POPULATION BIOLOGY OF THE GREENBACK GREY MULLET, *Chelon subviridis* (Valenciennes, 1836) IN MERBOK ESTUARY, KEDAH

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by

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2. Nor-Aziella, M. R., Mansor, M. I. and Shu-Chien, A. C. (2012). Growth, mortality and recruitment pattern of greenback grey mullet, *Chelon subviridis* (Valenciennes, 1836) in Merbok estuary, Kedah, Malaysia. *Tropical Life Sciences Research* (in press).

LIST OF SYMBOLS AND ABBREVIATIONS

1^{st} GR	=	First gill rakers
2^{nd} GR	=	Second gill rakers
AFE	=	Anal fin element
ANOVA	=	Analysis of variance
BD	=	Body depth
BL	=	Body length
BW	=	Body weight
BWidth	=	Body width
D_1F-D_2F	=	First dorsal fin-second dorsal fin
D_1FE	=	First dorsal fin element
D_2F-AF	=	Second dorsal-anal fin
D_2FE	=	Second dorsal fin element
DFA	=	Discriminant function analysis
DMRT	=	Duncan multiple range test
E	=	Exploitation rate
ED	=	Eye diameter
ELEFAN I	=	Electronic Length-Frequency Analysis I
E_{max}	=	Maximum allowable limit of exploitation
F	=	Fishing mortality
FISAT II	=	FAO-ICLARM Stock Assessment Tools II
FL	=	Fork length
HD	=	Head depth
HL	=	Head length
HWidth	=	Head width
K	=	Condition factor
K	=	Growth constant
$L\infty$	=	Asymptotic length
Lc	=	Length at first capture
LLR	=	Length- length relationship
LS	=	Lateral scales
LWR	=	Length-weight relationship

M	=	Natural mortality
Ø’	=	Growth performance index
P_1FE	=	Pectoral fin element
P_2F-AF	=	Pelvic fin-anal fin
P_2FE	=	Pelvic fin element
PCA	=	Principal component analysis
R^2	=	Regression coefficient
SE	=	Standard error
SL	=	Standard length
Sn-AF	=	Snout-anal fin
Sn-D_1F	=	Snout-first dorsal fin
Sn-D_2F	=	Snout-second dorsal fin
SNKT	=	Student Newman Keuls test
SnL	=	Snout length
Sn-P_1F	=	Snout-pectoral fin
Sn-P_2F	=	Snout-pelvic fin
SPSS	=	Statistical package for social science
TL	=	Total length
TS	=	Transverse scales
vBGF	=	von Bertalanffy growth function
Y’/R	=	Relative yield per recruit
Z	=	Total mortality

BIOLOGI POPULASI IKAN BELANAK, *Chelon subviridis* (Valenciennes, 1836) DI MUARA SUNGAI MERBOK, KEDAH

ABSTRAK

Kajian ini menyelidik biologi populasi ikan belanak, *C. subviridis* di muara Sg. Merbok selama satu tahun dari November 2010 hingga November 2011. Kajian ini dibahagikan kepada empat komponen utama iaitu: (i) pengenalpastian spesies ikan belanak menggunakan morfometrik dan meristik; (ii) hubungan panjang-berat, hubungan panjang-panjang dan faktor keadaan; (iii) biologi pembiakan; dan (iv) kadar pertumbuhan, kematian dan corak recruit. Untuk komponen pertama, 19 ciri morfometrik dan 9 ciri meristik digunakan. Kesemua ciri-ciri ini dianalisis menggunakan analisis univariat (analisis varians) dan multivariat (analisis komponen utama dan analisis fungsi diskriminan). Tuntasnya, ciri morfometrik yang paling penting untuk mengenalpasti spesies Mugilidae ialah lebar kepala, panjang muncung, kedalaman badan dan jarak dari sirip dorsal pertama ke sirip dorsal kedua. Bagi ciri meristik pula, jumlah tulang lembut pada sirip pektoral dan jumlah bilangan sirip lateral merupakan ciri yang paling penting bagi mengenalpasti spesies Mugilidae. Komponen kedua menunjukkan bahawa hubungan panjang-berat adalah dalam pertumbuhan alometrik negatif bagi ikan jantan; $W = 0.0128\ L^{2.9347}$, ikan betina; $W = 0.018\ L^{2.8127}$ dan gabungan ikan jantan dan betina; $W = 0.0175\ L^{2.823}$. Hubungan panjang-panjang antara panjang keseluruhan (TL), panjang piawai (SL) dan panjang ekor (FL) *C. subviridis* adalah saling berkait rapat ($r^2 > 0.9579$; $p < 0.001$) antara satu sama lain. Selain itu, nilai purata faktor keadaan bagi *C. subviridis* adalah 1.067 ± 0.092, sekaligus menunjukkan bahawa muara Sg. Merbok adalah agak sesuai bagi *C. subviridis.*

