LENGTH-WEIGHT, CONDITION FACTOR AND FEEDING GUILD *Periophthalmus chrysospilos* (Bleeker, 1852) (GOBIIDAE: OXUDERCINAE), FROM BAYAN BAY COASTAL WATER, PENANG

by

MOHD ILMAN BIN CHE ABDULLAH

Thesis submitted in fulfillment of the requirement

for the degree of

Master of Science

August 2016

ACKNOWLEDGEMENT

Praise be to Allah, the most gracious and the most merciful, finally I managed to finish this study even though I faced a lot of difficulties during the course of my study. Being a part time student conducted a full research study, and a full-time worker under the Majlis Amanah Rakyat (MARA) had possessed an enormous challenge for me to balance the job requirement and study performance.

I would like to extend a huge appreciation for my supervisor Dr. Khaironizam Md Zain for his guidance and patience in supervising my study. My sincerest thanks to Prof. Dr. Amirul Al-Ashraf Abdullah, Dean of School of Biological Sciences, Universiti Sains Malaysia for providing all facilities and equipment during my study.

Last but not least, I would like to express my deepest gratitude to my pillars of strength my wife, Wan Salwani Wan Sidi, my father Che Abdullah Che Endok and my mother Fauziah Mohamed for their continuous support and motivation during the course of my study. May God bless them all and thank you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

LIST OF PLATES

Page

LIST OF APPENDICES

LIST OF SYMBOLS AND ABBREVIATIONS

a	Constant of proportionality
ANCOVA	Analysis of covariance
b	Length exponent/slope
CI	Confidence interval
DO	Dissolved Oxygen
E	Exploitation rate
ELEFAN	Electronic Length-Frequency Analysis I
F	Fishing mortality
FISAT II	FAO-ICLARM Stock Assessment Tools II
K	Fulton condition factor
K	Growth constant
$L\infty$	Asymptotic length
*L*c	Length at first capture
LWR	Length-weight relationship
M	Natural mortality
SPSS	Statistical Package for Social Science
T	Mean water temperature
TL	Total length
VBGF	von Bertalanffy Growth Function
Z	Total mortality
Ø'	Growth performance index
ρ	Spearman correlation

PANJANG-BERAT, FAKTOR KEADAAN DAN CORAK PEMAKANAN *Periophthalmus chrysospilos* (Bleeker, 1852) (GOBIIDAE, OXURDERCINAE), DARI PERAIRAN TELUK BAYAN, PULAU PINANG

ABSTRAK

Satu kajian populasi dinamik dan biologi pemakanan ikan belacak *Periophthalmus chrysospilos*, telah dijalankan di kawasan perairan Teluk Bayan, Pulau Pinang dari Julai 2013 hingga Julai 2014. Kajian ini terdiri daripada tiga komponen: (i) perhubungan panjang-berat (LWR) dan faktor keadaan Fulton (K); (ii) tumbesaran, mortaliti dan corak rekrut, dan (iii) analisa kandungan perut. Objektif utama kajian ini adalah (i) untuk menyiasat hubungan panjang-berat *P. chrysospilos* bagi jantina dan bulan yang berbeza, (ii) untuk menjelaskan faktor keadaan Fulton dan perhubungan dengan bulan-bulan yang berbeza dan parameter kimia-fizik air, (iii) mengkaji parameter pertumbuhan, kematian, dan corak rekrut dan yang terakhir (iv) menentukan aktiviti pemakanan dan corak pemakanan *P. chrysospilos* berdasarkan jantina, bulan dan jenis air pasang. Keputusan menunjukkan nilai eksponen (*b*) bagi hubungan panjang-berat (LWR) bagi semua individu (N=714), ikan jantan, ikan betina, dan ikan yang ditangkap dalam bulan kering dan hujan mempunyai nilai melebihi 3, yang menunjukan tumbesaran positif alometri. Faktor keadaan Fulton bagi semua individu, ikan jantan, ikan betina dan ikan yang ditangkap dalam bulan kering dan bulan hujan adalah 0.998 ± 0.121, 0.9907 ± 0.106, 1.008 ± 0.138, 1.018 ± 0.115 dan 0.998 ± 0.123. Nilai *b* dan K untuk ikan jantan dan ikan betina didapati tidak berbeza dengan bererti. Nilai *b* di bulan kering adalah lebih tinggi secara bererti berbanding di bulan hujan. Walau bagaimana pun, nilai K untuk ikan yang ditangkap dalam bulan hujan di dapati lebih tinggi secara bererti berbanding pada bulan kering.

Di dapati tiada sebarang kesan parameter persekitaran (suhu air, kelembapan relatif, saliniti air, jumlah pepejal terlarut, oksigen terlarut, konduktiviti dan pH) ke atas faktor keadaan ikan. Perbandingan faktor keadaan Fulton berdasarkan panjang keseluruhan menunjukkan nilai terendah faktor keadaan Fulton adalah 11 cm dan nilai yang tertinggi adalah 10 cm. Parameter populasi dinamik menunjukkan panjang asimptot ($L\infty$) adalah 13.20 cm, pekali pertumbuhan (K) adalah 0.68 tahun^{-1}, indek kemajuan pertumbuhan (Ø') adalah2.074, kadar kematian keseluruhan (Z) adalah 2.47 tahun^{-1}, Kematian semasa penangkapan (F) adalah 0.70 tahun^{-1}. Aras eksplotasi (E) ikan adalah 0.28 tahun^{-1} menunjukan ekploitasi yang rendah dan anggaran panjang pada tangkapan yang pertama adalah 7.69 cm. Corak rekrut tahunan *P. chrysospilos* adalah dua puncak setahun. Analisa kandungan perut terhadap 424 *P. chrysospilos* menggunakan kaedah analisa frekuensi kedapatan menunjukkan tabiat pemakanan *P. chrysospilos* adalah karnivoros di mana kandungan isi perutnya di dominasi oleh bahan-bahan dari haiwan seperti copepods, polychaetes, udang dan krustasia. Bahan tumbuhan adalah terdiri daripada alga, diatom and makrofit yang tidak dapat dikenalpasti. Analisis kepenuhan perut menunjukkan bahawa *P. chrysospilos* di perairan Teluk Bayan adalah pemakanan secara kerap di mana hanya 30.2 % daripadanya mempunyai kandungan perut yang kosong. Selebihnya mengandungi bahan makanan dalam pengukuran kurang daripada 50% perut penuh = 37.5%, lebih daripada 50% perut penuh =14.6 dan perut penuh sepenuhnya = 17.7 %. Tidak terdapat perbezaan bererti kepenuhan perut *P. chrysospilos* antara berlainan jantina dan bulan. Walau bagaimana pun kepenuhan perut semasa air surut adalah lebih tinggi secara bererti berbanding semasa air pasang. Ini menunjukkan bahawa *P. chrysospilos* biasanya mencari makan pada waktu air surut. Kesimpulannya, kajian ini memberi maklumat penting bagi tujuan polisi pemuliharaan dan pengurusan *P. chrysospilos*.

