Faculty of Resource Science and Technology

Ichthyoplankton Assemblages and Its Distribution Along Selected Sarawak Coastal Waters

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Ichthyoplankton Assemblages and Its Distribution Along Selected Sarawak Coastal Waters

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DECLARATION

The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

A study was conducted in order to obtain spatio-temporal data on fish larvae assemblages within Sarawak coastal waters. Spatial study was conducted with one time sampling at six intertidal areas (Pantai Teluk Pandan, Pantai Rambungan, Pantai Puteri, Pulau Satang, Pulau Sampadi and Pantai Mukah) using modified seine net with bag (April 2012-March 2013), while spatio-temporal study was focused at Sungai Sibu Laut-Sungai Salak estuaries using plankton net with monthly sampling for a year (October 2012-September 2013). Seine net (1 mm mesh) was pulled by two people along the beach for about two minutes, while plankton net (0.5 mm mesh) was towed obliquely by boat for about 10 minutes. Simultaneously, physico-chemical parameters of water (dissolved oxygen, temperature, turbidity, salinity and pH) were measured *in-situ*. Checklist of fish larvae family was prepared with general description of each family. Throughout this study, a total of 25,297 fish larvae were collected which consist of 13 orders belonging to 38 identified families. In addition, a total of 27,527 fish eggs with two specific shapes (spherical and elliptical) were collected at Sungai Sibu Laut-Sungai Salak estuaries. Intertidal fish larvae obtained from spatial study consist of 18 families with Clupeidae and Gerreidae were found at all sampling sites, while Ambassidae is the most abundant family (46.5%). Spatio-temporal study reveals 30 families, where four families namely Blenniidae, Carangidae, Engraulidae and Gobiidae were recorded every month, with Gobiidae is the most abundant family (76.76%). The highest density of fish eggs occurred in April 2013 (4,826 eggs/100 m^3) and has a weak positive correlation with fish larvae density ($r=0.303$, $p=0.019$). Intertidal fish larvae have higher total length than subtidal fish larvae. Meanwhile, all growth stages (preflexion, flexion and postflexion) were observed from spatio-temporal study with preflexion larvae showed to be dominant for four families that were available every month. According to principal component analysis, no direct

relationship was observed between fish larvae family abundance and physico-chemical parameters of water for intertidal fish larvae. Meanwhile, fish larvae density from spatio-temporal study showed a weak positive correlation with dissolved oxygen ($r=0.384$, $p=0.002$) and turbidity ($r=0.271$, $p=0.036$). In contrast, no significant correlation was observed between fish eggs density and physico-chemical parameters of water. All physico-chemical parameters of water for spatio-temporal study showed significant difference among stations and among months. In conclusion, findings of this study had shed some information regarding the morphological characteristics and spatio-temporal pattern of larval fishes in Sarawak coastal waters that can act as baseline data for future management of fish stock.

Keywords: Ichthyoplankton, diversity, family composition, spatio-temporal distribution pattern, Sarawak waters.

Pengumpulan dan Taburan Iktioplankton di Beberapa Kawasan Sepanjang Perairan Pantai Sarawak

ABSTRAK

Satu kajian telah dijalankan untuk mendapatkan data mengenai pengumpulan spatio-temporal larva ikan di kawasan perairan Sarawak. Kajian spatial dijalankan secara persampelan satu kali sahaja di enam kawasan antara pasang surut (Pantai Teluk Pandan, Pantai Rambungan, Pantai Puteri, Pulau Satang, Pulau Sampadi and Pantai Mukah) menggunakan pukat tarik yang diubahsuai yang mempunyai kantung (April 2012-Mac 2013, manakala kajian spatio-temporal dilakukan di muara Sungai Sibu Laut-Sungai Salak menggunakan jaring plankton secara bulanan selama setahun (Oktober 2012-September 2013) bagi mendokumenkan pengumpulan dan corak taburan iktioplankton di perairan Sarawak. Pukat tarik (mata jaring 1 mm) ditarik oleh dua orang sepanjang pantai selama 2 minit, manakala jaring plankton (mata jaring 0.5 mm) ditunda oleh bot secara oblik selama 10 minit. Pada masa yang sama, beberapa parameter fiziko-kimia air (oksigen terlarut, suhu, turbiditi, saliniti dan pH) diukur secara in-situ. Senarai semak famili larva ikan disediakan beserta dengan penerangan am morfologi untuk setiap famili larva ikan. Sepanjang kajian ini, sejumlah 25,297 ekor larva ikan berjaya dikumpulkan dan dikenalpasti yang terdiri daripada 13 order merangkumi 38 famili. Manakala, sejumlah 27,527 biji telur ikan yang mempunyai dua jenis bentuk yang spesifik (bulat and bujur) telah diperolehi di muara Sungai Sibu Laut-Sungai Salak. Bagi kajian spatial di zon antara pasang surut, larva ikan yang diperolehi terdiri daripada 18 famili, yang mana Clupeidae dan Gerreidae telah dijumpai di semua lokasi kajian, manakala Ambassidae merupakan famili yang paling banyak dijumpai (46.5%). Kajian spatio-temporal pula memperolehi 30 famili yang mana empat famili iaitu Blenniidae, Carangidae, Engraulidae dan Gobiidae telah direkodkan pada setiap bulan, serta

Gobiidae merupakan famili yang paling banyak dijumpai (76.76%). Kepadatan telur ikan paling tinggi adalah pada bulan April 2013 (4,826.59 biji telur/100 m^3) dan mempunyai korelasi positif yang lemah dengan kepadatan larva ikan (r=0.303, p=0.019). Panjang penuh larva ikan dari kawasan antara pasang surut lebih tinggi daripada larva ikan subpasang surut dan ini menunjukkan peringkat pertumbuhan yang berbeza di antara mereka. Sementara itu, kesemua peringkat pertumbuhan (preflexion, flexion dan postflexion) dijumpai dalam kajian spatio-temporal dengan larva peringkat preflexion adalah paling dominan bagi empat famili yang dijumpai setiap bulan. Mengikut analisis komponen principal, tidak hubungan secara terus diperhatikan antara kepadatan famili larva ikan dengan parameter fiziko-kimia air untuk larva ikan di kawasan pasang-surut air. Sementara itu, kepadatan larva ikan daripada kajian spatio-temporal menunjukkan korelasi positif yang lemah dengan oksigen terlarut (r=0.384, p=0.002) dan turbiditi (r=0.271, p=0.036). Sebaliknya, tiada hubungan yang signifikan dijumpai di antara kepadatan telur ikan dan semua parameter fiziko-kimia air. Kesemua parameter fiziko-kimia air menunjukkan perbezaan yang signifikan dalam kalangan stesen dan bulan untuk kajian spatio-temporal. Kesimpulannya, kajian ini telah mendedahkan sedikit maklumat mengenai ciri-ciri morfologi dan corak taburan spatio-temporal larva ikan di perairan Sarawak yang boleh berfungsi sebagai data asas bagi pengurusan sumber ikan di masa hadapan.

Kata kunci: *Iktioplankton, kepelbagaian, komposisi famili, corak taburan spatio-temporal, perairan Sarawak.*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CPUE	Catch per unit effort
D	Margalef's Richness Index
DO	Dissolved oxygen
FAO	Food and Agriculture Organization
H'	Shannon-Wiener Diversity Index
IPRC	International Pacific Research Center
J	Pielou's Evenness Index
KWNP	Kuching Wetland National Park
PCA	Principal Component Analysis
SCS	South China Sea
SD	Standard deviation
TL	Total length

CHAPTER 1

GENERAL INTRODUCTION

1.1 Introduction

Marine capture fisheries in Malaysia can be divided into coastal fishery and deep-sea fishery and their productions accounted for 87% and 13% of the total marine fish landings, respectively. Total landings have been stable and are believed that the yield has already reached its maximum (Abu Talib and Alias, 1997). Since 2005, Food and Agriculture Organization (FAO) estimated that most fish landings were already near overexploited, while others have faced overexploitation and in a recovery processes (Markowski, 2009).

The demand for fish as the main source of protein is expected to increase making the task of managing fisheries resources on a sustainable basis becoming increasingly complex (Abu Talib and Alias, 1997). Without a proper management and legislation on the natural fish stocks, marine fisheries sector might collapse in future. Therefore, information about the fish recruitment in their natural habitats is needed in order to understand their life history and biological activities for future management purposes. One of the important components in understanding the natural fish stocks is their early life stage or known as ichthyoplankton. Ichthyoplankton refers to fish eggs and larvae that are comparatively small in size that made up the total zooplankton and usually feed on smaller sizes plankton, while they themselves become the prey for larger animals in the aquatic ecosystems. These early stages of fish can be found drifted in the water column with the sea current due to their limited swimming ability (Ré and Meneses, 2009).

The study of ichthyoplankton offers many important outcomes especially for ecosystem-based management of fisheries resources. The abundance of ichthyoplankton can be used to estimate the recruitment of fish population (Zhou *et al*., 2011) which is the basic

understanding for marine fish recruitment mechanism (Köster *et al*., 2001) as well as freshwater fish (Termvidchakorn and Hortle, 2013). Meanwhile, Galacatos *et al*. (2004) suggested that it is useful to examine the factors that can affect the larval fish community by studying the spatial and temporal patterns of diversity, distribution and species composition of fish larvae. Furthermore, the establishment of larval identification is crucial to fisheries management purposes as well as to monitor the aquatic environment through record of ichthyoplankton in the target waters (Ara *et al*., 2011a).