Komponen ketiga menunjukkan bahawa *C. subviridis* mempunyai lima tahap kematangan yang dikenalpasti secara makroskopik dan mikroskopik. Panjang pada kematangan pertama bagi ikan jantan dan betina ialah pada saiz 16.5 cm dan 16.8 cm. Hubungan antara fekunditi dengan panjang keseluruhan dan fekunditi mutlak dengan berat badan diungkapkan dengan persamaan: $F = 12769L - 166650$ dan $F = 836.83W + 7718.9$. Fekunditi *C. subviridis* adalah tinggi dengan bilangan telur 16 832 hingga 324 491 bagi saiz ikan 13.4 cm hingga 33.2 cm. Berdasarkan indeks gonadosomatik ovari, ikan belanak mampu bertelur sepanjang tahun dengan dua puncak peneluran iaitu pada bulan September dan Disember. Komponen terakhir memperolehi anggaran parameter berikut: panjang asimptot, $L\infty$ = 35.05 cm, pekali pertumbuhan, K = 0.62 tahun^{-1}, panjang pada tangkapan pertama, L_C = 11.2 cm, kematian keseluruhan, Z = 3.19 tahun^{-1} (kematian semula jadi, M = 1.25 tahun^{-1} dan kematian semasa penangkapan, F = 1.92 tahun^{-1}) dan kadar eksploitasi, E = 0.60 tahun^{-1}. Dengan menggunakan fungsi hasil per rekruit Beverton dan Holt, nilai kadar eksploitasi (E) memberikan hasil maksimum relatif per rekrut (Y'/R), E_{max} = 0.686 tahun^{-1}. Rekruit tahunan *C. subviridis* berlaku sebanyak dua puncak setahun. Secara keseluruhan, semua maklumat yang diperoleh ini adalah penting untuk penilaian keadaan relatif populasi ikan belanak, biologi, pengurusan spesies dan perikanan serta penilaian stok dan diharapkan ia akan menyumbang kepada perancangan pemuliharaan yang lebih baik dan sekaligus memantapkan lagi strategi pengurusan perikanan bagi memastikan sumber perikanan yang mampan pada masa akan datang.

POPULATION BIOLOGY OF THE GREENBACK GREY MULLET, *Chelon subviridis* (Valenciennes, 1836) IN MERBOK ESTUARY, KEDAH

ABSTRACT

The present research investigated population biology of the greenback grey mullet, *C. subviridis* in Merbok estuary for one year period from November 2010 to November 2011. This study is divided into four major components: (i) mullet fish identification using morphometric and meristic; (ii) length-weight relationship, length-length relationship and condition factor; (iii) reproductive biology; and (iv) growth, mortality and recruitment pattern. For the first component, 19 morphometric and 9 meristic characteristics were utilized. These characteristics were analyzed by univariate (analysis of variance) and multivariate analysis (principal component analysis and discriminant function analysis). Herein, the most important morphometric characteristics for classifying Mugilidae species were head width, snout length, body depth and distance from first dorsal fin to second dorsal fin. For meristic characteristics, the total number of soft rays at pectoral fin and total number of lateral scales was the most important meristic characteristics in the classification of Mugilidae species. The second component elucidated that the length-weight relationship (LWR) was in negative allometric pattern for males; $W = 0.0128\ L^{2.9347}$, females; $W = 0.018\ L^{2.8127}$ and combined sex; $W = 0.0175\ L^{2.823}$. Length-length relationship between total length (TL), standard length (SL) and fork length (FL) of *C. subviridis* were highly significant and highly correlated ($r^2 > 0.9579$; $p < 0.001$). Besides, the mean condition factor of *C. subviridis* was 1.067 ± 0.092, had revealed that the Merbok estuary is in good ambience for survival and slightly favorable for *C. subviridis*. The third component revealed that five maturity stages were macroscopically and microscopically identified in *C. subviridis*. Length at first maturity was attained at 16.5 cm and 16.8 cm in male and female fish. The relationship between absolute fecundity with total length and absolute fecundity with body weight can be expressed as $F = 12769L - 166650$ and $F = 836.83W + 7718.9$. The fecundity of *C. subviridis* was high with the absolute fecundity for fish measuring 13.4 cm to 33.2 cm in total length ranged from 16 832 to 324 491 eggs. By using the gonadosomatic index (GSI) of the ovaries, it suggested that the fish was able to spawn throughout the year with two spawning peaks in September and December. The last component acquired the following parameter estimates; asymptotic length, $L\infty$ = 35.05 cm, growth coefficient, K = 0.62 yr^{-1}, length at first capture, L_C = 11.2 cm, total mortality, Z = 3.19 yr^{-1} (natural mortality, M = 1.25 yr^{-1} and fishing mortality, F = 1.92 yr^{-1}) and exploitation rate, E = 0.60 yr^{-1}. By using the Beverton and Holt yield per recruit function, the value of exploitation rate (E) giving the maximum relative yield per recruit (Y'/R), E_{max} = 0.686 yr^{-1}. The annual recruitment of *C. subviridis* was observed to occur in two pulses per year. Overall, all these information were of great importance to evaluate the relative condition of mullet fish populations, biology, species management and fisheries as well as stock assessment and hopefully it will contribute to the establishment of a better planning conservation and management strategies for sustainable fishery resources in future.

