba* were determined from a logistic curve fitted to the proportion (P) of sexually mature males and females using the following equation (King, 2007).

$$P = \frac{1}{\{1 + exp[-r_i(L - L_{50})]\}}$$
(3)

where, $L50$ is the mean length at sexual maturity. $L50$ was estimated by transforming this equation to linear form as follows:

$$ln[1-(1-P)] = r_i L_{50} - rL$$
(4)

where, r_i is the slope of the curve of the curve.

Gillnet selectivity

Collected mesh-wise length frequency data were used to estimate the gillnet selectivity pattern. Mesh-wise length data were raised to estimate the total frequency of each length class. The total length frequency data were adjusted for unit effort (F_{adj}) as the number of fish for length class L, per 1000 m^2 of gillnet per day.

Baranov-Holt method was used to analyze the adjusted length frequency data. In this analysis, it was assumed that the length frequency distribution of a fish species caught by two gillnets with slightly different mesh sizes exhibits the same standard deviation, same height of selection curves and similar fishing mortalities (Holt, 1963; Hamley, 1975).

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According to Gulland (1983), the logarithms of catch ratios (in numbers) of overlapping regions of two gill nets with slightly different mesh sizes are linearly related to the length of the fish as;

$$Ln\ C_2/C_1 = a + bL \qquad (5)$$

where, C_1 and C_2 are F_{adj} in a length class in mesh sizes M_1 and M_2 respectively, and a and b are constants. The intercept (a) and the slope (b) of the equation 5 were used to determine the optimal length for each mesh size as follows: (Hamley, 1975).

For mesh size M_1:

$$L_{opt(1)} = 2a \cdot M_1/[b(M_1 + M_2)] \qquad (6)$$

According to Hamley (1975), the standard deviation (SD) of both selection curves can be estimated as;

$$SD = \sqrt{\frac{2a(M_1 - M_2)}{b^2(M_1 + M_2)}} \qquad (7)$$

When there were two estimates for L_{opt} and SD for a given mesh size, the mean of these two values was taken. Using, $L_{opt(1)}$, $L_{opt(2)}$ and SD values, probabilities of capture (P_1 and P_2) of length L, in each mesh size (M_1 and M_2) were estimated as per the following equation.
For mesh size M_1:

$$P_1 = \exp[-(L - L_{opt(1)})^2/2SD^2] \qquad (8)$$

Statistical Analysis

The statistical significance of sex ratio was assessed using the chi-square test (χ^2). The regression relationships between length and weight as well as GSI and body size were determined for male and female separately. All the statistical analyses were performed using R version 2.8.1 (R Development Core Team 2015, http://www.rproject.org). Differences were considered significant at a probability level of 0.05.

RESULTS

The fishery
E. heteroloba is mainly caught off the west coast of Sri Lanka using drift gillnets of 1.1 cm, 1.2 cm and 1.8 cm stretched mesh sizes. Fiberglass Reinforced Plastic (FRP) boats powered with 15 and 25 HP outboard engines are used as the major fishing vessel. Normally, two fishermen are on board and they leave for fishing between 3.00 am and 6.00 am and return to the coast around 8.00 am to 3.00 pm. Although accurate fishing positions are not available, fishing is carried out in the shallow coastal waters from 8-10 km away from the shore. The true fishing time varies from 15 minutes to 2 hours. As an average, 18 ± 2 net pieces are used in gill net fishing operation.

Monthly variation in the total number of FRP boats operated for the anchovy fishery off Negombo, Sri Lanka is shown in fig. 1. The highest fishing effort was recorded in October (2080 boats) and the lowest effort was in May (256 boats). Catch rates (CPUE) decreased gradually from February to May and started to increase since June reporting the highest CPUE in September (150 ± 66 kg boat^{-1} day^{-1}). The estimated total catch of E. heteroloba at the Negombo fish landing site from January to December 2015 was 751 tonnes (Fig. 2).
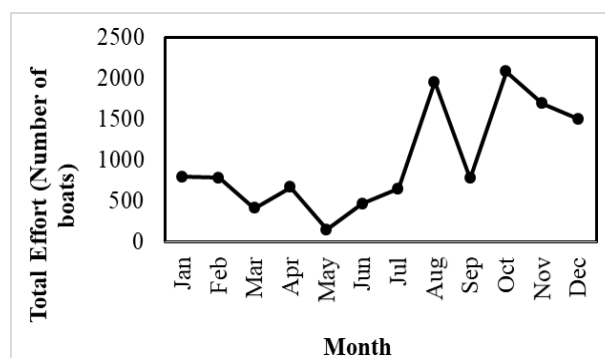