Climate change due to global warming is another factor being debated that contributes to the decline of fish stock worldwide. As a result of global warming, the sea level rises due to increase in the ocean temperature which melts the glacier and polar ice (Ong, 2001). Sea level rises and global warming will affect mostly on mangrove areas which act as nursery ground for most marine fishes as well as coral reefs and seagrass beds (Rijnsdorp *et al*., 2009). Thus, ichthyoplankton could be the most affected as it is planktonic that only drifted with the ocean current (Brunel and Boucher, 2007) and is being forced into unsuitable water condition which can lead to mortality.

The studies on ichthyoplankton have been conducted worldwide but in Malaysia, this research is quite limited. Almost two decades ago, Blaber *et al*. (1997) studied on the composition, distribution and habitat affinities of ichthyoplankton that focused on selected estuaries in Sarawak (20 sites) and Sabah (3 sites). Recently, ichthyoplankton studies were made to compare the larval fish density between two different habitats at Southwestern Johor (Ara *et al*., 2011a) and feeding habits of Clupeidae larval fishes in the Sungai Pendas estuary in Johor (Ara *et al*., 2011b). Another published article by Muhamad and Rahim (2013) reported a preliminary data on fish larvae and fish eggs at several locations of Sarawak coastal waters. Since there is very little up-to-date information on ichthyoplankton in Sarawak, the

current ichthyoplankton assemblages might have changed due to the influence of climate change, habitat deterioration (from natural and anthropogenic activities) and unsustainable fishing activities.

1.2 Ichthyoplankton in the Water Column

Ichthyoplankton is derived from the Greek words; *ichthys* means fish and *planktos* means to wander or drift. Generally, it is the term for eggs and larvae of fish which can be found drifting in the subsurface of the water column and up to about 200 m deep (Ré and Meneses, 2009). Size of fish eggs basically ranged from 0.5 to 5.5 mm in diameter and can be identified specifically by the appearance of size, number and size of oil globules, chorion surface, yolk, pigmentation and morphology of developing embryo (Figure 1.1) (Ré and Meneses, 2009). The stage after hatched is known as yolk-sac larva which is not well developed yet, featuring unformed mouth, unpigmented eyes and undeveloped pectoral fins with extending primordial fin from the top of the head, around the caudal region and forward the posterior margin of the yolk (Figure 1.2) (Ré and Meneses, 2009). Baran (2002) classified fish larvae as immature free-living fish with a developed or residual yolk sac.

Identifying the fish during larvae stages can be divided into meristic and morphometric (Ré and Meneses, 2009; Konishi *et al*., 2012). Identification using meristic involves counting the myomeres and fin-rays. Meanwhile, identification using morphometric includes the shape of the body, gut, head, snout, mouth and eyes. In addition, fin formation and head spination are also important characters. Pigmentation pattern, location, size and shape are also being use as key characters as well as the body length of the fish larvae. In order to determine the larval growth stages (preflexion, flexion and postflexion), the bending of notochord is observed at the caudal fin (Ré and Meneses, 2009) as shown in Figure 1.3.

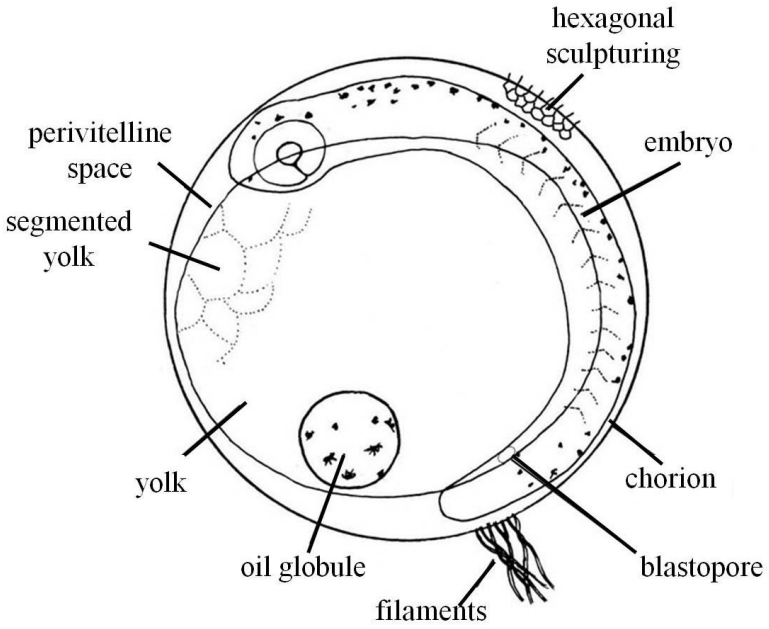


Figure 1.1: Anatomic features of fish egg (source from Ré and Meneses, 2009).

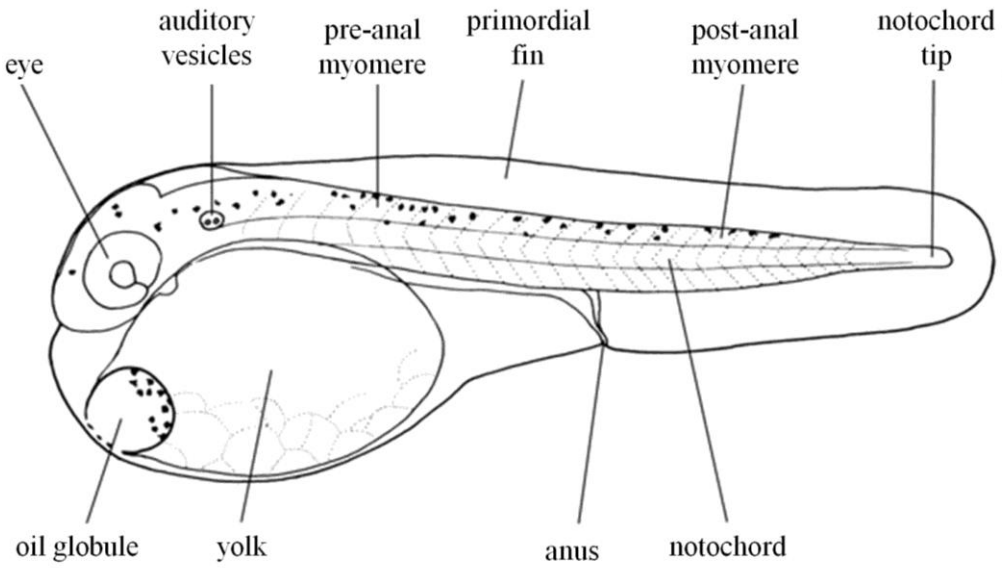


Figure 1.2: Anatomic features of yolk-sac larva (source from Ré and Meneses, 2009).

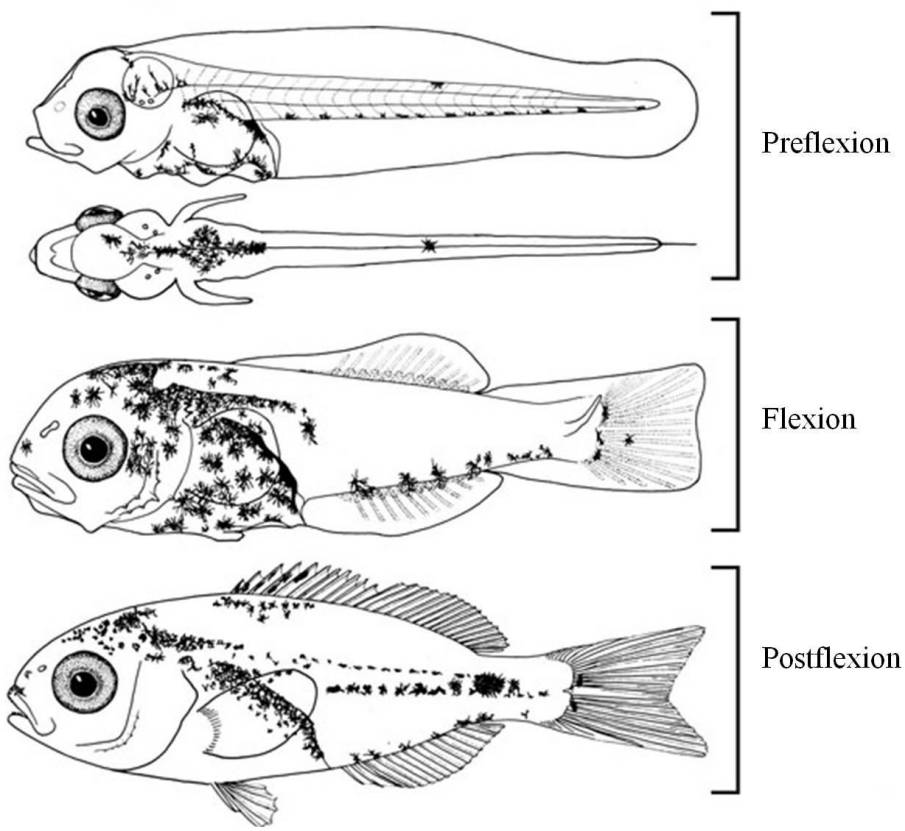


Figure 1.3: An example of larval growth stages of *Diplodus sargus* (source from Ré and Meneses, 2009).