CHAPTER 1

GENERAL INTRODUCTION

1.1 General aspect of population biology

Population is all the organisms that belong to the same species or group and at the same time live in the same geographical area. Whereas, biology is a vast subject of natural science relates to the study of life and living organisms, involving their structure, growth, function, evolution, origin, taxonomy and distribution. The combination of population biology leads to the meaning of a study of populations of organisms. It concerns the regulation of population size and life history traits such as clutch size and extinction. The population biology is often used interchangeably with population ecology (Wikipedia, 2012).

1.2 General description of Merbok estuary

Mangroves considered as a dominant tropical coastal ecosystem and could be one of the most productive natural ecosystems. They are nursery and over-wintering areas for variety of marine fish species (Beyst *et al*., 1999). Mangroves are essential for producing timber, maintaining coastal fisheries, hosting a wide variety of organisms and sequestering carbon. In addition, mangroves are important in protecting coastal area from erosion, storms, hurricanes and tsunamis (Mazda *et al*., 2005). The massive and intricate root system of mangroves is believed to be efficient in dissipating wave energy (Massel *et al*., 1999).

The Merbok estuary is one of the representative mangrove reserves located in the northwestern Peninsular Malaysia. It covers an area of about 45 km^2 of mangroves and waterways. The Merbok River that flows into the Straits of Malacca is situated at 5º40´ N and 100º 25´ E. The length of the river is about 35 km whereas the width of this river varying from 2 km at the mouth to 20 m towards the upper reaches of estuary with depth ranges from 3 to 15 m except with a few 20 m deep holes where tributaries join the Merbok estuary (Ong *et al*.,1991). At low tide, the waterways covers approximately 10 km^2 and 45 km^2 is inundated at high tide (Simpson *et al*., 1997).

According to Ong *et al.* (1991), the water catchment area of Merbok estuary comprises an area of 550 km^2 is made up of alluvium deposits, overlying an extensive span of ferruginous shale and mudstone with a few scattered outcrops of granite and ferruginous sandstone or quartzite. Dominantly, the catchment area probably rice fields and small patches of rubber and oil palm. Some of the villagers near to Merbok estuary rely on mangrove and its resources such as fishes, shrimps, clams and mangrove timber. Marvellously, the mangroves are luxuriant, very productive, growing up to 30 m and high species diversity which usually dominated by *Rhizophora apiculata* and *Bruguiera parviflora* (Ong *et al*., 1980 & Ong, 1995).

1.3 Activities in Merbok estuary

1.3.1 Capture fisheries

Fisheries sector play important role for the livelihood of the local people. Essentially, this sector provides sources of employment and protein supply. In general, most of the fishermen in Merbok applied artisanal fishery with low technology practices, limited manpower and moderate average daily income of RM 50 (pers. com., 2011). The common fishing gears are barrier nets, fishing stake and mangrove crab traps.

1.3.2 Other utilization

There were shrimp and fish hatchery pond for aquaculture purposes alongside Merbok estuary (FAO/BOBP, 1984). Besides, the activities of the mollusca collection have been applied in Merbok estuary. Other than that, the aesthetic activities such as birds watching, recreational fishing and wedding photoshoot also performed for the eco-tourism purposes.

1.4 Selected species

Merbok estuary contributes to the convenience habitat for fish population. There were a lot of fish species inhabiting Merbok estuary due to their suitable environment and continuously supply of nutrients. The priority candidates of fish species for present study were *C. subviridis*, *L. vaigiensis*, *V. engeli*, *V. seheli* and *V. speigleri*. These entire species are categorized in Mugilidae family. The details about these five species are discussed in Chapter 2. These fish has economic important as they are the dominant species landed by fishermen and the market prices of these fish ranges from RM 11.00 to RM 13.00 per/kg (pers. com., 2011).

1.5 Rationales of the study

The growth of fisheries industry alongside Merbok estuary is moderately managed. Some negative impact such as pollution, over-exploitation and resource degradation could retard the fisheries industry. Therefore, the future development of fisheries sector in Merbok estuary should be towards an ecologically friendly and sustainable. The data on morphometric, meristic, reproductive biology, length-weight relationship, growth, mortality and recruitment pattern of fish are crucial for fish resources management, conservation and sustainable development. In order to achieve that, exclusive emphasize had been given on some aspect on the population biology of the greenback grey mullet, *C. subviridis*, which is one of the dominant species as a model for the sustainable management of the fish biota in Merbok estuary.

Scientific publication on the population biology of *C. subviridis* in Merbok estuary is sporadic and scarcity. Nevertheless, there were several studies on Mugilidae species in different water body related to morphometric and meristic (Ibáñez *et al*., 2006; Turan *et al*., 2011), reproductive biology (Chan and Chua, 1980; Albieri and Araújo, 2010), length-weight relationship and condition factor (Mortuza and Tawfeequa, 2006; Renjini and Bijoy Nandan, 2011) and growth (Al-Daham and Wahab, 1991; Hakimelahi *et al*., 2010). Therefore, the present study attempted to provide valuable information and knowledge on some aspect on the population biology of *C. subviridis* thoroughly for the management of the Merbok estuary which is vital for sustainable development of the capture fisheries particularly in this water body.