Fig 1 Monthly variations in total number of outboard fiberglass reinforced plastic (OFRP) boats operated for the anchovy fishery at the Negombo fish landing site, west coast of Sri Lanka

Reproductive biology
A total of 4340 specimens was sampled during the study period, of which 2296 were females and 2044 were males. The higher number of males than females were reported in April, May, June, August and October while females were dominant in the catches in the rest of the month (Table 1). The expected 1:1 sex ratio was observed only in September and the statistical analysis proved that sex ratio was significantly different from 1:1in

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April, May, June, October and November (p<0.05, χ^2 test). Monthly variation in GSI (mean ± SD) of male and female *E. heteroloba* was computed (Fig.3). GSI of males ranged from 0.60 ± 0.45 to 2.38 ± 0.64 and in females it ranged from 1.22 ± 0.42 to 3.22 ± 0.53. In both sexes, GSI gradually increased from January to July reporting the highest GSI in July.
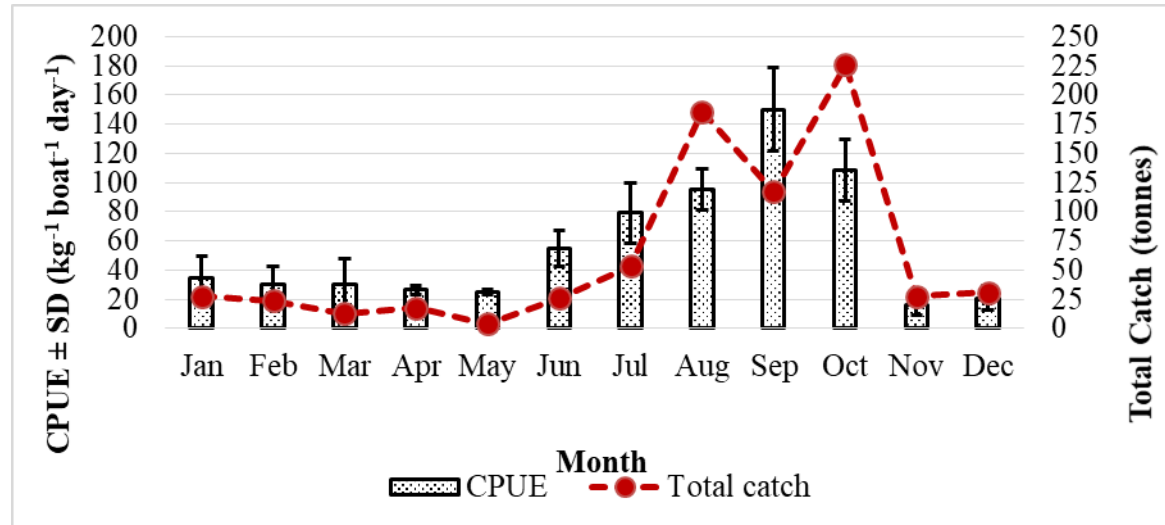

Fig. 2 Monthly variation in catch rates (CPUE ± SD in kg boat⁻¹day⁻¹) and total catch (tonnes) of *E. heteroloba* landed at the Negombo fish landing site, west coast of Sri Lanka.

Table 1 Monthly variation in sex ratio (male: female) of *E. Heteroloba* landed at the Negombo fish landing site, west coast of Sri Lanka from January to December 2015. Number of *E. Heteroloba* (n) used to estimate sex ratio in each month are given within brackets.

Month	Sex ratio (Male : female)	P value
January	1.0:1.1(*n=310*)	0.65
February	1.0:1.2 (*n=302*)	0.47
March	1.0:1.1 (*n=403*)	0.65
April	1.0:0.7 (*n=385*)	0.05·
May	1.0:0.5 (*n=346*)	0.00*
June	1.0:0.5 (*n=383*)	0.00*
July	1.0:1.05 (*n=365*)	0.78
August	1.0:0.8 (*n=411*)	0.19
September	1.0:1.0 (*n=394*)	0.78
October	1.0:0.5 (*n=352*)	0.00*
November	1.0:1.7 (*n=328*)	0.02*
December	1.0:1.2 (*n=361*)	0.63

*Significant difference at a level of 95%; $p < 0.05$

A sharp declined in GSI was reported in August, but it made a small peak again in September and gradual declined in October (Fig. 3). Although, GSI varied with the body size, a significant relationship was not evident (p>0.05). However, males reported the highest GSI in the length range of 7.0 - 7.2 cm and for females it was in the length range of 9.1 - 9.3 cm (Table 2). Length weight relationship indicated that *E. heteroloba* had an isometric growth.