LENGTH-WEIGHT, CONDITION FACTOR AND FEEDING GUILD OF *Periophthalmus chrysospilos* (Bleeker, 1852) (GOBIIDAE: OXUDERCINAE), FROM BAYAN BAY COASTAL WATER, PENANG

ABSTRACT

A study on population dynamics and feeding biology of mudskipper, *Periophthalmus chrysospilos* was conducted in Bayan Bay coastal water, Penang from July 2013 to July 2014. This study comprised of three components: (i) Length-weight relationships (LWR) and Fulton condition factor (K); (ii) growth, mortality, and recruitment pattern, and (iii) stomach content analyses. The main objectives of this study are: (i) to investigate the length-weight relationships of *P. chrysospilos* in different sexes and months, (ii) to elucidate the Fulton condition factor and its relation to the monthly variations and water physio-chemical parameters, (iii) to study the growth parameters, mortality and recruitment pattern of *P. chrysospilos* and finally (iv) to determine the feeding activities and feeding guild of *P. chrysospilos* according to different sex, months and water tide. Results show the exponential values (b) of the LWR for all individuals (N = 714), male and female fish, and fish caught during dry and rainy months were greater than 3, indicating of positive allometric growth. The Fulton's condition factor (K) for all individuals, male, female, and fish caught in dry and rainy months were 0.998 ± 0.121, 0.9907 ± 0.106, 1.008 ± 0.138, 1.018 ± 0.115 and 0.998 ± 0.123, respectively. The b and K values for male and female fish were not significantly different. The b value in dry months is significantly higher than in rainy months. However, K values for fish caught in rainy months was significantly higher than those caught in dry months. There are no effects of physical parameters (water temperature, relative humidity, water salinity, total dissolved solid, dissolved oxygen, conductivity, and pH) measured on fish condition factors. Comparison of Fulton condition factor based on the total length revealed that the lowest value of condition factor is observed in the total length of 11 cm, and the highest value is 10 cm. The parameters of population dynamic show the asymptotic length ($L\infty$) of 13.20 cm, growth coefficient (K) of 0.68 $year^{-1}$, growth performance index ($\varnothing'$) of 2.074, total mortality (Z) of 2.47 $year^{-1}$, and fishing mortality (F) of 0.70 $year^{-1}$. The exploitation level (E) was 0.28 $year^{-1}$ indicating of low exploitation and estimation of length at first capture was 7.69 cm. The annual recruitment pattern of *P.chrysospilos* was recruited in two peaks per year. The stomach content analysis on 424 *P. chrysospilos* using the frequency of occurrence method reveals that *P. chrysospilos* has carnivorous feeding habits where animals materials such as copepods, polychaetes, shrimps, and crustacean dominated its content. The plant materials consist of algae, diatom, and unidentified macrophyte. Stomach fullness analyses discovered that *P. chrysospilos* in coastal water of Bayan Bay are regular feeder where only 30.2 % show an empty stomach. The rest of the stomach, containing the food material in the measurement of less than 50% filled stomach = 37.5 %, more than 50% filled stomach = 14.6 % and fully filled stomach = 17.7 %. No significant different between stomach fullness of *P. chrysospilos* between different sexes and seasons. However, stomach fullness during low tide is significantly higher than high tide. This shows that *P. chrysospilos* is normally fed during the low tide. In conclusion, this present study provides important information for conservation and management policy of *P. chrysospilos* .

CHAPTER 1

INTRODUCTION

Mangrove is defined as the habitat of a complex group of vegetation, which normally occurs above the mean sea level in the intertidal zone of marine coastal environmental or estuarine and usually distributed in the tropical and sub-tropical areas. Even though Malaysian mangrove forest is not as rich and diverse as the rainforest, its structures are unique (Macnae 1968). It houses many trees and shrubs species, which their structural roots developed firmly in the mud and at the same time exposed to the harsh environmental conditions, such as daily changes of tide level, air temperature, humidity, water salinity and other environmental parameters.

Hemati et al. (2014) reported that mangrove areas of the world are now decreasing in size due to land reclamation and development, with approximately less than 15 million hectares recorded in the year 2000. A similar situation was reported in Malaysia, where the current size of mangrove areas is less than those reported by Chong (1996) i.e. about 455,267 hectares were distributed along the coastal areas of Sabah and Sarawak, and about 111,589 hectares in Peninsular Malaysia (Latif 2012). The State of Penang constitutes a fraction of total mangrove coverage in Peninsular Malaysia with approximately 279 hectares, but it is highly exploited. Rapid land reclamation used for industrial and domestic development particularly in the area of Bayan Bay had posed a significant threat to many marine organisms that totally dependent on this ecosystem such as mudskippers. Therefore, it is crucial to conduct a comprehensive ecological study in this area. Furthermore, this area is known to be inhabitant by amphibious fish which were commonly known as mudskippers.