1.6 Objectives of the study

The present research on the population biology of greenback grey mullet, *C. subviridis* in Merbok estuary, Kedah comprised of four main objectives;

1) To determine general mullets fish identification by morphological variation of Mugilidae species.
2) To determine the length-weight relationship, length-length relationship and condition factor of *C. subviridis.*
3) To study some aspect on reproductive biology of *C. subviridis* in Merbok estuary.
4) To study the population parameters of *C. subviridis* through estimation of growth parameters, mortality coefficients and annual recruitment patterns based on length-frequency data set using FiSAT software.

1.7 Significance of the study

Present study is important due to several factors;

1) Providing database and valuable information on the mullets fish biodiversity
2) Decisive morphometric and meristic for taxonomic identification on mullet species.

3) Estimation of spawning season and exploitation rates for conservation strategies of aquatic resources in order to protect them from extinction.
4) The dynamics of the mullet fish in the estuary.

1.8 Outline of the study

Present study involved one year data collection of mullet, Mugilidae species throughout the Merbok estuary. This study divided into two major stages. First stage is the evaluation of morphometric measurements and merictic counts of five Mugilidae species namely *C. subviridis*, *L. vaigiensis*, *V. engeli*, *V. seheli* and *V. speigleri*. This information could be used to identify, classify, differentiate and determine the Mugilidae species. In the second stage, *C. subviridis* was selected as the priority candidate for further estimation on their i) length-weight relationship, length-length relationship and condition factor, ii) reproductive biology and iii) population parameters namely growth, mortality and recruitment pattern.

This thesis is divided into eight chapters (four working chapters and four additional chapters). Each working chapter consisted of a brief introduction, materials and methods, results, discussion and conclusion.

CHAPTER 2

LITERATURE REVIEW

2.1 Diversity of mullets or Mugilidae

Nowadays, fish are economically very important in our life. Fish have worldwide distribution, very diverse and categorized in different ways between one species to another species. They inhabit either tropical or temperate seas, freshwater or brackish water. Many fish species have been discovered. Mugilidae is often known as mullet and could be found throughout the world, especially in coastal temperate and tropical waters. Some of Mugilidae species inhabit freshwaters and they can penetrate lagoons, estuaries and migrating back to the sea to spawn (Johnson and Gill, 1998). They utilized estuarine nursery habitats where they could largely feed on plant material obtains by grubbing through bottom detritus (Cervigo´n *et al*., 1993). In addition, they also play an important part in small-scale coastal fisheries in several regions of the world (Tzanatos *et al*., 2005).

Mugilidae species are typically coastal-estuarine and euryhaline or adaptable to great changes in salinity. For example, *Liza abu* has evolved into freshwater habitat. Besides, Mugilidae have been important food fishes since ancient times and fished commercially and usually caught with setnets, castnets, liftnets, beach seines, stake nets and barrier nets. They are often used in fishpond culture as they can grow rapidly and considered a hardy species (Carpenter & Niem, 1999).

Mullets comprised about 80 species from 17 genera (*Agonostomus, Aldrichetta, Cestraeus, Chaenomugil, Chelon, Crenimugil, Joturus, Liza, Moolgarda, Mugil, Myxus, Neomyxus, Oedalechilus, Rhinomugil, Sicamugil, Valamugil, Xenomugil*). Generally they are distinguished by the presence of two separate dorsal fins, small triangular mouths, and absence of a lateral line organ. Other than that, they have long intestine, muscular stomach and also a complex pharynx to help in digestion (Johnson and Gill, 1998; Nelson 2006).

The external morphology of this family is highly conservative, which contributes to uncertainty with regard to evolutionary relationships at both generic and specific levels (Crosetti *et al.*, 1994). Mugilidae is elongated fishes with a broad, blunt snout and flattened head. Adipose eyelid or fatty tissue partly covered their eyes, mouth rather small terminal inferior, teeth small, feeble, hidden or absent and premaxilla protrusible (Carpenter & Niem, 1999; Nelson 2006).

The body of Mugilidae is almost cylindrical or a little compressed. Their body color varies between species. According to Carpenter and Niem (1999), some of them are dark blue, dark olive, greenish or grayish dorsally and silvery on flanks with distinct dark stripes following rows of scales. The ventral parts of their body also silvery or pale yellowish, fins dusky or pale yellowish with dusky margin and dark spot sometimes dorsally at base of pectoral fins.

Mugilidae is structured by the presence of two short dorsal fins; first with IV slender spines and second dorsal fin with 9 or 10 soft rays. The anal fin is short with II or III spines and 7 to 12 soft rays. Their caudal fin is emarginate, truncate or forked. The pectoral fins set rather high on body. The pelvic fin located subabdominal with I spine and 5 soft rays. Their pelvic fin base is about equidistant between pectoral fin base and origin of first dorsal fin. Other than that, the scales of Mugilidae are large or moderate-sized and axillary scales or modified scales may present below first dorsal fin and above pectoral and pelvic fins (Carpenter & Niem, 1999).