Figure 4 shows that *E. heteroloba* is sexually active throughout the year. Spawning individuals were evident throughout the study period with a peak in July. The highest percentage of 'spent females' was reported in August followed by October. This study revealed that size at first sexual maturity of *E. heteroloba* males was 7.40 cm (total length) while females attain sexually mature at 7.45 cm (Fig. 5).
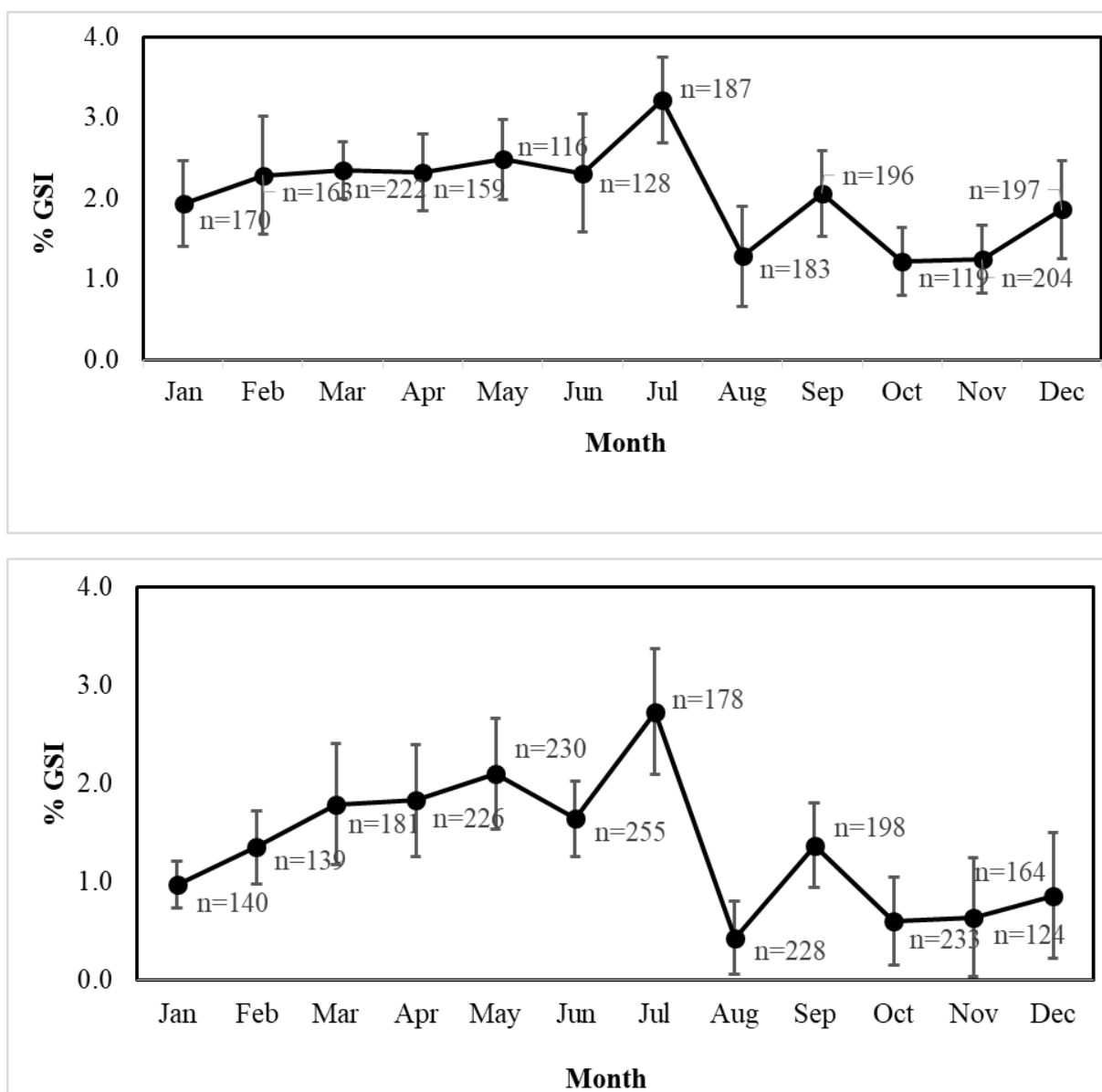

Fig 3 Monthly variation in GSI (± SD) of *E. heteroloba* female (upper) and male (below) in the coastal waters off Negombo, Sri Lanka, from January to December 2015.