1.1 Mudskippers

Mudskippers belong to the subfamily Oxudercinae of the largest marine fish family, Gobiidae (Murdy 1989; Blaber 2000). Best known for their amphibious lifestyle which is active during low tides and spends most of their time out of water in mangrove habitats (Khaironizam & Norma-Rashid 2002a). They are common on an intertidal mudflat, estuary and mangrove areas of the Indo-Pacific and West Africa regions (Tytler & Vaughan 1983; Murdy 1989; Shukla et al. 2014). Worldwide, ten genera with 41 species have been recorded base on their distributional ranges (Eggert 1935; Murdy 1989; Lee et al. 1995; Murdy & Takita 1999; Darumas & Tantichodok 2002; Larson & Takita 2004; Jaafar & Larson 2008; Polgar et al. 2013). This fish possesses particular physiological and morphological adaptations, which allow it to survive in amphibious lifestyle (Kruitwagen et al. 2007; Chew & Ip 2014; Michel et al. 2014).

Mudskippers utilise mudflat and intertidal area for growth, foraging, and reproduction (Ishimatsu et al. 1998; Mazlan & Rohaya 2008; Chukwu & Deekae 2013). This fish has a distinctive behaviour on burrowing as most mudskippers species reside in a burrow excavated in the mudflat. The burrow plays a vital role in protecting the fish from its predators, for temperature regulation, and egg deposition (Swennen et al. 1995; Ishimatsu et al. 1998; Lee et al. 2005; Dinh et al. 2014; Toba & Ishimatsu 2014).

According to Murdy (1989), the diversity of mudskippers at different localities are different. African continent possesses only two species of mudskipper, Arab peninsula consists of three species, India has 10 species, Australia, and Papua New Guinea have 14 species, China, Taiwan, Hong Kong, Korea, and Japan consist only 7 species, and South East Asia countries have 21 species of mudskipper. Of the South East Asian number of mudskippers, Peninsular Malaysia has the highest mudskippers diversity with 17 species are distributed in the intertidal areas (Khaironizam 2004).

The documented study on mudskippers in Peninsular Malaysia may firstly reported in the middle of 19^{th} century by Cantor (1849) where he listed six species of mudskippers from Penang waters, namely *Periophthalmus schlosseri* (now is *Periophthalmodon schlosseri*), *Boleophthalmus boddarti*, *Boleophthalmus pectinirostris*, *Boleophthalmus viridis* (now is *Sartelaos histophorus*), *Apocryptes lanceolatus* (now is *Pseudapocryptes elongatus*), and *Apocryptes nexipinis* (now is *Oxuderces dentatus*). The number of mudskippers has increased since then due to discovery and a new record for this region. Murdy (1986) recorded another four species namely *Periophthalmus chrysospilos*, *Periophthalmus novemradiatus* (now is *Periophthalmus variabilis*), *Periophthalmus gracilis* and *Periophthalmus argentilineatus*. Khaironizam & Norma-Rashid (2000a) compiled the number of mudskippers found in Peninsular Malaysia and added another four species to the list as they found another four new records of mudskippers, *Periophthalmus spilotus*, *Periophthalmus walaikake*, *Periophthalmodon septemradiatus* and *Parapocryptes serperaster*.

One of the most conspicuous mudskipper species inhabitants the coastal water of Bayan Bay is *Periophthalmus chrysospilos* (Bleeker, 1852) or commonly known as golden spotted mudskipper. Based on the fact that its natural habitat had being altered in such an alarming rate might pose a serious threat to their survivable in the next future. Up to this date, only a few study on this particular species are available in this region. Thus, it is very important to have a comprehensive knowledge of the biological information of *P. chrysospilos* such as length-weight relationship, condition status, growth parameters and feeding habit. Knowledge in this aspect is important and could be used by scientist and policy maker in the future for a better understanding of this fish and leads to a sustainable conservation and management policy of this species in this state. Since the study of mudskipper in Peninsular Malaysia has been little known to the public and yet their importance also scarcely reported. Here the occurrence of *P. chrysospilos* was reported abundantly occurred in Peninsular Malaysia but the knowledge on the population dynamic and feeding biology are lack and need to be addressed.

1.2 Study objectives

The aims of this study are:

I. To investigate the length-weight relationships of *Periophthalmus chrysospilos* in different sexes and months in the coastal water of Bayan Bay.

II. To elucidate the Fulton condition factor and its relation to the monthly variations and water physio-chemical parameters in the coastal water of Bayan Bay.

III. To study the growth parameters, mortality and recruitment pattern of *Periophthalmus chrysospilos* in the coastal water of Bayan Bay.

IV. To determine the feeding activities and feeding guild of *Periophthalmus chrysospilos* in the coastal water of Bayan Bay according to different sexes, months and water tides.

CHAPTER 2

LITERATURE REVIEW

2.1 General characteristics of *Periophthalmus chrysospilos* (Bleeker, 1852)

P. chrysospilos is also commonly known as the golden spotted mudskipper and is distinguished from another mudskipper by the occurrence of numerous orange spots on the lateral and ventral surface of the head and trunk (Plate 2.1). In the preservation, these orange spots change into pale or white colour. Another characteristic that can be used to distinguish it from other species of mudskipper is its pelvic fins with a strong frenum and are totally united into a rounded disc. The dorsal fin of this species is divided into two parts: first dorsal fin (D1) and second dorsal fin (D2), and both dorsal fins are not connected. The D1 tall with 7-10 spines, bright orange coloured, its margin slightly arch with dark stripe at the two-third of the posterior part, the first spine elongated, and the first spine in male fish is relatively longer than in female fish which indicating sexual dimorphism (Murdy 1989). D2 short with 12-13 rays, and its distal margin reddish coloured with a black stripe in the middle. Pectoral, pelvic and anal fins transparent coloured, and with 13-16, 7-8, and the 11-13 number of rays, respectively. Caudal fin rounded and dusky coloured. Lateral line scale counts 64-77.