2.2 Fish identification using classical morphometric and meristic

According to Beeg and Waldman (1999), a lot of information should be collected for identification of fish stocks on the exploited resource. Several methodologies can be performed such as research study by Ihssen *et al.* (1981), ICES (1996) and Pawson and Jennings (1996). The most favorable methodologies for identification of fish stocks are the analysis of morphometric and meristic data (Meng & Stocker, 1984; Junquera & Perez-Gándaras, 1993; Elliot *et al.*, 1995; Huribut & Clay, 1998; Murta, 2000; Saborido-Rey & Nedreaas, 2000), cohorts separation of a single species (Austin *et al.*, 1999) and verification of taxonomic groups (Misra & Ni, 1993; Marcus *et al.*, 1996; Gallo da Silva *et al.*, 1998).

2.2.1 Morphometric technique

Species of fish can be differentiated directly by using morphometric which involves the measurement of length on various parts of fish such as standard length, total length, body width and head depth of the fish (Hubbs & Lagler, 1958). Morphometric analysis has been widely used and vital for separating fish species and fish populations. Therefore, morphometric is important to identify and verify the study population in order to understand its dynamics in fisheries (Ibanez-Aguirre *et al.*, 2006).

2.2.2 Meristic technique

Meristic characteristics related to the part of fish that are countable such as the number of gill rakers on arch, spines and rays of each fin, the number of barbels, branchiostegal ray number, an index of snout bluntness and the number of scales along the lateral line (Doherty & McCarthy, 2004). The meristic study is often a difficult task because the counting of the features of a fish is not as easy as we think. Meristic or countable trait can be used either to describe a particular species of fish or to identify an unknown fish species. The meristic traits are often described using meristic formula. Meristic formula is a method to describe how the fin rays or bones of fish are arranged. Ichthyologists follow a basic set of rules when performing a meristic analysis in order to remove as much ambiguity as possible. Nevertheless, the specific practice may vary depending on the type of fish (Wikipedia, 2011).

2.2.3 Taxonomy and morphology of Mugilidae species

The taxonomy and morphology of this family could be classified as follows according to the information obtained from Fishbase (2011):

Kingdom : Animalia

Phylum : Chordata

Class : Actinopterygii

Order : Mugiliformes

Family : Mugilidae

Genus : Liza

Valamugil

Species : *Chelon subviridis* (Valenciennes, 1836)

Liza vaigiensis (Quoy & Gaimard, 1825)

Valamugil engeli (Bleeker, 1858-59)

Valamugil seheli (Forsskål, 1775)

Valamugil speigleri (Bleeker, 1859)

a) *Chelon subviridis* (Valenciennes, 1836)

C. subviridis or greenback grey mullet (Figure 2.1) distributed in Indo-Pacific region, covering Red Sea to Samoa, north to Japan and South Africa (Heemstra, 1995). They are demersal and catadromous species that could be found in marine, freshwater and brackish water (McDowall, 1997). *C. subviridis* are important for commercial fisheries, aquaculture and usually use as bait (Thomson, 1984).

Figure 2.1. Morphology of *Chelon subviridis*

According to Harrison and Senou (1997), *C. subviridis* consist of dorsal spines: 4-5; dorsal soft rays: 8-9; anal spines: 3; anal soft rays: 9. For physical characteristics, *C. subviridis* is dark greenish dorsally, white ventrally, brownish on head, 3-6 indistinct, dark stripes along upper rows of scales, caudal fin bluish with black margin, grayish dorsal fin, pectoral fin yellowish and blue spot at fin origin may present.

C. subviridis shoals in shallow coastal waters and searching for foods by entering lagoons, estuaries and fresh water. They feed on diatoms, fine algae and benthic detrital material taken in with mud and sand whereas fry feed on zooplankton, diatoms, inorganic sediment and detrital material (Harrison & Senou, 1997). The spawning event of *C. subviridis* took place at sea. They are oviparous, produce non-adhesive and pelagic eggs (Breder & Rosen, 1966).

b) *Liza vaigiensis* (Quoy and Gaimard, 1825)

The suitable environment for *L. vaigiensis* or squaretail mullet (Figure 2.2) is in marine, brackish, freshwater, reef-associated and catadromous (McDowall, 1997). This fish inhabit tropical climate ranging from 32°N - 24°S and distributed in Indo-Pacific: from Red Sea and East Africa to Tuamoto Islands, north to southern Japan, south to southern Great Barrier Reef and New Caledonia (Harrison & Senou, 1997).

L. vaigiensis can reach at maximum total length of 63.0 cm whereas the common length was 35.0 cm. According to Harrison and Senou (1997), some meristic characteristics of *L. vaigiensis* are dorsal spine: 4-5, dorsal soft rays: 8-9, anal spines:

3, anal soft rays: 7-9. Their bodies are silvery flanks, olive-brown dorsally, white or suffused pale yellow abdomen, yellow patches in iris, dusky or yellowish white margin of fins, darkened margin on scales, yellowish caudal fin, black pectoral fin in small fish and yellowish lower section of pectoral fin in adults. There were also six longitudinal stripes on flanks. The axillary scale was absent in the pectoral fins (Myer, 1999).