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Table 2 Mean (± SD) values for Body weight (± SD), gonad weight (± SD) and Gonado Somatic Index (± SD) males and females of different length groups of *E. heteroloba* in the coastal waters off Negombo, Sri Lanka. Number of males (n) and females (n) examined in each length group are given within brackets.

|	**Male**				**Female**		
Total length (cm)	Mean body weight (± SD) (g)	Mean gonad weight (± SD) (g)	Mean %GSI (± SD)	Total length (cm)	Mean body weight (± SD) (g)	Mean gonad weight (± SD) (g)	Mean %GSI (± SD)
5.5. - 5.7 (n= 133)	1.20 ± 0.17	0.02 ± 0.02	1.67 ± 0.94	5.5. - 5.7 (n= 121)	1.82 ± 0.2	0.03 ± 0.01	2.21 ± 0.96
5.8 - 6.0 (n= 161)	1.62 ± 0.27	0.03 ± 0.02	1.10 ± 1.07	5.8 - 6.0 (n= 163)	2.08 ± 0.39	0.04 ± 0.02	2.01 ± 0.91
6.1 - 6.3 (n= 153)	1.73 ± 0.22	0.04 ± 0.02	1.05 ± 1.38	6.1 - 6.3 (n= 142)	2.23 ± 0.56	0.04 ± 0.02	2.15 ± 0.84
6.4 - 6.6 (n= 202)	2.00 ± 0.26	0.04 ± 0.02	1.10 ± 1.03	6.4 - 6.6 (n= 214)	2.20 ± 0.54	0.04 ± 0.02	2.01 ± 0.77
6.7 - 6.9 (n= 211)	2.27 ± 0.32	0.04 ± 0.01	1.69 ± 0.76	6.7 - 6.9 (n= 223)	2.45 ± 0.57	0.04 ± 0.02	1.99 ± 0.79
7.0 - 7.2 (n= 285)	2.55 ± 0.26	0.05 ± 0.03	2.22 ± 0.98	7.0 - 7.2 (n= 257)	2.69 ± 0.52	0.04 ± 0.02	1.75 ± 0.73
7.3 - 7.5 (n= 219)	2.64 ± 0.23	0.03 ± 0.01	1.26 ± 0.71	7.3 - 7.5 (n= 267)	2.68 ± 0.53	0.04 ± 0.02	1.80 ± 0.86
7.6 - 7.8 (n= 163)	2.93 ± 0.29	0.03 ± 0.01	0.97 ± 0.65	7.6 - 7.8 (n= 296)	3.02 ± 0.35	0.05 ± 0.03	1.90 ± 1.08
7.9 - 8.1 (n= 162)	3.55 ± 0.35	0.04 ± 0.03	1.05 ± 0.81	7.9 - 8.1 (n= 219)	3.50 ± 0.38	0.06 ± 0.03	1.78 ± 0.89
8.2 - 8.4 (n= 128)	4.26 ± 0.29	0.06 ± 0.03	1.43 ± 0.65	8.2 - 8.4 (n= 164)	3.83 ±0.44	0.08 ± 0.03	2.11 ± 0.85
8.5 - 8.7 (n= 135)	4.66 ± 0.35	0.07 ± 0.02	1.65 ± 0.64	8.5 - 8.7 (n= 142)	4.36 ± 0.47	0.07 ± 0.05	1.82 ± 1.12
8.8 - 9.0 (n= 91)	4.90 ± 0.91	0.08 ± 0.04	1.69 ± 0.91	8.8 - 9.0 (n= 78)	4.8 ± 0.79	0.11 ± 0.04	2.42 ± 0.65
9.1 - 9.3 (n= 0)	-	-	-	9.1 - 9.3 (n= 11)	5.28 ± 0.71	0.15 ± 0.03	3.05 ± 0.80
Length-weight relationship	Y = 2.6713x – 1.7027			Length-weight relationship	Y = 2.6848x – 1.6208		