Ichthyoplankton studies that have been done extensively throughout the world and are mostly focused on the diversity, composition, density and distribution of ichthyoplankton in the water column (Bailey, 1981; Evseenko, 1982; Gruber *et al*., 1982; Sherman *et al*., 1983; Richards *et al*., 1985; Brewer and Kleppel, 1986; Ferreiro and Labarta, 1988; Brodeur and Rugen, 1994; Conway *et al*., 1997; Ehrlich *et al*., 1999; Smith and Suthers, 1999; Chamchang and Chayakul, 2000; Ocana-Luna and Sanchez-Ramirez, 2003; Freitas and Muelbert, 2004; Anand and Pillai, 2005; Catalán *et al*., 2006; Fleischer, 2007; Boeing and Duffy-Anderson, 2008; Sarpedonti *et al*., 2008; Lee, 2010; Marcolin *et al*., 2010; Avsar and Mavruk, 2011; Zhou *et al*., 2011) and some of them studied about the spatial and temporal patterns of

ichthyoplankton (Lafontaine *et al*., 1984; Breitburg *et al*., 1995; Huang and Chiu, 1998; Castro *et al*., 2002; Doyle *et al*., 2002; Hernandez-Miranda *et al*., 2003; Koutrakis *et al*., 2004; Sampey *et al*., 2004; Greve *et al*., 2005; Arkhipov, 2009; Hermes-Silva *et al*., 2009).

1.3 Habitats Preferences

Living as planktonic organisms, ichthyoplankton cannot choose the place to live and grow. Most of the fish eggs are floating near the sea surface and their movement are controlled by the current (Baran, 2002). The same goes to the fish larvae which could not navigate but can only circulate themselves in the water column for survival (Rothlisberg *et al*., 1996). Therefore, the role of choosing the location to grow depends on the adult fishes, where it is called as spawning location and the nursery ground (Lasiak, 1986; Baran, 2002). The preferred habitat by fish larvae for the nursery ground is where the water is generally shallow and avoided by the large predator. This place is usually located at seagrass beds, estuaries, littoral areas and reef habitats (Breitburg *et al*., 1995; Baran, 2002; Anand and Pillai, 2005; Ara *et al*., 2011a; 2011c), where food availability is high, predation rate is low and stable ocean condition for growth (Joseph, 1973; Freitas and Muelbert, 2004). However, not all fish stay at their spawning area or breeding ground. Some fishes do migrate to other regions as they grow and will come back again during spawning season (Gibson, 1982). This type of fish is called as transient species. On the other hand, fishes that do stay at their spawning area or nursery ground throughout entire life are called as resident species (Gibson, 1982).

1.4 Predator and Prey

It is common to suggest that in the water column, larger animals will prey on smaller animals. In regards to ichthyoplankton and zooplankton, they generally preyed on each other based on

the size of the predator and the prey, as well as their food preferences (Sanvicente-Añorve *et al*., 2006; Espinosa-Fuentes *et al*., 2009). This predator-prey factor could influence the abundance of fish larvae in the water column (McGurk, 1986; Devi *et al*., 1996; Ara *et al*., 2011a). The small sizes of fish larvae would be attracted to smaller zooplankton, while larger zooplankton could possibly preyed on smaller fish larvae (Espinosa-Fuentes *et al*., 2009; Islam and Tanaka, 2009). Therefore, the predator-prey relationships are affected by the mating time of the adult fish and also the growth of zooplankton in the water column (Cushing, 1975). Besides that, some species of fish larvae are found to consume other food items such as phytoplankton or any plant-like materials (Ara *et al*., 2011b) and food consumption could varies with seasons as it depends on the prey availability, spatially and temporally (Robichaud-LeBlance *et al*., 1997).

1.5 Relation with Environmental Factors

Basic step to forecast population dynamics of a specific fish species is through understanding the influence of oceanographic processes towards its fish larvae and exchange between populations (Knights *et al*., 2006). Environmental factors are getting more attention as an important component for the restructuring of marine ecosystem (Southward, 1980; Anderson and Piatt, 1999; Beaugrand *et al*., 2002). Physico-chemistry of the water quality, topographical, hydrological characteristics and habitat destruction could play important roles on species richness, diversity and survival of aquatic habitats (Ara *et al*., 2011a).

Oceanographic and meteorological factors are often associated with seasonal patterns of fish larvae abundance (Lasker and Smith, 1976; Houde, 1989; Moser and Boehlert, 1991; Hernandez-Miranda *et al*., 2003) as these two factors can influence the feeding of the organisms and the transportation of eggs and larvae by currents (Bailey, 1981; Freitas and

Muelbert, 2004). It is suggested that different fish species and life stage require different environmental factors at any given time (Sameoto, 1984). Hydrodynamics in reef ecosystem play important role in spatial pattern of larval settlement, both through active responses of larvae to flowing water and also the passive transport which are critical to their recruitment capabilities to suitable habitat for juvenile growth and later reproduction (Breitburg *et al*., 1995).

1.6 Importance of Ichthyoplankton Research

The presence of fish larvae can be an indicator of the health of aquatic environment as fish will use this area as the spawning grounds (Chamchang and Chayakul, 2000; Freitas and Muelbert, 2004; Deepananda and Arsecularatne, 2013) and suitable for their recruitment (Baran 2002; Arkhipov, 2009). For a better sustainability assessment of local fisheries, it is important to obtain knowledge of larval stages including their dispersal and settlement events which can be key factors to become reef reserves that will ensure consistent stock recruitment to the adjacent harvest zones (Baran, 2002). Spawning time of a particular fish species could possibly be determined through the understanding the fisheries biology regarding the information on the occurrence of fish eggs and larvae (Deepananda and Arsecularatne, 2013).

Ichthyoplankton survey is a way of generating fishery-independent stock assessment and key component in understanding the function of marine ecosystem (Moser and Smith, 1993) as well as the ecological processes involved not just in that particular habitat but could cover a wider range (Espinosa-Fuentes *et al*., 2009; Deepananda and Arsecularatne, 2013). Distribution patterns of marine fish larvae can determine the ecological processes of that particular fish and has crucial implications in the assessment of abundance (Brodeur and

Rugen, 1994). Besides that, it could be use as guideline for the fisheries industries to control or manage their fishing activities especially during spawning season (Greve *et al*., 2005).

1.7 Justification of the Study

Sarawak is the largest state in Malaysia that occupied 700 km coastline along the north western side of Borneo and facing the South China Sea (SCS) which is a part of the western Pacific Ocean that borders the Southeast Asian mainland (Encyclopaedia Britannica, 2012). Based on International Pacific Research Center (IPRC) (2005), SCS is branch of the Indo-Pacific warm pool that attached the strong atmospheric convection of the rising branches of the Walker and the global Hadley circulations resulting in monsoonal season annually. It is reported that at least 3,365 species of fish had been recorded from SCS, but mostly from inshore area, while the pelagic and deep sea zone is not well studied (Randall and Lim, 2000). Previous ichthyoplankton studies in Malaysia only covered the estuarine ecosystem (Blaber *et al*., 1997; Ara *et al*., 2011b) and coral reef area (Mohamad-Norizam and Ali, 2009). Ara *et al*. (2011a) compared the density of larval fishes inside and outside of the seagrass area. This shows that scientific information of ichthyoplankton in Malaysia is still very limited and not enough comprehensive baseline data to support a sustainable fish resource management.

Coastal waters of Sarawak are subjected to the influence of many large rivers which transport sediment and nutrients to the coastal areas. The economic activities in Sarawak such as logging and converting forest into palm oil plantations will affect the watershed that lead to high sedimentation and degrade water quality at coastal habitats. In addition, aquaculture activities destroy the mangrove areas that act as biofilter system and barrier from those unwanted products like sediment and excessive nutrients (Mokhtar and Ghani Aziz, 2003). Furthermore, road constructions (Windle and Cramb, 1997) and land reclamations to cater the

increasing human population (Ghazali, 2006) are another factors that cause the habitat destruction in coastal areas of Sarawak. In recent years, the anthropogenic activities as mentioned above are happening extensively, while the impact on ichthyoplankton assemblages is not being monitored. Therefore, it is timely to document the current assemblages of ichthyoplankton in Sarawak coastal waters.

1.8 Objectives and Organization of Thesis

Generally, this study aims to: 1) prepare a family checklist of fish larvae at selected coastal waters of Sarawak; 2) determine the spatio-temporal density, diversity and distribution of ichthyoplankton at selected coastal waters of Sarawak, and 3) determine relationship between ichthyoplankton and physico-chemical parameters of water.

Documentation on fish larvae family is scarce in Malaysian waters. Therefore, Chapter 2 focused on preparing the checklist of fish larvae family found throughout this study with general morphological description. The descriptions are basically based on the key characters used in the common identification books and published journals. The identified larvae are grouped under respective order to identify the systematic arrangement of each family.