Figure 2.2. Morphology of *Liza vaigiensis*

L. vaigiensis prefers estuaries, lagoons, reef flats, coastal creeks in protected sandy shores and shallow coastal areas. They probably enter freshwater with the help of tidal influence, ascending for about 10 km into rivers. This species forms large shoals especially in mangrove areas (Randall *et al*., 1990). Besides, this fish can be used as bait and juveniles frequently found in mangroves and rice fields (Harrison & Senou, 1997). According to Breder and Rosen (1966), they are oviparous, eggs non-adhesive and pelagic. In fisheries, this fish are important for commercial aquaculture, aquarium and bait.

c) *Valamugil engeli* (Bleeker, 1858-59)

V. engeli (Figure 2.3) is distributed in Indo-Pacific, from east Africa to the Marquesan and Tuamoto islands and north to the Yaeyamas (Fishbase, 2011). *V. engeli* lives in tropical climate ranging from 25°N to 24°S and can reach a maximum size of 30.0 cm total length (Harrison & Senou, 1997) and common total length of 25.0 cm (Bianchi 1985).

Figure 2.3. Morphology of *Valamugil engeli*

Some meristic measurements of *V. engeli* are dorsal spine: 4, dorsal soft rays: 9-10, anal spines: 3 and anal soft rays: 8-9. The colors of *V. engeli* are olive dorsally, silvery flanks and abdomen. Their fins are hyaline and pectoral fins with dark spot dorsally at origin (Harrison & Senou, 1997).

According to Breder and Rosen (1966), *V. engeli* inhabit shallow protected sandy to muddy areas of reef flats and shallow lagoons and sometimes their juveniles have been encountered in tide pools. They are benthopelagic fish (Mundy, 2005). They are oviparous, egg non-adhesive and pelagic (Breder & Rosen, 1966).

According to Harrison and Senou (1997), this mullet is marketed fresh and usually used as live bait in pole and line fishing for tuna fish.

d) *Valamugil seheli* (Forsskål, 1775)

V. seheli or bluespot mullet (Figure 2.4) inhabit marine, freshwater, brackish, reef-associated and catadromous (McDowall, 1997). *V. seheli* lives in tropical climate, ranges from 32°N to 23°S and distributed in Indo-Pacific Region; South Red Sea to Transkei, South Africa (Smith and Smith, 1986), east to Hawaiian and Marquesan islands, north to southern Japan, south to New Caledonia and Norfolk Island (Francis, 1993). The maximum total length was 60.0 cm (Lieske & Myers, 1994), common length was 40.0 cm (Bouhlel, 1988) and maximum published weight was 8 kg (Myers, 1999).

Figure 2.4. Morphology of *Valamugil seheli*

The dorsal spines of *V. seheli*: 4-5, dorsal soft rays: 8-9, anal spines: 3 and anal soft rays: 8-10. This species could be identified by bluish brown or green color dorsally, silvery on flanks and abdomen, present of dusky spot on upper row of scales (Harrison & Senou, 1997). Their caudal fin with dark blue tip on dorsal and upper lobe and anal fin, pelvic fin and pectoral fin are yellowish. Dark blue spot also present dorsally at origin of pectoral fin and their pectoral fin axil scale was very long.

This species inhabit shallow coastal waters and penetrate into rivers or estuaries to feed on filamentous algae, microalgae, diatoms, detritus and forams (Harrison & Senou, 1997). *V. seheli* schooling among themselves and they are oviparous, producing non-adhesive and pelagic egg (Breder & Rosen, 1966). *V. seheli* could be caught using barrier nets, stake nets and pouch nets during spawning. They are probably marketed fresh, boiled (Thailand), frozen or canned (Australia) and their roe marketed salted (Harrison & Senou, 1997).

e) *Valamugil speigleri* (Bleeker, 1858)

Speigler's mullet or *V. speigleri* (Figure 2.5) lives in tropical climate and their environment could be marine, freshwater, demersal, brackish or catadromous (McDowall,1997). They distributed in Indo-West Pacific, from Pakistan through Southeast Asia to New Guinea. *V. speigleri* can reach maximum total length 35.0 cm but the common total length was 17.5 cm (Harrison & Senou, 1997).

Figure 2.5. Morphology of *Valamugil speigleri*

V. speigleri are distinguished by their dorsal spines: 4, anal spines: 3 and anal soft rays: 9. Other than that, their body greenish dorsally, silvery on flanks and abdomen, black margin on first dorsal fin, dusky on other fin and dark spot dorsally at origin of pectoral fins (Harrison & Senou, 1997).

V. speigleri shoaling in shallow coastal water and enters freshwaters or estuaries. They spawn at sea and their juveniles could be found in mangrove swamps and rice fields (Harrison & Senou, 1997). Juveniles feed on diatoms, small algae, organic matter and detritus whereas fries feed on floating algae and copepods. *V. speigleri* are oviparous, producing non-adhesive and pelagic eggs (Breder & Rosen, 1966). This fish marketed fresh, boiled (Thailand) and frozen or canned (Australia). Their roe marketed salted (Harrison & Senou, 1997).