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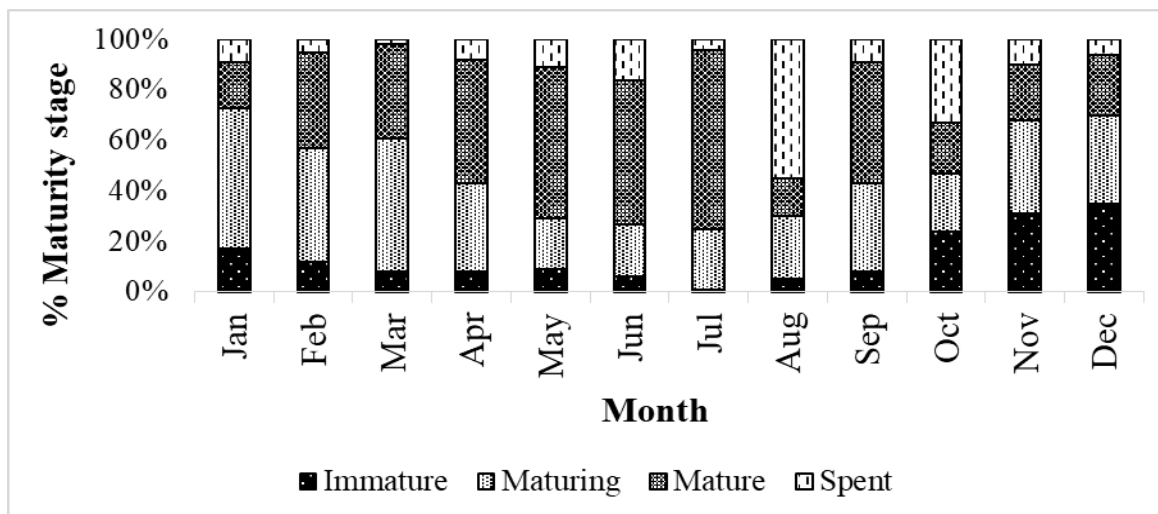
Fig 4 Monthly variations in maturity stages of *E. heteroloba* females in the coastal waters off Negombo, Sri Lanka from January to December 2015
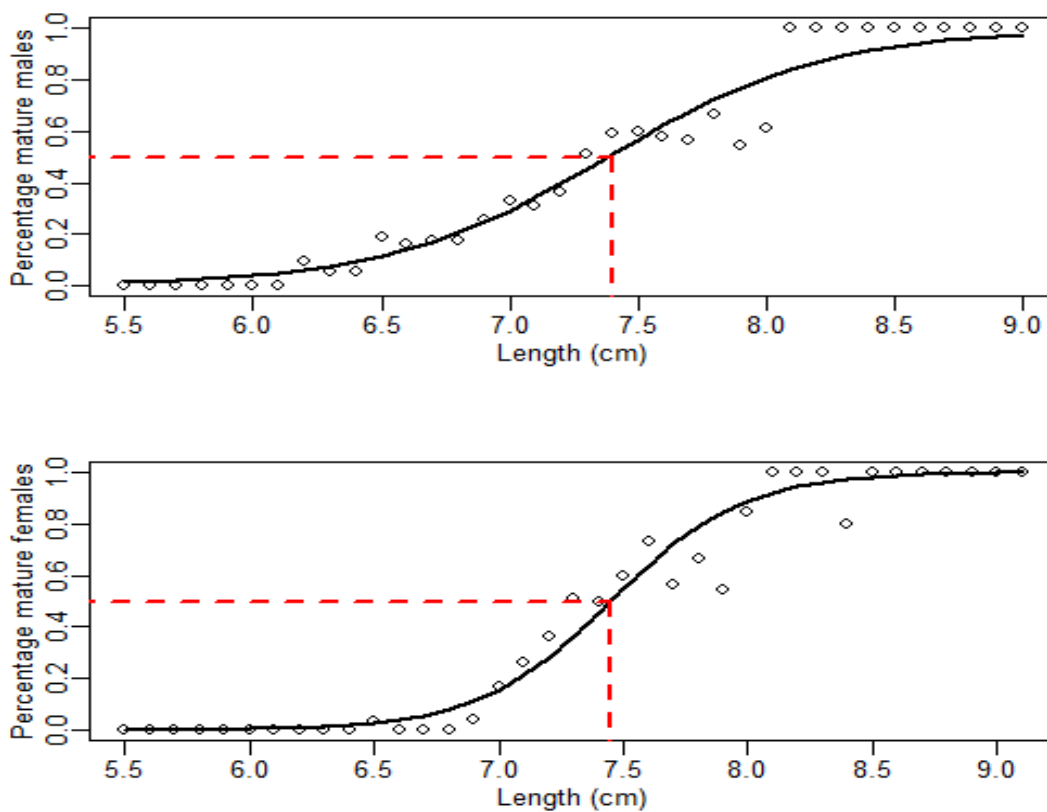