This species of mudskipper can be found in abundance in pioneering mangroves of *Avicennia alba* and mixed forest zones of *A. alba* and *Sonneratia alba* (Takita & Ali 1999). This species also can be found in the brackish mangroves, and nipa palm areas from the east coast of India to the Gulf of Thailand, Java Sea (Murdy 1989). According to Chew & Ip (1990), this fish can also be found in the littoral zone of the shore with 30-34 ppt of salinity.

Like other mudskippers of the genera *Periophthalmus*, this species also reported to has better terrestrial adaptation (Chew & Ip 1990). Mazlan et al. (2006a) and Chew & Ip (1990) reported that *P. chrysospilos* possesses wrinkled secondary lamellae with a decrease in size towards the filament tip. In fact, *P. chrysospilos* is more adaptable to aerial respiration compared to water respiration. This fact was supported by the study of Low et al. (1990) that he reported that the counter-current mechanism for oxygen absorption in *P. chrysospilos* was inefficient. Therefore, this kind of mudskipper needs to rely more on its aerial respiration.

This mudskipper species has better terrestrial breathing because of several modification in its gill structures: 1) a bended and twisted filament, 2) its secondary lamellae are not positioned parallel to the respiratory water current, 3) it has a relatively smaller filament number, 4) a shorter filament length and 5) the smallest gill area as compared to other mudskippers. Thus, oxygen uptake must rely on other means of mechanisms such as cutaneous air breathing. The skin of *P. chrysospilos* contains many mucous cells scattered over the epithelium cells and dense micro ridges, which allow cutaneous respiration through its skin.

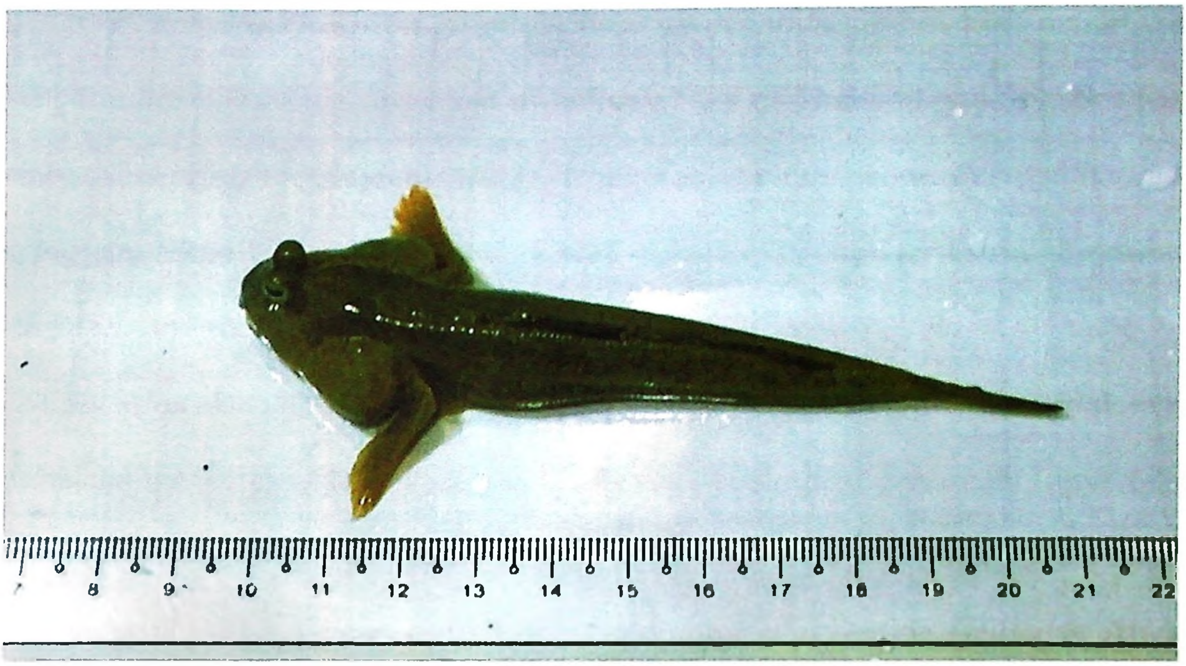

Plate 2.1. General appearance of *Periophthalmus chrysospilos* (Bleeker, 1852)

Systematically, this species is arranged as follow (Murdy 1989):

Kingdom: Animalia

Phylum: Chordata

Class: Actiopterygii

Oder: Perciformes

Family: Gobiidae

Subfamily: Oxudercinae

Genus: *Periophthalmus*

Species: *chrysospilos*

2.1.1 Morphometric count

The morphometric count for *P. chrysospilos* is mentioned by (Murdy 1989) : head with 12.6-21.8 SL (mean =17.3%); pelvic fin length 12.4-16.8% SL (mean = 14.3%); length of anal fin base 16.7-20.6% SL (mean =18.5%); length of D2 base 16.3-24.3 % SL (mean =21.2%).

2.2 Habitat and distribution of *P. chrysospilos*

P. chrysospilos is an intertidal fish that inhabits the brackish mangrove and nipa palm areas from the east coast of India to Gulf of Thailand and Java Sea (Murdy 1989). According to Clayton (1993), a member of the genus *Periophthalmus* are having an amphibious lifestyle and well adapted to the terrestrial environment compared to the mudskipper of the genus *Scartelaos*, *Boleophthalmus* and *Periophthalmodon*. The distribution of mudskippers species in the intertidal zone are influenced by various factors such as tidal cycle, ecological parameter, physiological adaptation, feeding behavior and substrate properties, tidal cycle and vegetation types (Gordon et al. 1985; Chew & Ip 1990; Colombini et al. 1995; Takita & Ali 1999; Polgar & Crosa 2009).