Recently, the coastal areas of Sarawak are experiencing drastic development with the increment of human population and to boost the local economy. However, information and impact on fish larvae diversity and assemblages at the coastal areas are not well understood. Therefore, current information on composition and distribution of fish larvae in Sarawak coastal waters are presented in Chapter 3. Modified seine net was used at intertidal area of six selected sampling sites in Sarawak coastal waters that represented different habitat characteristics. One sampling site (Pulau Sampadi) was chosen to compare the differences in

fish larvae composition between its intertidal and subtidal zones. Plankton net was used to collect the fish larvae at subtidal zone.

Estuary is known to act as nursery ground for most fishes. However, the most current available data regarding the ichthyoplankton composition in Sarawak estuaries are about two decades ago. Therefore, this study provides the current information on spatio-temporal pattern of ichthyoplankton in Sarawak estuaries which is presented in Chapter 4. Sungai Sibu Laut-Sungai Salak estuaries were chosen as the study sites because these areas represent a protected area (Kuching Wetland National Park). Samples were collected monthly for one year period using plankton net at five sampling stations located along the Sungai Sibu Laut-Sungai Salak estuaries.

CHAPTER 2

CHECKLIST OF ICHTHYOPLANKTON AT SELECTED SARAWAK COASTAL WATERS

2.1 Introduction

Cataloguing or documenting data on species or family is crucial in order to convey the information to the public (Tamutis *et al*., 2011). In addition, the information should be expressed in an organized manner depending on the author's interpretation and specification (Laurenne *et al*., 2014). In term of fisheries management, documenting fish species is needed to monitor the fish in their natural environment.

Documentation on adult fishes had extensively been made and is available through published journals and books. Even Malaysia has already produced several fish identification books that are available according to the habitat types which are marine, brackish and freshwater (Kuiter and Debelius, 1994; Mohsin and Ambak, 1996; Atack, 2006; Matsunuma *et al*., 2011). However, this identification guide is not applicable for the early life stage of fish larvae because of the differences in their physical appearances which are not fully developed yet, giving them a different look from the adult fishes. Therefore, the identification of fish larvae needs its own morphological description.

Detail guidebook or identification key for Malaysian ichthyoplankton is not available and a few published articles only touched on fish larvae assemblages at specific ecosystem of certain locations. Mohamad-Norizam and Ali (2009) studied the fish larvae at coral reef habitat in the east coast off Pulau Payar Marine Park, Kedah while Ara *et al*. (2011a; 2011b; 2011c) and Arshad *et al*. (2012) focused on fish larvae at seagrass beds and estuary of Johor. The most recent study was a short survey done by Muhamad and Rahim (2013) at several locations in western part of Sarawak. However, these articles did not describe the morphology

of fish larvae in detail. Therefore, the objective of this study was to prepare a family checklist on fish larvae collected at selected Sarawak coastal waters with the general morphological description of each family.

2.2 Materials and Methods

2.2.1 Sampling Sites

Ichthyoplankton samples were collected from April 2012 until September 2013 at various locations of Sarawak coastal waters (Table 2.1). Eight sampling sites were selected, namely Pantai Lundu, Pantai Rambungan, Pantai Puteri, Pulau Sampadi, Pulau Satang, Sungai Sibu Laut and Sungai Salak are located at the western part of Sarawak, while Pantai Mukah is located approximately in the middle of Sarawak coastline (Figure 2.1).

Six out of eight sampling sites were conducted at the intertidal zone namely Pantai Teluk Pandan, Pantai Rambungan, Pantai Puteri, Pulau Sampadi, Pulau Satang and Pantai Mukah. These sampling sites have different characteristics that were explained in Table 2.1. In addition, ichthyoplankton samples were also collected at the subtidal zone surrounding Pulau Sampadi. Meanwhile, the last two sampling sites at Sungai Sibu Laut and Sungai Salak are at river estuaries. Other than the differences in site's characteristics, these sampling sites were chosen because of the easy excess by road and boat. In addition, those two river estuaries were chosen because of less impact from waves and winds but with semidiurnal tidal influence.

Table 2.1: List of sampling sites, dates of sample collection, collection methods and habitat characteristics of each sampling site. Pantai = beach; Pulau = island; Sungai = river.

Sampling Site	Date of Collection	Site Description
Pantai Teluk Pandan	Apr 2012	Flat sandy beach; partially covered with rocks; strong wave action
Pantai Rambungan	May 2012	Narrow sandy beach; small rocks covered the floor; logs and concrete rubble
Pantai Puteri	May 2012	Flat sandy-muddy shore; small patch of mangrove trees
Pulau Sampadi	Jul 2012	Rocky floor
	Nov 2012	Flat muddy floor covered with gravels; rock beach; partially covered with seagrass
Pulau Satang	Sep 2012	Small rocks covered the floor with slightly muddy substrate; surrounded by patches of coral reef and seaweeds
Sungai Sibu Laut	Oct 2012 – Sep 2013	Semidiurnal tidal influenced with mangrove habitat along the river
Sungai Salak	Oct 2012 – Sep 2013	Semidiurnal tidal influenced with mangrove habitat along the river
Pantai Mukah	Mar 2013	Flat beach with very murky water

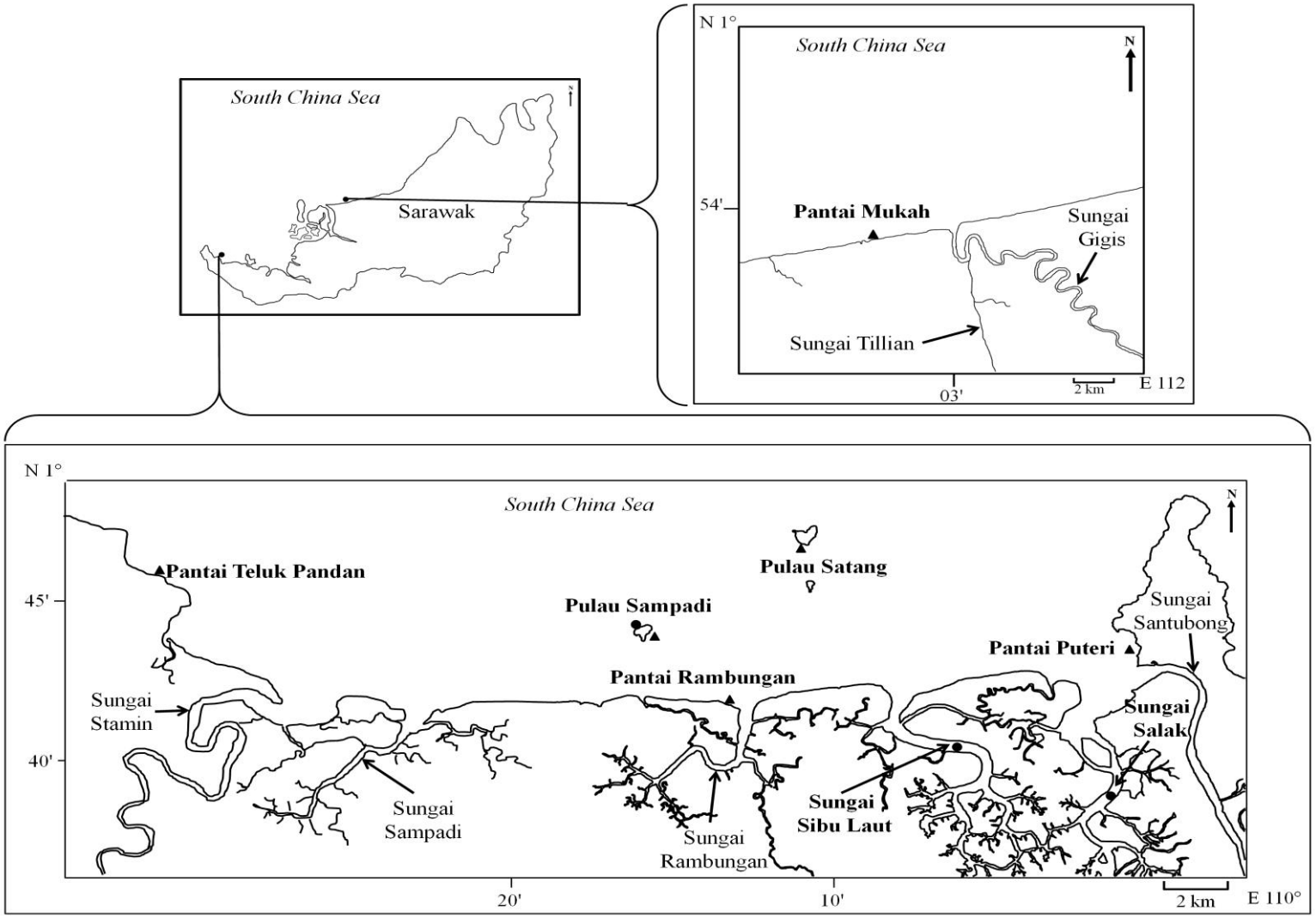


Figure 2.1: The location of eight sampling sites is indicated by triangle for the intertidal sampling using seine net, while circle for subtidal and estuaries samplings using plankton net.