Fig. 5 Plots of percentage maturity of *E. heteroloba* against fish length for males (above panel) and females (below panel) in the coastal waters off Negombo, Sri Lanka. The mean length at maturity, i.e., length corresponding to 50% maturity (L_{50}) in each panel is shown as broken lines.

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Gillnet selectivity

The regression relationships of logarithmic catch ratio of three mesh sizes (1.0 cm, 1.2 cm and 1.8 cm) against the corresponding midpoint of length classes are summarized in fig. 6. The estimated optimum length (L_{opt} ± SD) of *E. heteroloba* for 1.0, 1.2 and 1.8 cm mesh gillnets were 5.60 ± 0.62, 6.42 ± 0.79 and 9.19± 0.97 cm, respectively. The selection range for 1.0 cm mesh size was 4.98 - 6.22 cm and for 1.2 cm and 1.8 cm mesh sizes, these value ranges were 5.63 - 9.21cm and 8.22 - 10.16 cm, respectively (Table 3). As there were two estimates for L_{opt} and SD for the 1.2 cm mesh size, the mean value was taken. The gillnet selection curves plotted for three different mesh sizes are shown in fig. 7.

The estimated selection range for different mesh sizes was compared with the length range of *E. heteroloba* obtained from the commercial catches and their size at first sexual maturity. The results revealed that currently used gillnets with 1.0 cm (94%) and 1.2 cm (73%) mesh sizes landed very high percentage of immature individuals (Table 4). Further, the mean lengths of *E. heteroloba* landed by 1.0 cm and 1.2 cm mesh sizes were below the estimated size at first sexual maturity.
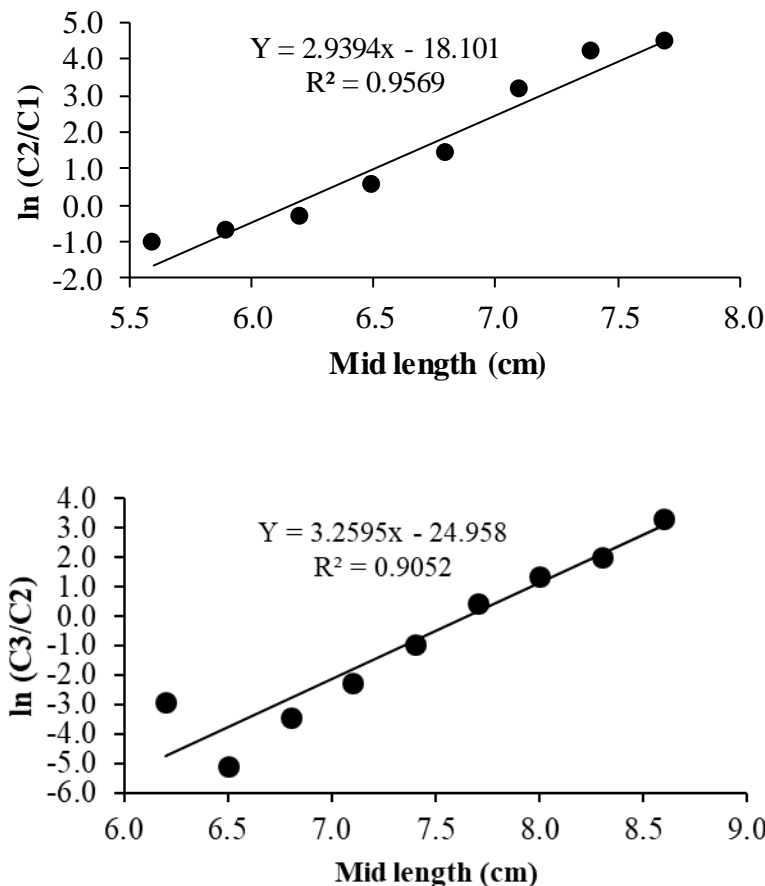

Fig. 6 Regression relationships of ln catch ratio against total length (mid length) of *E. heteroloba*. C1, C2 and C3 are catches in numbers (i.e. adjusted frequencies) in mesh size 1 (1.0 cm) mesh size 2 (1.2 cm) and mesh size 3 (1.8 cm), respectively.