According to Chew et al. (1990), *P. chrysospilos* lives in the littoral zone of the mudflat and is frequently found on land adjacent to the water edge either during high or low tide. Ali & Norma-Rashid (2005) reported that the juveniles of *P. chrysospilos* could be located in mangrove forest floor, as it is used as a shelter and refuge site from their predators. However, the mature offspring of *P. chrysospilos* will migrate to open mudflat for foraging and mating. This mudskipper species is also known to live in proximity to human settlement and fishing boat jetty (Takita & Ali 1999). This species usually swims in a small school consisting of 20-40 of them along the water edge. During high tide, *P. chrysospilos,* will move away from the incoming water by climbing a mangrove root or any large structure available (Polgar & Crosa 2009). However, the burrow of *P. chrysospilos* can only be found on a muddy beach or bank despite its habitat that ranges from mud to sand (Takita & Ali 1999). This is correlated to Al-Behbehani & Ebrahim's (2010) findings as they reported that mudskipper would only dig a burrow in a mud substrate with sticky particles compared to loose sand particles that easily collapsed.

2.3 Terrestrial adaptation of *P. chrysospilos*

Being an amphibious fish, *P. chrysospilos* faces a list of problems due to its amphibious lifestyle such as aerial respiration, body temperature regulation, predation, osmoregulation and waste excretion (Chew & Ip 1992b; Clayton 1993; Colombini et al. 1995; Aguilar et al. 2000; Al-Behbehani & Ebrahim 2010). Thus, this type of mudskipper practices several adaptations to survive in the terrestrial environment. *P. chrysospilos* can lower its metabolic rate in a hypoxic condition, thus reducing the oxygen demand for the tissue (Chew et al. 1990; Chew & Ip 1992b). Furthermore, the buccopharyngeal-opercular cavity of mudskipper is wider compared to the non-amphibious fish, and its will retain air bubbles while on land. This adaptation will efficiently increase the surface area for gaseous exchange and prevent their gills from becoming coalesced and from them having hypoxia. In general, the gills of mudskipper are shorter and stiff with a thicker filament, thus reducing the chance of gills to collapse when the mudskipper is out of the water. Mudskippers' gills are modified to have an accessory breathing organ to suit their aerial breathing (Sayer 2005; Gonzales et al. 2011).

2.4 Feeding guild of *P. chrysospilos*

Information on diet and feeding behaviours of fish may provide a fundamental knowledge of the understanding of trophic interactions and food wed in the aquatic environments. This information will then be used in the interpretation of feeding strategy, habitat use, competition and predation especially to fish that inhabitant the high fluctuation environment such as intertidal area (Blanco-Garrido et al. 2008; Manikandarajan et al. 2014). Additionally, feeding behaviours may also regard as the key factor in understanding the evolutionary process of the amphibious lifestyle of fishes in the intertidal area (Sayer 2005).

Feeding behaviours also may play an important role in fish distribution and migration and have a great influence on the growth of fish (Chukwu & Deekae 2013).

Studies on feeding and diet of mudskippers also have received much attention by the researchers for the last few years (Faridah-Hanim 1995; Colombini et al. 1996; Khaironizam & Norma-Rashid 2002c; Mazlan et al. 2006b; Zulkifli et al. 2012; Chukwu & Deekae 2013; Ravi 2013). Mudskippers of the genera *Boleophthalmus*, *Psudapocryptes*, *Oxuderces* and *Parapocryptes* are classified as herbivores (Khaironizam 2004), where diatoms dominate stomach contents and algae (Chlorophyta and Cyanophyta). While mudskipper of the genus *Scartelaos* can be classified as an omnivorous habit as their stomach contents consists of both animal (crustaceans and worms) and plant (diatom and algae) materials (Clayton 1993; Khaironizam 2004). *Periopthalmodon* is strictly carnivorous with crustaceans topped ranked and followed by insects, worms, arachnids, molluscs and fishes. Mudskippers of the genera *Periophthalmus* is opportunistically carnivorous and is known to feed on plant materials during its juvenile stage (Bob-Manuel 2011; Chukwu & Deekae 2013). This is supported by the stomach content analyses of *P. chrysospilos* by Khaironizam (2004) and Amalina-Husna (2013). Clayton (1993) and Khaironizam (2004) reported that this fish ate more crustaceans, insects, and worms. However, Khaironizam (2004) reported that small portion of algae and diatom may be found in the stomach of mudskipper of the genus *Periophthalmus* as it may be accidentally taken during capturing the prey on the mudflat or in water.

The feeding guild of mudskipper reported to be varied according to the species, stage of growth, sex and food accessibility (Colombini et al. 1996; Mazlan et al. 2006a; Bob-Manuel 2011; Zulkifli et al. 2012; Chukwu & Deekae 2013; Ravi 2013). Mudskippers also reported to have an array of food preferences and their feeding habits may influence by their food preferences (Mittelbach 2002). Khaironizam (2004) studied the food preference of mudskippers from Klang Straits of Selangor and found that small crustaceans (i.e. copepods, isopods, cladocerans, amphipods, small shrimps and juvenile crabs) are highly ranked followed by insects (dipterans and hymenopterans), worms (polychaetes and nematodes), molluscs (gastropods and bivalves) and small portion of algae and diatoms in the stomach *Periophthalmus*.

2.5 Distribution and physiological adaptations

Base on the fact that fish solely depend on water body to sustain their biological activities such as breathing, feeding, reproduction, and other metabolism function, studies on water quality and other ecological parameters in the fishery are crucial as these factors significantly affect the fish life. Water quality can be defined as the chemical and physical contents of water that regularly change according to the seasons and geographic areas (Lawson 2011b). In the aquatic ecosystems, the interaction between the abiotic components such as dissolved oxygen, temperature, salinity, pH, conductivity, total dissolved solute and rainfall will influence the distribution, survival, reproduction, physiology and well-being of fish and other aquatic organisms (Kausar & Salim 2006; Sachidanandamurthy & Yajurvedi 2008; Natarajan et al. 2009; Lawson 2011a; Shultz et al. 2011).