2.3 Length-Weight Relationship, Length-Length Relationship and Condition Factor

2.3.1 Length-weight relationship

Generally, the length-weight relationship is used to extract information about the growth condition of fish and to find out whether the fish somatic growth was isometric or allometric (Le Cren, 1951; Ricker, 1973). In addition, by using length and weight data, one can predict the fish growth parameters as well as predict the mortality rate which is useful in fish stock assessment (Samat *et al.,* 2008). Usually, the size of fish is more biologically relevant than age because several ecological and physiological factors are more size-dependent than age-dependent. As a result, variability in size has important implications for diverse aspects of fisheries science and population dynamics (Erzini, 1994). The length and weight data are useful for fish sampling programmes as they are needed to estimate growth rates, length and age structures, and other components of fish population dynamics (Kohler *et al*., 1995).

According to Pitcher and Hart (1982), length weight relationships are beneficial in fishery management to estimate weight from the obtained length observations in order to provide information on stock or organism condition at the corporal level as well as to calculate production and biomass of fish population. The length weight relationship is vital in estimating the average weight at a given length group and become as important tool in fishery management (Beyer, 1987). Other than that, length weight relationships are used to estimate and compare life history and morphological aspects between populations from different regions in this world (Goncalves *et al*., 1997; Stergiou & Moutopoulus 2001). Consequently, length-weight relationship used to assess the relative wellbeing of a fish population (Bolger & Connoly, 1989).

The length weight relationship is expressed by the equation, $W = aL^b$. This mathematical relationship between length and weight of fishes is a practical index appropriate for understanding their survival, growth, general well-being, maturity and reproduction (Le Cren, 1951). Frequently, length-weight has been using for analyses of fisheries data (Mendes *et al*., 2004). Mansor *et al*. (2010) have been used this equation in different fish species obtained from two different environmental conditions; Kerian River Basin and Pedu Reservoir.

The length weight relationship becomes very valuable for fisheries research because they yield the conversion of growth in length equations to growth in weight for use in stock assessment models in fisheries management, allow an estimation of fish condition, allocate the comparisons of life histories of certain species between regions, give the estimation of biomass from fish length observations and valuable component in FishBase species (Goncalves *et al*., 1997; Froese & Pauly 1998; Moutopoulos & Stergiou 2002).

Length-weight regressions have been used frequently to estimate weight from length because direct weight measurements can be time-consuming in the field sampling (Sinovcic *et al*., 2004). Nonetheless, length weight relationships also used to compare life history and morphological aspects of fish populations inhabiting different regions (Goncalves *et al*., 1997; Stergiou & Moutopoulus, 2001). Basically, length weight relationships used to provide preliminary information on condition of fish and determine whether growth of fish is positive allometric, negative allometric or isometric (Ricker, 1975). According to Lizama *et al*. (2002), the knowledge of quantitative aspects such as length weight relationship, condition factor, growth, mortality and recruitment of fishes have taken into consideration to become an important tool for the study of fish biology.

The obtained data on length and weight could provide logical clues to the change in human subsistence practices, climatic changes and environmental degradation (Pauly 1984; Luff & Bailey, 2000). Thus, length weight relationships of fishes are vital in population assessment (Ricker 1968; Khaironizam & Norma-

Rashid, 2002) and the data could be used to assess the age and year classes of fish, mortality rate and sustaining power of the fishery stock (Samat *et al*., 2008).

The metabolism of each fish species and the environmental condition where fish live could affect their length and weight (Gonzalez-Ganadara *et al*., 2003). According to Samat *et al*. (2008), the size of individual fish may vary because of competition for food, supply of nutrients and climatic parameters. In addition, environmental deterioration could reduce growth rates and decrease average age of the fish. However, in reality, the interactions between growth rates and environmental changes are believed to be complex and argumentative to explain.

Likewise, the length-weight relationship parameters are important in fish biology as it can give information on stock condition (Bagenal & Tesch, 1978), used on commercial scales in population assessments (Steeby *et al*., 1991; Ali *et al*., 2000), actuate the weight of an individual fish of known length from length frequency distribution (Froese, 1998; Koutrakis & Tsikliras, 2003) and applicable in estimating the standing stock biomass, indices of condition and comparing the ontogeny of fish population from one region to another region (Petrakis & Stergiou, 1995; Odat, 2003). Nonetheless, the length weight parameter of the fish may differ in fish population of the same species due to fishing, feeding and reproduction activities (Eqbal *et al*., 2011). Therefore, the length weight relationships ascertain a crucial pre-requisite in fishery biological investigations as it deals with the variation in expected weight from the known length groups. At the same time, it becomes an indication of breeding and feeding state, fatness and suitability to the environment (Soumendra *et al*., 2009).