2.2.2 Sample Collection

Ichthyoplankton samples were collected using two different gears: 1) modified seine net with bag and 2) plankton net. Modified seine net is about 4 m × 1 m area net with 1 mm mesh size that has a bag-like structure in the middle and attached with two poles at each end. This gear can only be used at intertidal area where the water level is not more than a metre deep. Meanwhile, plankton net is an enlarged plankton net with a 1 metre opening diameter and 0.5 mm mesh size that can only be operated in more than five meter deep of water level.

Modified seine net was used at all intertidal sampling sites namely Pantai Teluk Pandan, Pantai Rambungan, Pantai Puteri, Pulau Sampadi, Pulau Satang and Pantai Mukah. The seine net was pulled by two people at shallow water for about two minutes along the shore with normal walking speed (Brazner, 1997). Meanwhile, plankton net was towed obliquely by boat for about 10 minutes against the water current (Mohamad-Norizam and Ali, 2009) at Sungai Sibu Laut, Sungai Salak and offshore of Pulau Sampadi. The plankton net was released and let to submerge until the desired depth which depends on the water depth at each site that was measured beforehand using Depthmate Portable Sounder (Speedtech Instruments) before being towed by the boat. The 10 minutes timing was counted when the boat started to move with gradual speed increment until it reach 2 knot (maximum speed) in order to make oblique tow that covered various depths. All samples were preserved with 10% buffered formalin seawater directly in the field. In the laboratory, the fish larvae were sorted out and then preserved with 75% ethanol.

2.2.3 Sample Analyses

The identification was done to the family level for most of the fish larvae through morphological characteristics with the aid of reference books (Jeyaseelan, 1998; Leis and

Carson-Ewart, 2000; Ré and Meneses, 2009; Blaxter, 2012; Konishi *et al*., 2012; Termvidchakorn and Hortle, 2013; Okiyama, 2014) and also expert from Kochi University Japan, Professor Dr. Izumi Kinoshita for further confirmation. The expert was also able to further identify some specimen up to genus and species level. The growth stage (preflexion, flexion or postflexion) of fish larvae was determined based on the bending of notochord (Figure 1.3, Chapter 1). Total length of fish larvae was measured to the nearest ± 0.02 mm using a dial calliper (Mitutoyo, D15HA) and each family was photographed (one or two figures per family as representative) using digital compact camera (Samsung, ES80) and microscope camera (Motic Image Plus 2.0ML) for documentation.

2.3 Results

A total of 25,297 fish larvae were recorded throughout the sampling period comprising 13 orders belonging to 38 identified families (Table 2.2). Order Perciformes was dominant with 20 families recorded. Ten families were collected as single individual namely, Muraenidae, Synodontidae, Exocoetidae, Myctophidae, Centrolophidae, Haemulidae, Ptereleotridae, Uranoscopidae, Paralichthyidae and Balistidae while the other ten families collected comprised of all growth stages (preflexion, flexion and postflexion) namely Atherinidae, Clupeidae, Engraulidae, Pristigasteridae, Callionymidae, Carangidae, Gobiidae, Leiognathidae, Sciaenidae and Tetraodontidae. General characteristics of each fish larvae family and their collection sites were described in the following subtopic.

Table 2.2: List of family of fish larvae that were recorded in this study according to their respective order together with their size range (mm) and growth stages. ('+' indicates the present of fish larvae at that particular growth stage; '*' indicates single individual).

Order	Family	Size Range (mm)	Growth Stages		
			Preflexion	Flexion	Postflexion
Anguilliformes	Muraenidae	47.20*			
Atheriniformes	Atherinidae	2.48-5.54	+	+	+
Aulopiformes	Synodontidae	38.70*			+
Beloniformes	Exocoetidae	4.10*		+	
	Hemiramphidae	7.76-32.34			+
Clupeiformes	Clupeidae	1.78-21.50	+	+	+
	Engraulidae	2.18-28.21	+	+	+
	Pristigasteridae	4.70-17.74	+	+	+
Elopiformes	Megalopidae	22.00-28.00			+
Gonorynchiformes	Chanidae	3.10-12.00	+		+
Myctophiformes	Myctophidae	3.10*	+		
Perciformes	Acropomatidae	1.02-5.68	+	+	
	Ambassidae	3.84-8.50		+	+
	Apogonidae	1.32-4.50	+		+
	Blenniidae	1.96-13.56	+		+
	Callionymidae	1.38-6.00	+	+	+
	Carangidae	1.26-13.00	+	+	+
	Centrolophidae	5.26*			+
	Gerreidae	4.44-25.18			+
	Gobiidae	1.02-14.06	+	+	+
	Haemulidae	6.70*		+	
	Leiognathidae	1.36-60.00	+	+	+
	Mugilidae	4.70-20.82			+
	Ptereleotridae	12.00*			+
	Scatophagidae	1.72-13.32	+		+
	Sciaenidae	1.96-22.90	+	+	+
	Scombridae	2.94-5.56	+	+	
	Serranidae	1.34-8.00	+		+
	Sillaginidae	7.60-14.00			+
	Terapontidae	13.00-25.22			+
	Uranoscopidae	2.10*	+		
Pleuronectiformes	Cynoglossidae	1.20-7.00	+	+	
	Paralichthyidae	5.46*		+	
Scorpaeniformes	Scorpaenidae	2.04-6.68	+	+	
Syngnathiformes	Syngnathidae	5.72-42.50			
Tetraodontiformes	Balistidae	13.20*			+
	Monacanthidae	2.04-3.28	+		
	Tetraodontidae	1.58-8.94	+	+	+

2.3.1 Anguilliformes

2.3.1.1 Muraenidae

One family under Anguilliformes, Muraenidae was found throughout the sampling period (Figure 2.2). Only one specimen was collected from Sungai Sibu Laut with a total length of 47.20 mm. Muraenidae has an elongated, transparent, leaf-like body structure; rounded tail with continuous dorsal, caudal and anal fins; visible teeth. The growth stage of this family could not be determined because no information is available in literature.

2.3.2 Atheriniformes

2.3.2.1 Atherinidae

One family under Atheriniformes, Atherinidae was found throughout the sampling period (Figure 2.3). Total length of the collected specimens ranged from 2.48 mm to 5.54 mm. Preflexion and flexion growth stages were observed at Sungai Salak and Pulau Sampadi (subtidal), while specimens from Pulau Satang and Pulau Sampadi (intertidal) are at postflexion stage. Atherinidae has an elongated, laterally compressed and shallow body; rounded broad flat head; a very short compact gut; short snout; small terminal mouth that reaches to about the anterior edge of the eye; large rounded to ovoid eye; heavy pigmentation over the midbrain and on the dorsal surface of the gut and a stripe or row of melanophores on the mid lateral surface of the tail.

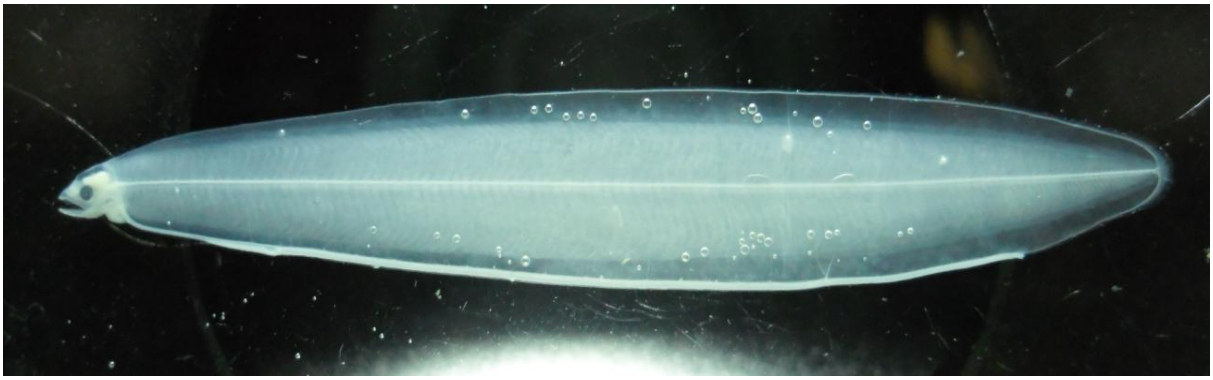


Figure 2.2: Lateral view of Muraenidae showing a leaf-like body structure with a continuous dorsal, caudal and anal fins and a rounded tail (TL: 47.20 mm).