2.5.1 Water temperature

The effects of temperature on fish biology have been well documented. The fact that fishes are poikilothermic animals means fishes are unable to regulate their body temperature. Therefore, the surrounding temperature will directly affect their physiological processes that involve the distribution of metabolism rate, food consumption and digestion, growth rate, reproduction, and diseases. Water temperature is regarded as the most influential abiotic factor that will influence the fish and other aquatic organisms responses compared to other factors (Kausar & Salim 2006; Handeland et al. 2008; Natarajan et al. 2009; Albert & Ransangan 2013).

The increase in water temperature will lead to the increment of metabolism of the aquatic organisms except if they possess some physiological adaptation to deal with such change. A noticeably high metabolism will reduce the amount of energy for their growth. A warmer environment will cause a longer growing season and a faster growth rate but at the expense of a shorter life span (Kausar & Salim 2006). Albert & Ransangan (2013) reported that a high temperature would increase the presence of *Vibrio harveyito* bacteria that could cause vibrosis, which was responsible for the fish's mortality. Furthermore, they also discovered that there was a strong positive correlation between temperature, *Vibrio* and fish mortality.

2.5.2 Rainfall

Heavy rains during wet season cause the water quality such as dissolved oxygen, temperature, salinity, pH, conductivity, and total dissolved solute in the aquatic ecosystem change due to of the influx of fresh water. This will be followed by the flushing of organic substances into the aquatic ecosystem, which will promote the growth and production of natural food. Various studies documented the effects of seasons on fish's length-weight relationship and body condition. According to Imam et al. (2010), Ikongbeh et al. (2012) and Akombo et al. (2014) fish in the African tropical countries will have better condition during the wet season, and this was due to good water quality. The juveniles of fish also stand a better chance to survive during the wet seasons due to an abundant amount of food (Etim et al. 2002).

2.5.3 Salinity

Salinity can be defined as the total concentration of electrically charged ions in water in part per thousand (ppt) (Lawson 2011b). Like other water quality parameters, salinity is also responsible for affecting the distribution and physiological adaptations of aquatic organisms. Most aquatic organisms can adapt to a constant level of salinity. However, in the estuary where an extreme fluctuation of salinity frequently occurs, only certain aquatic organisms like mudskippers can tolerate this situation (Gordon et al. 1985; Chew & Ip 1990; Ni et al. 2005). The level of salinity also has influenced the oxygen solubility (Chew & Ip 1990). The increase in salinity will marginally reduce the solubility of oxygen.

2.5.4 pH

The pH value is measured based on the concentration of Hydrogen ion present in the water body and is considered as one of the vital parameters that affect aquatic organisms. The pH value might increase due to several factors such as the decaying of the organic matter at the bottom of the aquatic ecosystem, the existence of domestic and industrial waste. As well as the high rate of photosynthesis involving the phytoplankton. For most aquatic organisms in the estuary, the optimum pH value ranges between 7.5 to 8.5, and if the pH value drops to less than 4, it can have lethal consequences for the fish (Abowei 2010a; Lawson 2011b).

2.5.5 Conductivity

Conductivity is measured based on the ability of water to conduct an electrical current, and it is highly affected by the presence of dissolved solutes. A considerable amount of total dissolved solutes will increase conductivity. Generally, during the dry seasons, the conductivity is high due to the existence of high salt contents.

On the contrary, during the wet seasons, the conductivity is low because of the influence of the influx of fresh water into the estuary causing the dilution of dissolved salts (Lawson 2011b). In water quality management, the rise of conductivity level might reflect water pollution such as the flushing of sewage into the water environment.

2.5.6 Total dissolved solid

The total dissolved solute is defined as the presence of inorganic salts, organic matters and dissolved materials in the water. The concentration of total dissolved solute is influenced by heavy precipitation, domestic and industrial waste, and solubility of rocks and soils (Weber-Scannell & Duffy 2007). A high amount of total dissolved solute will change the salinity, ionic composition, and clarity of the water. This can cause toxicity to the fish. Reducing the water's clarity can affect the depth of light penetration into the water, thus reducing the photosynthesis rate in the water.

2.5.7 Dissolved Oxygen

In an aquatic ecosystem, the organisms obtain the oxygen needed for their aerobic metabolism in the form of dissolved oxygen. The dissolved oxygen is usually measured by milligram per liter (mg/l) or according to the percentage of air saturation. The dissolved oxygen is influenced by several factors such as the temperature, rate of biological oxygen demand, aeration and rate of photosynthesis involving the aquatic plants (Natarajan et al. 2009; Lawson 2011a). For example, during the dry seasons when the temperature is high, dissolved oxygen will decrease. This phenomenon is accompanied by the high rate of the decomposition of organic matter by the decomposers. Thus, this will significantly increase the biological oxygen demand in the environment as a result of the reduction of the dissolved oxygen.

The need for dissolved oxygen by fish depends on the types of the fish, their life stages, metabolism rates and habitats. For example, fish that live in a warmer environment, have a higher metabolism rate, thus requiring more dissolved oxygen compared to the fish in a colder environment. Normally, in coastal water, the dissolved oxygen can range between 4 mg/L to 5mg/L, and this is considered the optimum requirement for the ecosystem to function at its highest carrying capacity (Abowei 2010a).

Fish are commonly subjected to the physiological challenges caused by the exposure to hypoxia condition. For amphibious fish, to suit their terrestrial lifestyle, mudskippers develop secondary mechanisms such as cutaneous air breathing and a wider buccopharyngeal-opercular cavity to increase their oxygen absorption (Murdy 1989; Aguilar et al. 2000; Dabruzzi et al. 2011).