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Table 3 Some parameters of gear selectivity of *E. heteroloba* for three different gill net mesh sizes in the in the coastal waters off Negombo, Sri Lanka.

Aspects	Mesh sizes		
	1.1 cm	1.2 cm	1.8 cm
Optimum length (± SD)	5.60 ± 0.62	6.42 ± 0.79	9.19± 0.97
Selection range(cm)	4.98 - 6.22	5.63 - 9.21	8.22 - 10.16
CPUE (catch per boat per day)	19± 5	22± 5.5	15±16
Exploited length range	5.0 – 7.8	5.5 – 8.7	7.1 – 10.0
Overall mean total length	6.3 ± 0.4	7.0 ± 0.5	8.2 ± 0.6
Overall % of specimens $< L_{50}$	94%	73%	4.4%
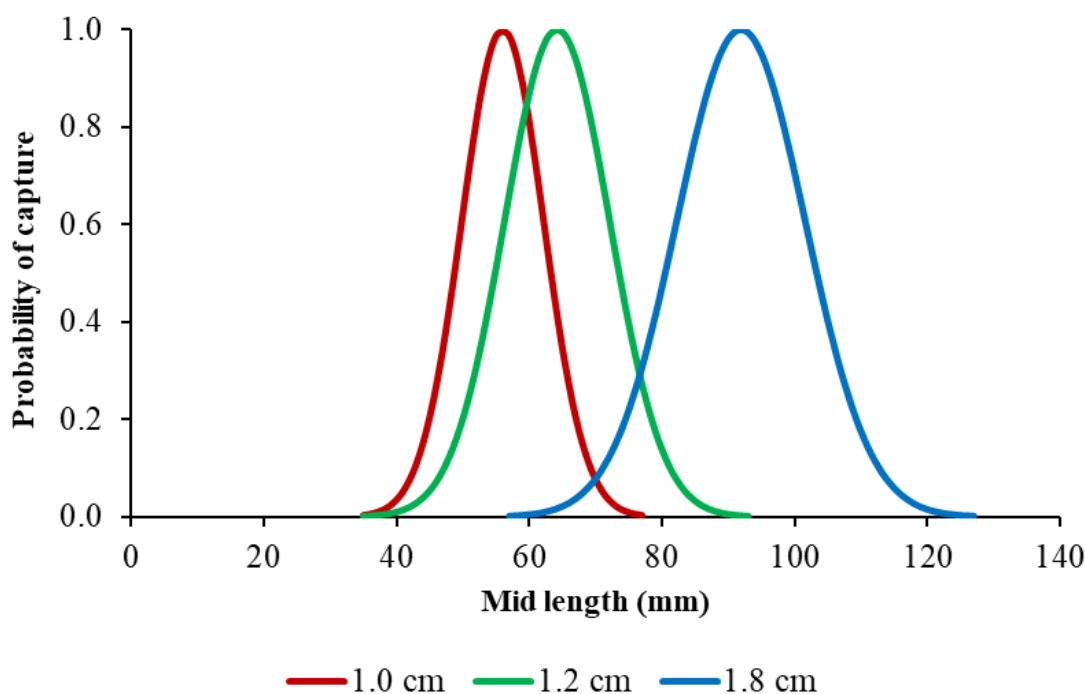
Fig 7 Gill net selection curves of *E. heteroloba* exploited by 1.0 cm, 1.2 cm and 1.8 cm stretch mesh sizes in the coastal waters off Negombo, Sri Lanka

DISCUSSION

E. heteroloba is considered as one of the important species in the coastal small pelagic fishery of Sri Lanka due to its contribution to the total marine capture fishery production and coastal livelihood. However, no scientific studies related to aspects of fishery, biology and stock assessment of this species have been carried out so far.