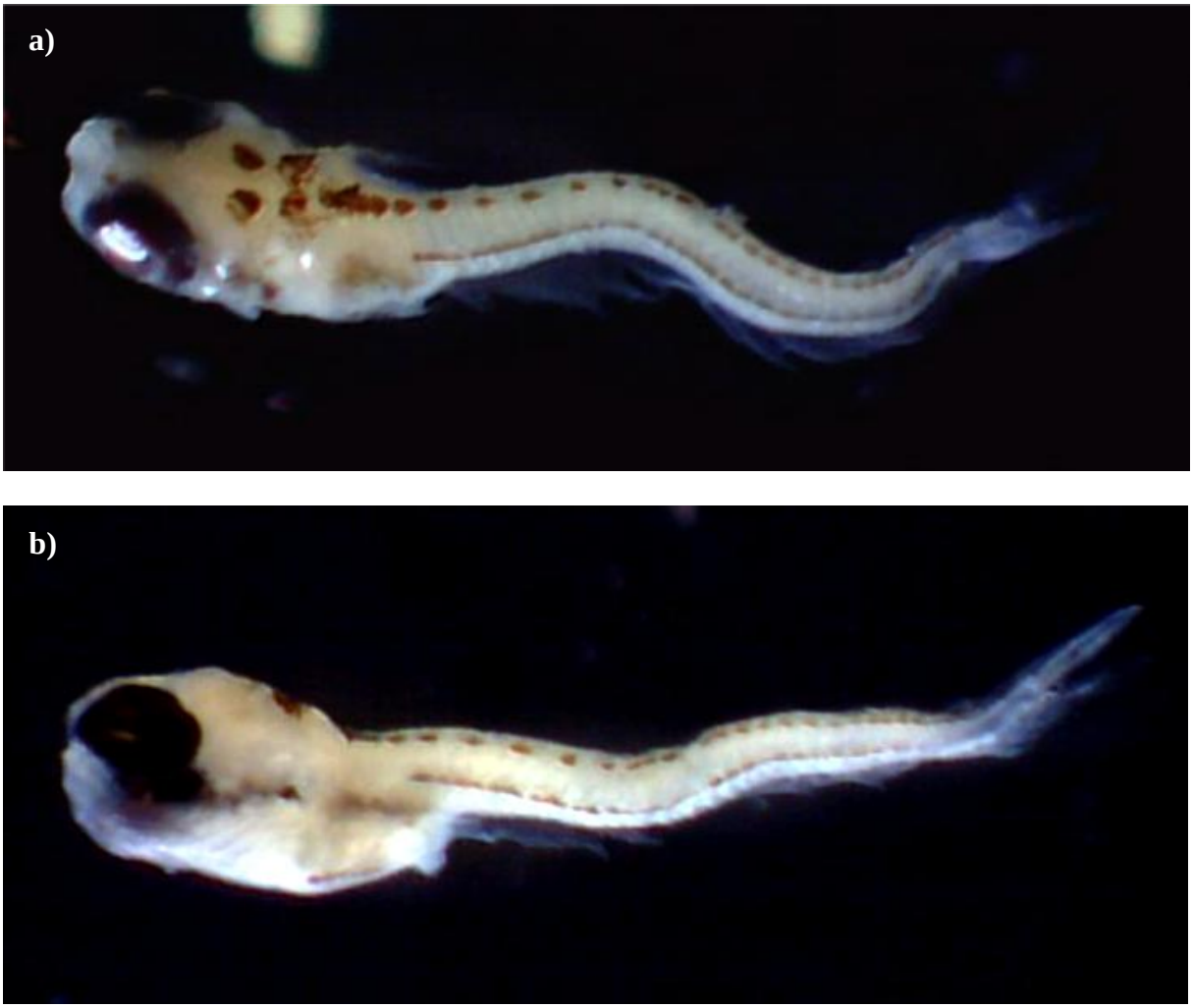


Figure 2.3: Dorsal (a) and lateral (b) views of Atherinidae showing a heavy pigmentation starting from over the midbrain towards the caudal in both dorsal and lateral parts of the body (TL: 3.00 mm; preflexion).

2.3.3 Aulopiformes

2.3.3.1 Synodontidae

Synodontidae was the only family found under Order Aulopiformes throughout the sampling period (Figure 2.4). One postflexion stage larva was recorded at Sungai Sibu Laut with a total length of 38.70 mm. This family has a very elongated body and round in cross section; head is small and dorsoventrally flattened; moderate and pointed snout; terminal and large mouth that reaches beyond the mid eye; small and rounded eyes; dorsal fin anlage appears at about the mid body and the rays form; adipose fin becomes apparent as a remnant of the dorsal fin fold. This single specimen was identified until species which is *Harpadon nehereus* (Hamilton, 1822).

2.3.4 Beloniformes

Two families under this order, namely Exocoetidae and Hemiramphidae were recorded throughout the sampling period.

2.3.4.1 Exocoetidae

One individual was collected at Pulau Sampadi (subtidal) with 4.10 mm in total length and at flexion growth stage (Figure 2.5). This family has an elongate body with compressed or squarish in cross section; heavy pigmentation throughout the body; a short snout and somewhat pointed; small and oblique mouth that reaches to the anterior edge of the eye; large and somewhat elongate to round eyes; dorsal and anal fins are located opposite to each other in the posterior body while pectoral fin becomes enlarge with growth; lower lobe of the caudal fin becomes elongate.

Figure 2.4: Lateral view of Synodontidae (*Harpodon nehereus*) showing a terminal large mouth that reaches beyond the mid eye with small-rounded eyes (TL: 38.70 mm; postflexion).

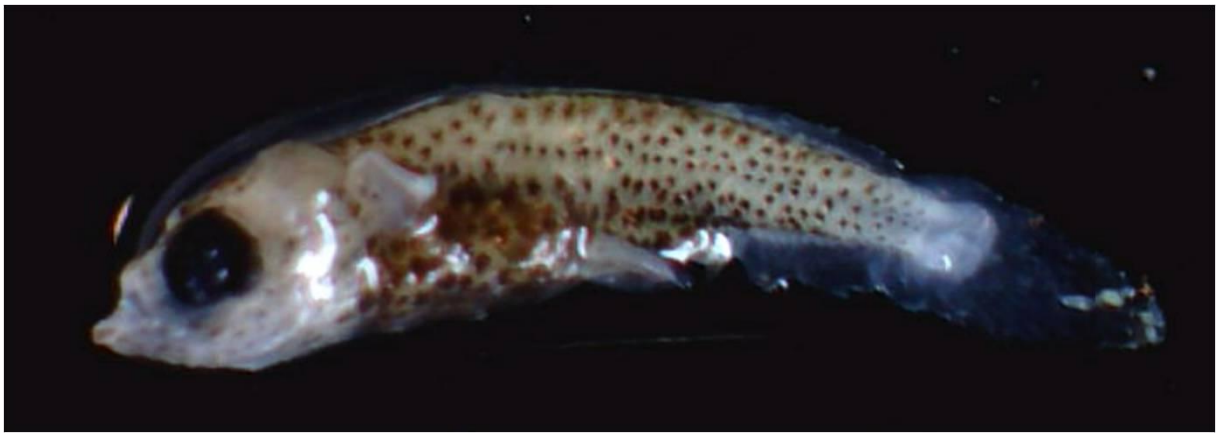


Figure 2.5: Lateral view of Exocoetidae showing pigmentation throughout the body and a small oblique mouth (TL: 4.10 mm; flexion).

2.3.4.2 Hemiramphidae

This family was collected at Pulau Satang, Sungai Sibu Laut and Sungai Salak with total length ranging from 7.76 mm to 32.34 mm and at postflexion growth stage (Figure 2.6). Hemiramphidae has elongate body with squarish in cross section to moderately compressed; ovate head that later becomes increasingly elongate; short and pointed snout but later the lower jaw becomes elongate; small and oblique mouth that reaches anterior to the eye; small teeth on both jaws; eyes are somewhat elongate to round, dorsal and anal fins are located oppositely in the posterior body; moderate to heavily pigmented dorsally and sometimes ventrally, on the trunk, tail and on the dorsal surface of the head. Some specimens were identified until genus, which is *Hemiramphus*.

2.3.5 Clupeiformes

Clupeidae, Engraulidae and Pristigasteridae were recorded under this order.

2.3.5.1 Clupeidae

Clupeidae larvae collected at Pulau Sampadi (subtidal) and Sungai Sibu Laut-Sungai Salak estuaries (Figure 2.7) were at preflexion to flexion growth stages with total length ranging from 1.78 mm to 17.42 mm, while postflexion growth stage were collected from all sampling sites at intertidal zone and Sungai Sibu Laut-Sungai Salak estuaries with total body length ranging from 8.50 mm to 21.50 mm. This family has elongate body that becomes compressed with growth; small head and slightly depressed that later becomes moderate and compressed; short snout and concave which later becomes moderate and pointed or rounded; small mouth reaches to the anterior edge of the pupil or eye with the lower jaw projects slightly beyond the upper jaw; generally small to moderate eyes; dorsal and anal fin are not overlapping.