2.6 Length-weight relationships and Fulton condition factor

2.6.1 Length-weight relationships (LWR)

Ichthyologists all around the world had extensively studied the length-weight relationship for both marine and freshwater fishes as expressed by the equation (Le Cren, 1951):

$$W = aL^b$$

Where W = Weight of fish (g), L = Total length (TL) of fish in (cm), a = constant and b = length exponent.

To a certain extent, it is regarded as not an attractive topic by the present ichthyologists (Froese 2006). The length and weight parameters of the fish population are different according to some criteria such as the species, as well as the spatial and temporal variations. These variations can also be seen within the same species. The variations in these parameters are due to different food resources, feeds, reproduction activities, metabolism rates, water quality levels and fishing activities (Sarkar et al. 2013; Ahmed et al. 2011).

Such variations hinder ichthyologists from the accurately modelling aquatic ecosystem (Froese 2006). In consequence, the knowledge of the length-weight relationship is still of paramount importance in the field of fishery science. This knowledge offers a proper exploitation and management of the fish population, modelling the aquatic ecosystem, population assessment, and seasonal variations regarding fish growth (Froese 2006; Imam et al. 2010).

The studies on length-weight relationship provide much valuable information in fishery science. The information obtained from the studies on the length-weight relationship is applied for two major purposes. Firstly, the knowledge is used for the estimation of the degree of well-being, or it is also commonly known as the condition factor of the fish (Le Cren 1951; Ricker 1973). This provides a quantitative index for measuring the state of well-being of the fish, based on the assumption that the heavier the fish is at a given length, the better its condition is (Mansor et al. 2010). Secondly, the estimation of the fish's weight corresponds to the given length (Mansor et al. 2010; Abowei 2009). In reality, the estimation of weight for a large amount of fish stock using a weight measurement is impractical. Whereas, using length-weight regression, the weight of such fish stock can be estimated easily. Additionally, the data on length and weight allows for the assessment of the fish population dynamic parameters such as growth, reproduction, estimation of life span, mortality, stock composition and biomass (Samat et al. 2008; Mansor et al. 2010; Dar et al. 2012).

The discoveries of various data on the applications of length and weight in fishery science were because the essential biological processes in fish are influenced by their length rather than ages (Magnifico 2007). According to Magnifico (2007), the size of the fish will influence their maturation process. Fish of larger size possess several advantages such as lower predation mortality, increased fecundity, and a higher lifetime reproductive output.

Froese (2006) reported that based on the regression coefficient of *b* value obtained from the parabolic equation of length-weight relationship, $W = aL^b$ (Le Cren 1951), the growth patterns of the fish were classified into three categories namely, positive allometric growth, negative allometric growth, and isometric growth.

Fish are considered as having a positive allometric growth when the *b* value is larger than 3, but as possessing a negative allometric growth when the *b* value is lower than 3, and isometric growth when the *b* value is equal to 3. These also signify that the fish are either heavy, light or isometric. If the *b* value is larger than 3, the fish are considered as heavy fish, but if it is lower than 3, they are classified as light fish, while equal to 3, they are categorised as isometric fish.

2.6.2 Condition factor

In addition, the length-weight relationship allows scientists to estimate the condition factor of fish. The Fulton condition factor (K) compares the degree of well-being in fish (Bagenal & Tesh 1978). It is used based on the assumption that the heavier the fish are at a given length, the better their condition or well-being is.

Fulton condition factor is calculated based on the following equation:

$$K = \frac{100\ W}{L^3}$$

Where W = weight (g) and L = total length (cm)

The value of condition factor will decrease with the increase of fish's length, and this will influence their reproductive cycle. This type of index has been used extensively in fishery science to measure growth, feeding intensity and age (Dar et al. 2012; Mansor et al. 2010)

According to Ikongbeh et al. (2012), condition factor can supply some ideas regarding the estimation of the reproductive cycle of fish species without sacrificing it. This aspect is important when dealing with endangered fish species. Such index is also used to compare two populations of fish living in different conditions such as different feeding intensities and climates (Imam et al. 2010; Dar et al. 2012). A different value of the condition factor of a fish species can reveal the physical state of the fish's habitat, food source availability, feeding activities and sexual maturity (Sarkar et al. 2013). Therefore, condition factor is a crucial qualitative analysis in understanding the life cycle of fish species. Many researchers have studied the length-weight relationship and condition factor of mudskippers from various genera (Khaironizam & Norma-Rashid 2002a; Abdoli et al. 2009; Chukwu & Deekae 2011; Ghanbarifardi et al. 2014; Baeck & Park 2015).

2.7 Growth, Mortality, and Recruitment pattern

2.7.1 Growth

In fishery research and sustainable management, the information about population dynamics such as fish growth, mortality and recruitment pattern is regarded as the keystone information. This information can help fishery scientists to estimate the population productivity, period of maturity, determination of potential yields and exploitation rates of fish (Etim et al. 2002; Park et al. 2008; Sambo & Haruna 2012). Growth is measured as a change in size per unit of time. This process depends on several factors such as the metabolism (both catabolism and anabolism of individual species), quantity and quality of food consumed, and environmental quality. Besides, growth will also influence other biological processes such as maturation and fecundity. The maturation process and gamete production do not occur until a critical size is reached (Magnifico 2007). Therefore, growth influences the reproduction, recruitment and mortality of the fish population.

Growth is usually measured by length since length always increases with time, whereas weight is prone to fluctuation due to various factors such as the scarcity of food, competition, and diseases. Estimating growth parameters is a cornerstone of any fish stock assessment (Pauly 1984). This process relies on either the absolute or relative age of fish and the length-frequency analysis. However, the estimation of age using hard structures of fish like otolith, scales and opercula is always a daunting process. This process requires a specific expertise, sophisticated equipment, and labour demand. Thus, it is more challenging when dealing with tropical fish due to their steady-state environment (Abowei 2010b).