Different types of fishing gear are used to exploit this species in many parts of the world. Seines and stake nets are widely used in the South China Sea (Carpenter *et al*., 1997) and traditional or small scale purse seines and beach seines are famous in Iran. The most popular gear types in the Philippines waters include beach seine, ring net, drift gillnet, bagnet, liftnet, modified Danish seine, filter net, and trawl (Khan, 2000; Luther, 1979). This study revealed that small mesh gill nets are widely used off the west coast of Sri Lanka off Negombo.

From the present study, a seasonal variation in fishing effort and CPUE was evident and very low fishing effort and CPUE were reported from May to July. This could be due to rough sea condition prevailed this period with the onset of the southwest monsoon (May to September). Similar observations have been made earlier for some other small pelagic species off the west coast of Sri Lanka (Dissanayake and Sigurdsson, 2005; Karunasinghe and Wijeyaratne, 1995). Further, Luther (1979) reported the highest and lowest engraulid catches in the coastal waters off India in October (241.349×10^3 kg) and May (3.003×10^3 kg), respectively. According to Imran (2014), engraulid catches were very low during the east monsoon season in Krueng Raya Bay-Ache, Indonesia.

As the fishery for *E. heteroloba* is confined to limited geographical regions and as this species is mainly landed together with many other engraulid and *Sardinella* species, very limited information on the fishery and biology of *E. heteroloba* is available. As grouped or lumped catch data is available in many regions, including South Vietnam, South China Sea, the Philippines and Persian Gulf (Carpenter et al., 1997), it is difficult to make comparison with the current catch estimates. However, it was reported that, in the Philippines, the nominal CPUE of this species for the ring net fishery has fluctuated between 20 - 225 kg boat^{-1} day^{-1} since 2003 (BFAR-NFRDI 2017) and their values were higher than the CPUE values of the present study (17 – 150 kg boat^{-1} day^{-1}).

This study revealed a significant difference in 1:1 sex ratio in some months of the year and similar results have been recorded in previous studies (Laroche and Richardson, 1980; Millan, 1999). Although the exact reason for this observation could not be pointed out, differences in migratory pattern and habitat preferences of males and females, may be possible reasons for this effect.

According to Dalzell (1987), engraulids spawn throughout the year, particularly near the equator, with seasonal peaks associated with climatic conditions such as the monsoons. The present study also supports this finding as peak spawning of *E. heteroloba* occurred during the southwest monsoon period. According to Mohanth *et al.* (2004) mature anchovies were in the Indian coast throughout the year, but mature females with advanced stage of ovary were observed only from July to August. Only few studies have been done to estimate the size at first sexual maturity of *E. heteroloba* and Aripin and Showers (2000) reported that they attain sexual maturity at 7.00 cm in the Philippines waters and the L_{50} value estimated in this study was not much deviated from this value.

Fisheries managers always promote the use of selective fishing gear as catching of undersized fishes can be controlled by adjusting either mesh or hook sizes (Fonseca *et al.*, 2005). A mesh size selectivity of stationary lift net was reported for *Stolephorus commersonii* in Sorsogon Bay in the Philippines (Alba *et al.*, 2016) and selectivity of mid-water trawls was studied for *Engraulis encrasicolus* in the Mediterranean (Stewart, 2001). This study estimated the gillnet selectivity pattern of *E. heteroloba* off the west coast of Sri Lanka.

This study has shown that currently used gill nets with 1.0 cm and 1.2 cm mesh sizes caught high percentages of immature *E. heteroloba*. Therefore, limiting of the use of these gill nets to catch *E. heteroloba* off the west coast of Sri Lanka is suggested to minimize catching immature fish. Although some scientists argued that the management of anchovies cannot be considered in isolation in a tropical multispecies fishery (Kurup and Ravindran, 2006), the proposed measure will be useful to manage a localized and targeted fishery like *E. heteroloba* fishery in this study. According to the local fisheries statistics, engraulid species make the second highest contribution to the total small pelagic landings in the country (MFAR, 2015) and *E. heteroloba* is considered as one of the dominant species in the catches. Therefore, management of this fishery is a timely requirement specially to sustain the livelihood of small-scale coastal fishers in this region. Due to lack of time series data, this study focused only to estimate the catch rate and reproductive pattern of *E. heteroloba*, but assessment of stock status and level of exploitation based on yield-per-recruit approaches is recommended to implement more robust measures to manage this fishery. However, short-lived species with smaller body size having high turnover rates can withstand high fishing pressure. On the other hand, recruitment failures caused by climatic variability were reported to occur in pelagic fisheries in the world (Walsh et al. 1980).

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