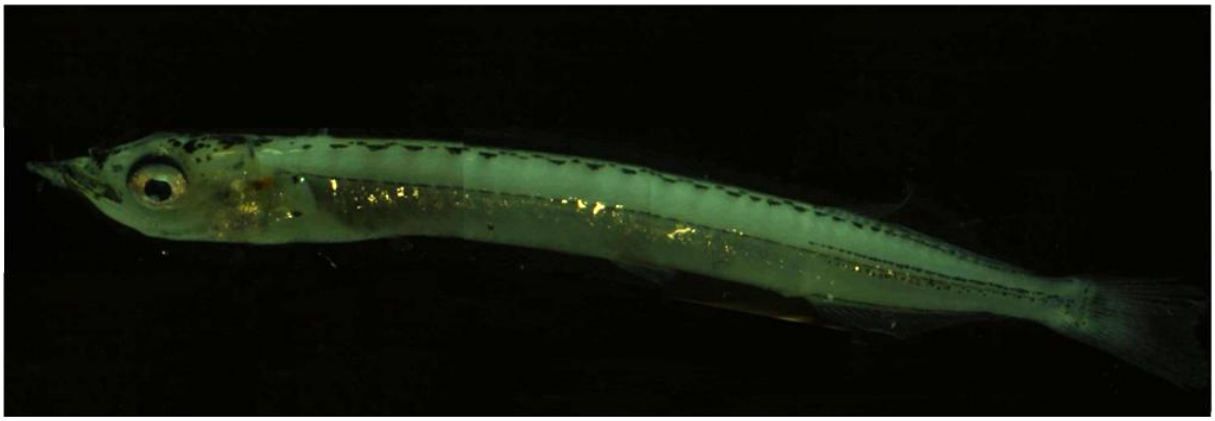


Figure 2.6: Lateral view of Hemiramphidae (*Hemiramphus* sp.) showing the ovate head with a pointed snout and a line of pigmentation starting from the head towards the caudal (TL: 27.98 mm; postflexion).

Figure 2.7: Lateral view of Clupeidae showing dorsal and anal fins that are not overlapping each other differentiate it from other families under Clupeiformes (TL: 11.72 mm; postflexion).

2.3.5.2 Engraulidae

This family was collected abundantly at six sampling sites except Pantai Rambungan and Pulau Satang (Figure 2.8). All three growth stages were observed at Sungai Sibu Laut and Sungai Salak with total length ranging from 2.18 mm to 28.21 mm, while postflexion larvae were collected at intertidal sampling sites with total length ranging from 11.70 mm to 27.00 mm. This family has a very elongate and cylindrical body that later becomes compressed; head is small, ovate and slightly depressed which later become compressed; short and slightly concave snout that later becomes convex and slightly pointed and bulbous; small and terminal mouth which reaches to the anterior half of the eye and later becomes moderate and large in size that reaches beyond the eye; eyes are large to moderate and slightly narrow to round that later becomes moderate to small and round; dorsal and anal fins overlapped.

2.3.5.3 Pristigasteridae

This family was collected from the Sungai Sibu Laut with total length ranging from 4.70 mm to 17.74 mm and consist of all growth stages (Figure 2.9). Pristigasteridae has a very elongated and compressed body; small, triangular compressed head; snout is short, slightly concave and pointed; small narrow eyes; small oblique mouth that reaches to the anterior edge of the eye; lower jaw protrudes beyond the upper; dorsal and anal fins are not overlapping like Clupeidae but anal fin extend towards the caudal. This family was identified until genus, which is *Ilisha.*

Figure 2.8: Lateral view of Engraulidae showing the overlapping dorsal and anal fins and the compressed head (TL: 13.06 mm; postflexion).

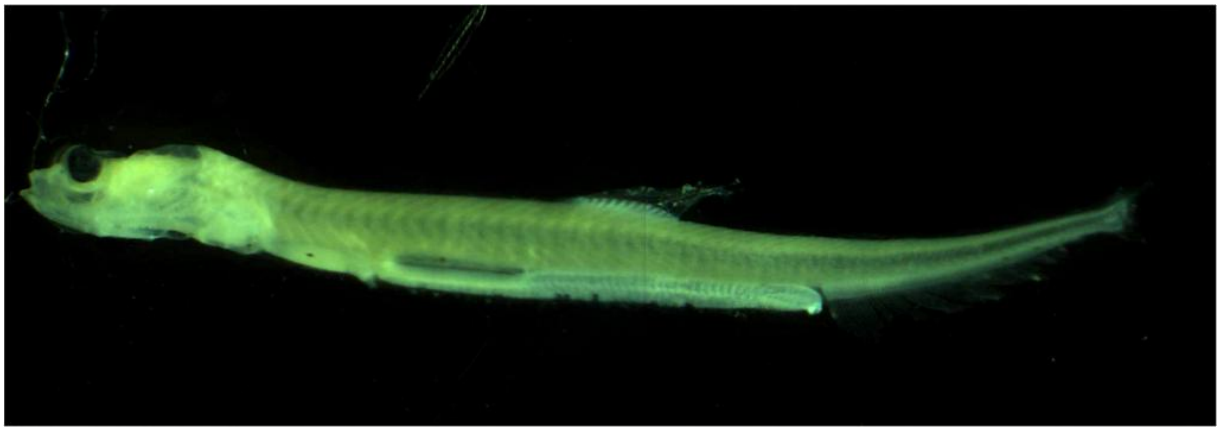


Figure 2.9: Lateral view of Pristigasteridae (*Ilisha* sp.) showing the dorsal and anal fins are not overlapping while the anal fin reaches toward the caudal (TL: 12.28 mm; postflexion).

2.3.6 Elopiformes

2.3.6.1 Megalopidae

Megalopidae was the only family found under Order Elopiformes. Specimens were collected only at Pulau Satang and the larvae are at their postflexion stage with a total length ranging from 22.00 mm to 28.00 mm (Figure 2.10). It has small rounded head; strongly compressed ribbon-like transparent body; bifurcated tail; dorsal and anal fins are overlapping each other.

2.3.7 Gonorynchiformes

2.3.7.1 Chanidae

One family, Chanidae under Order Gonorynchiformes was recorded only at Pulau Sampadi (Figure 2.11). The postflexion larvae were collected at intertidal zone (range of total length = 11.00-12.00 mm), while preflexion larvae were collected at subtidal zone (range of total length = 3.10-6.10 mm). It has elongated and moderately compressed body; small, elongated and slightly depressed head; short and concave to rounded snout; mouth is terminal and small reaches to the anterior edge of the eye; eye is large and slightly elongated to moderate and rounded; dorsal and anal fins formed posteriorly.

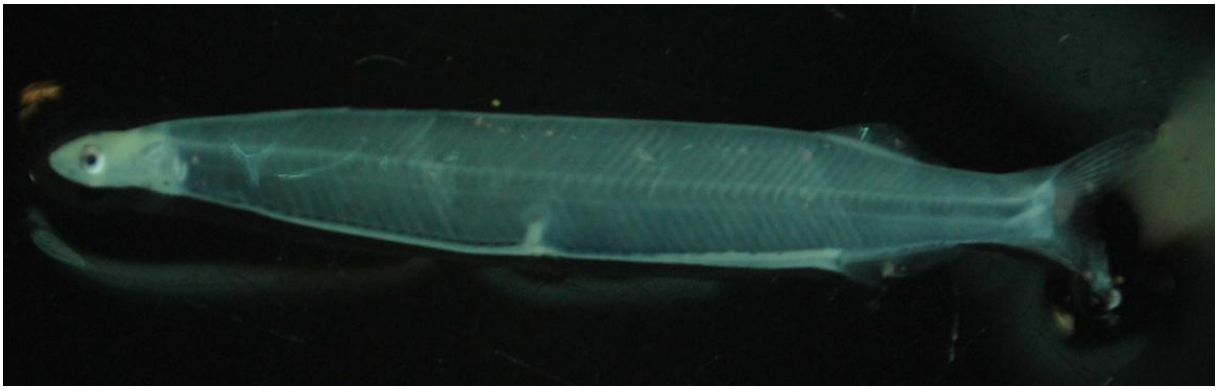


Figure 2.10: Lateral view of Megalopidae showing the transparent body with overlapping dorsal and anal fins (TL: 28.00 mm; postflexion).

Figure 2.11: Lateral view of Chanidae showing the large eye and moderately compressed body (TL: 3.66 mm; preflexion).

2.3.8 Myctophiformes

2.3.8.1 Myctophidae

Myctophidae was the only family found under Order Myctophiformes and only one larva at preflexion stage was collected at Pulau Sampadi (subtidal) with total length of 3.10 mm (Figure 2.12). Myctophidae has a moderately slender body shape that can range highly attenuate to markedly robust. Some species have deep body and laterally compressed; head is either large or flat; eye is stalked, elongated and either elliptical or rounded. The special feature of Myctophidae is that it is equipped with a non-bacterial luminescent organ on the head and body. However, this organ cannot be identified from the specimen because it develops late in larval period.

2.3.9 Perciformes

A total of 20 families were recorded under Order Perciformes throughout the sampling period.

2.3.9.1 Acropomatidae

Acropomatidae was recorded at Sungai Sibu Laut and Sungai Salak (Figure 2.13). The larvae collected consist of preflexion and flexion growth stages with total length ranging from 1.02 mm to 5.68 mm. This family has a moderate to deep and compressed body; large to very large head; snout is short and somewhat round; large and oblique mouth that reaches to the mid eye; eye is round and large.