On the other hand, estimating growth using length-data collection is easy, and requires minimal expertise. Furthermore, many fishery processes and fish biologies such as the selection of gear, predation, fecundity and maturation are influenced by the size rather than the age (Magnifico 2007). Thus, fishery scientists commonly use length-frequency analysis method to estimate growth parameters.

A commonly used mathematical model to describe growth is von Bertalanffy Growth Function (VBGF). This model uses body length as a measurement for age, given by the equation, $L_t = L\infty * (1 - exp[-K(t - t_0)]$ that L_t = mean length at age t, $L\infty$ = asymptotic length, K = growth coefficient, t = age of fish species and t_0 = hypothetical age at length equal to zero. Many scientists such as Ricker (1975), Gulland (1969) and Pauly (1984) later reviewed this growth model and proposed some more complex submodels namely, Ford-Walford plot, Gulland and Holt plot and von Bertalanffy Growth Function. Nowadays, FAO-ICLARM Stock Assessment Tools (FiSAT) is commonly used to estimate growth and mortality parameters of marine species.

2.7.2 Mortality

Mortality is defined as the process when the fish are removed from the population stock. This process is influenced by several factors such as age, diseases, predation, fishing activities and environmental stress. Fish mortality can be grouped into natural mortality and fishing mortality. Natural mortality means the removal of the fish from the population due to natural causes such as intraspecies and interspecies competition, diseases, predation and natural disasters. On the other hand, fishing mortality is caused by physical injuries, stress and asphyxia during the fishing process.

The estimation of fishing mortality is done based on this equation, $F = Z - M$ that F is fishing mortality, Z is total mortality and M is natural mortality. Total mortality (Z) is estimated using length converted catch curve method (Pauly 1984). Whereas, natural mortality (M) is estimated using the empirical relationship suggested by Pauly (1980): $\text{Log}_{10} M = -0.0066 - 0.279 \text{ Log}_{10} L\infty + 0.6543 \log_{10} K + 0.4634 \text{ Log}_{10} T$ that M = natural mortality, $L\infty$ = asymptotic length, K = growth coefficient and T = mean of water temperature. Using the value of M and Z obtained from the equation mentioned above, fishing mortality (F) is estimated using the equation, $F = Z - M$.

This allows for further estimation of exploitation rate (E) using the relationship proposed by Gulland (1971), $F = Z - M$. In fishery science, this value is used to quantify if a certain species population is an over-fishing or under-fishing one, thus, providing crucial information for a sustainable fishery policy. Optimum exploitation (E_{opt}) rate is equal to 0.5 based on the assumption that fishing mortality is equal to natural mortality ($F = M$).

2.7.3 Recruitment pattern

Recruitment pattern is defined as the number of young fish that survive and manage to enter the exploited fishing area and then are likely to become contact with fishing gear (Sparre & Venema 1998). This process can be due to the migration of young fish that become older from their nursery stage and manage to get into the main fishing area. The mean age of fish at recruitment depends on the type of mesh size of the fishing gear used. The annual recruitment pattern is obtained using FiSAT from the backwards projection on the length axis of the set of length frequency data analysis. According to Pauly (1982), tropical fish usually features double recruitment peak per year. This fact is supported by the findings of various studies involving a wide variety of tropical marine species, both fish and non-fish (Enin 1995; Nor-Aziella 2012). However, a single recruitment pattern has also been documented concerning tropical fish. Etim et al. (2002) reported that a single recruitment pattern was discovered involving the mudskipper species, *Periophthalmus barbarus*.

CHAPTER 3

GENERAL METHODOLOGY

3.1 Study area

This study was conducted in the mudflat area of Bayan Bay (5°20’53.56’’ N 100°18’47.68’’ E) in the south-eastern part of Penang (Figure 3.1). The Bayan Bay area is highly developed for the commercial centre and luxury housing, which directly affecting some remaining patches of fragmented mangrove trees from the species, *A. alba, S. alba,* and *R. mucronata*. Based on a preliminary study conducted before this research, this mangrove area sustained a significant number of *P. chrysospilos*. Based on this aspect, the coastal water of Bayan Bay was chosen as the sampling site during this study. During the last several months of this study, the local developer was cutting down all the mangrove trees, and other types of beach vegetation in that area as the new roads were being built adjacent to the area.

Figure 3.1 Map shows the area where this study was conducted from July 2013 to July 2014

Based on the chart datum of the tide level provided by Royal Navy of Malaysia (2013) the high spring tides level in Bayan Bay fluctuate from 0.7-1.75 meters and could reach the mangrove forest floor which about 4 meters away from the lowest spring tide level. The coastal water of Bayan Bay also experiences semi-diurnal tides, where two high tides and two low tides in a day. Even though no laboratory analysis was conducted on the sediment types in the coastal of Bayan Bay. However, based on visual inspection, the sediment in Bayan Bay consists primarily of silts and clay with a strong odor of decomposition.

3.2 Water physicochemical parameters

The rainfall data was obtained from the Meteorological Department of Malaysia at the Meteorology Station in Bayan Lepas, Penang (05°18'N, 100° 16'E) which is about 5 km from Bayan Bay. The data duration was from July 2013 to July 2014. Other physical parameters of water such as salinity, water temperature, dissolved oxygen, and pH were taken from the site using Eutech Portable Cyberscan 650 series during the high tide of spring tide at every month. The relative humidity was measured using a whirling hygrometer. Three replicates were taken from the same area for accuracy testing. The tide level was obtained from the Royal Navy of Malaysia (2013).

3.3 Sample collection

Monthly random sample collection was conducted during the low tide of spring tide from July 2013 to July 2014 which covering both the dry and rainy months. Upon reaching the study site, about 10 to 15 minutes was needed to calm down the mudskippers from feeling threatened by the presence of the individuals involved in the research.