2.3.2 Length-length relationship

Length-length relationship estimate the relationship between types of length used in fish measurement either total length, fork length, standard length or body length. The length-length relations of a fish species under various environmental conditions should be investigated. According to Moutopoulus and Stergiou (2002), the length-length relationship evolves as an essential component for comparative growth studies in fisheries management. Therefore it is necessary to use standard measures for all populations to render the results more reliable when making comparisons between populations.

On the other hand, the length-length relationship could be used to evaluate the influence of environmental changes in particular area (Adeyemi, 2011). Besides, according to Ricker (1968), the length-length relationships have been applied for the basic uses for assessment of fish stocks and populations. Interestingly, the fish growth, mean weight of a given body length of fish estimation and the relative well-being in fish could be predictable via the length-length relationship together with the length-weight relationship (King, 1996).

2.3.3 Condition factor

The relationship of length-weight estimates condition factor of the fish species and fish biomass through the length frequency (Fishbase, 2011). According to Bagenal and Tesch (1978), condition factor used to compare the wellbeing of a fish in an environment. They make a hypothesis that heavier fish of a given length are in better condition. Aside from that, condition factor of same species in different fish population probably give information pertaining the timing and duration of breeding and food supply (Weatherley & Rogers, 1978). Therefore, condition factor has been used as an important index of fish growth and feeding intensity (Fagade, 1979).

At the same time, fish with a high value of K are heavy for its length, whereas fish with a low 'K' value are lighter (Ibrahim *et al*., 1980), indicating that condition factor decrease with increase in length (Bakare, 1970; Bagenal and Tesch, 1978; Fagade 1979; Wootton, 1998; Zafar *et al*., 2003). Froese (2006) reported that the relative condition factor also can be used for comparing the observed weight of an individual fish with the mean weight for that length. According to Ndimele *et al*. (2010), condition factor become a useful index in order to monitor the growth rates in fish, their age and feeding intensity. Consequently, condition factor used as an index to assess the status of the aquatic ecosystem in fish habitat which influenced by both abiotic and biotic environmental conditions (Anene, 2005). The condition factors of different tropical fish species were investigated by Ricker (1973) and Alfred-Ockiya and Njoku (1995).

Generally, there were three equations used in condition factor study namely relative condition factor (K_{rel}), Fulton's condition factor (K) and relative weight (W_{rm}) (Hadi-Raeisi *et al*., 2011). The relative condition factor for individual fish is calculated using equation by Le Cren (1951); $K_{rel} = W/aL^b$, where W is the body weight (g), L length (cm) and a and b are specific parameters of length-weight relationship. The Fulton's condition factor is calculated according to the formula by Htun Han (1978); $K = 100W/L^3$, where W is body weight (g) and L is length.

According to Froese (2006), this formula is widely used in fish biology studies and fisheries. Whereas the relative weight estimated using formula by Froese (2006); $W_{rm} = 100W/a_mL^b$, where W is body weight (g), a_m is geometric mean a and b_m is the mean b across all available, non-questionable length weight estimates for a species as parameters of the mean length–weight relationship that cited in the Fish base (Froese, 2006). According to Lizama and Ambrósio (2002), the study of the condition factor is important to understanding the fish life cycle as well as contributes to the proper management of fish species and maintains the ecosystem in equilibrium.

2.4 Reproductive Biology

Reproductive biology of fish defined as the combination of the species-specific reproductive mode and reproductive traits (Murua & Saborido-Rey, 2003). The reproduction biology investigates the reproductive aspects such as maturity stages, gonadosomatic index, length at first sexual maturity, egg diameter and fecundity (Allam, 1996; Abdallah & Faltas, 1998; Ibrahim, 1999). This reproductive study is important to understand a fish population because they provide insight into the estimation of the spawning season, reproductive potential over time as well as enabling survival and continuation of species. Some related aspects in reproductive biology are reproductive strategy, reproductive system, fecundity, gonadal development, gonadosomatic index and length at first maturity.

2.4.1 Reproductive strategy

The reproductive strategies of fishes related to the anatomical differences between the sexes, female and male fishes in order to maximize the production of the offspring and their survival in relation to their environment, parental life expectancy and available energy (Roff, 1992; Pianka, 2000).

According to Balon (1975 & 1984), spawning behaviors of fish can be classified into reproductive guild which based on how the eggs are fertilized (internal or external), where the eggs are deposited (pelagic or benthic) and whether and how parents look after the eggs after spawning (bearers, guarders and non-guarders). Bearers are fish that carry their embryos with them internally or externally. Guarders are fish that protect eggs and offspring after spawning by parental care or brood care. Whereas non-guarders are fish that do not protect their eggs and offspring after spawning. In Mugilidae, they are practicing external fertilization, producing pelagic eggs and categorized into non-guarders (Nelson, 2006).

2.4.2 Reproductive system

According to Wallace and Selman (1981) and De Vlamming *et al*. (1982), the development pattern of fish oocyte could be categorized into synchronous, asynchronous or group synchronous. Synchronous pattern are known as total spawners. This pattern means that the development of oocyte is simultaneously and in unison. The egg and sperm of fish only will be produced and fertilized once in their lifetime, indicating that fish in this category only have one reproductive cycle and a