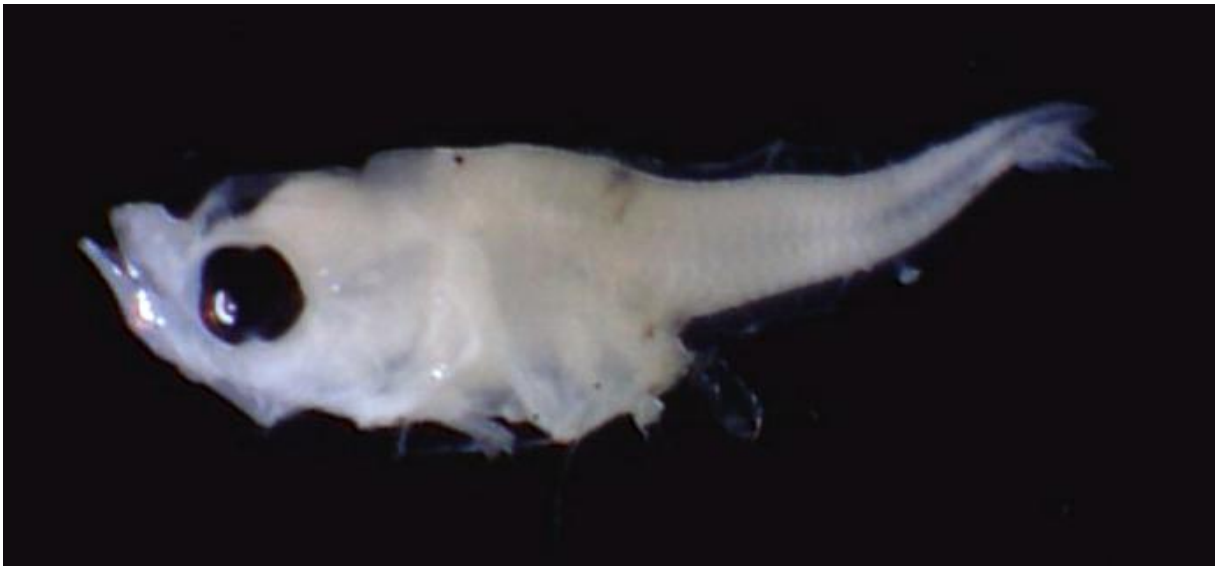


Figure 2.12: The slender body of Myctophidae with rounded eye (TL: 3.10 mm; preflexion).

Figure 2.13: The deep and compressed body of Acropomatidae with large head and eye (TL: 3.28 mm; preflexion).

2.3.9.2 Ambassidae

Most of the Ambassidae larvae collected at Pulau Sampadi (intertidal and subtidal), Pulau Satang, Sungai Sibu Laut, Sungai Salak and Pantai Mukah are at flexion and postflexion growth stages, with total length ranging from 3.84 mm to 8.50 mm (Figure 2.14). The body is moderate depth and compressed; head is compressed and round but later becomes slightly elongate; snout is short, steep and slightly concave to irregular rounded in profile; mouth is small and oblique but does not reach to the eye; eye is moderate to large and round in shape. Some specimen under this family was identified until genus, which is *Ambassis*.

2.3.9.3 Apogonidae

Most of the Apogonidae larvae caught at Pulau Sampadi (subtidal), Sungai Sibu Laut and Sungai Salak are at their preflexion stage (range of total length = 1.32-2.90 mm) (Figure 2.15). However, only at Pulau Sampadi (subtidal), a few postflexion larvae (range of total length = 4.00-4.50 mm) were also collected. The body is moderate to deep and compressed mostly with the long caudal peduncle; head is moderate to large; short to elongate and round to truncate snout; mouth is oblique that reaches to about the mid eye; eye is round and moderate to large in size; pigmentations varies in intensity, distribution and pattern along the body.

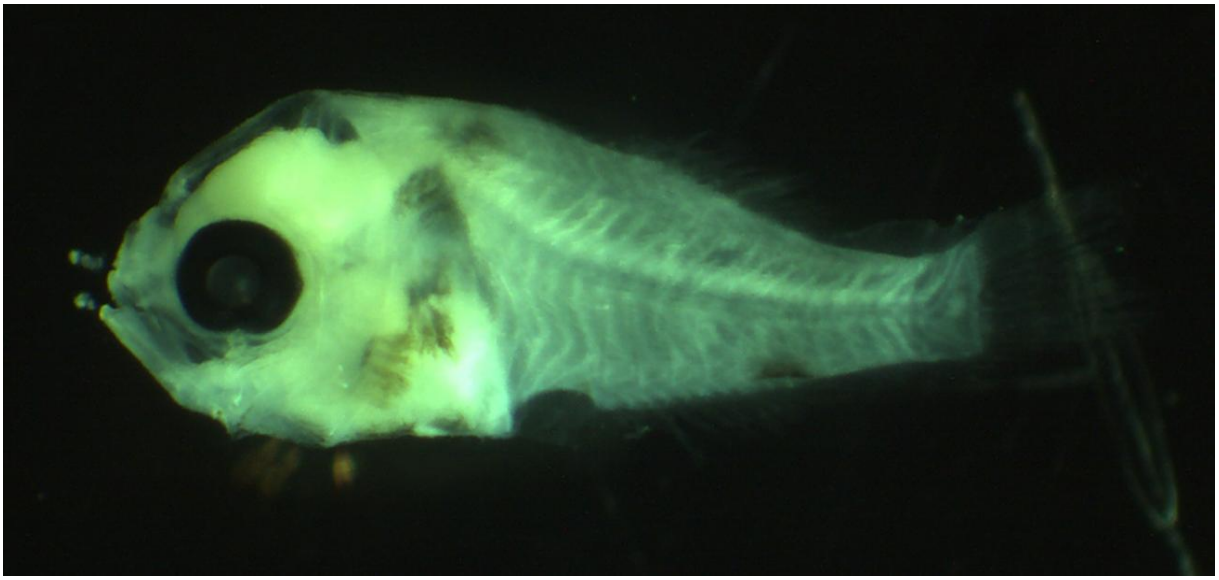


Figure 2.14: The compressed body of Ambassidae (*Ambassis* sp.) with rounded head (TL: 7.58 mm; postflexion).

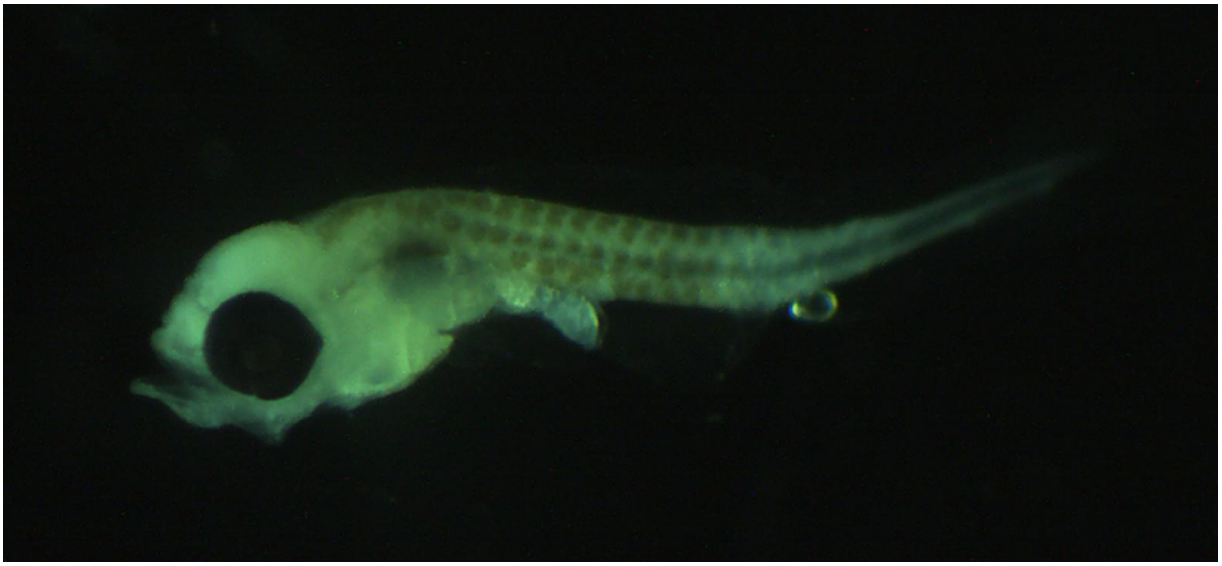


Figure 2.15: Lateral view of Apogonidae showing the moderate and compressed body with a long caudal peduncle and a heavy pigmentation throughout the body (TL: 2.46 mm; preflexion).

2.3.9.4 Blenniidae

Blenniidae larvae were recorded at six sampling sites except Pantai Teluk Pandan and Pantai Rambungan (Figure 2.16). The larvae collected at Pulau Sampadi (subtidal), Sungai Sibu Laut and Sungai Salak are at their preflexion stage (range of total length = 1.96-4.59 mm), while at Pantai Puteri, Pulau Satang and Pantai Mukah, the larvae are at their postflexion stage (range of total length = 12.00-13.56 mm). It has an elongate to moderately deep body; a compressed trunk and tail; head is broad, rounded and moderate size; snout is short and rounded which elongate later on; mouth reaches just pass the interior border of the eye; large and rounded eye; radially or slightly pigmented and pointed pectoral fin. Some specimen under this family was identified until genus, namely *Omobranchus*.

2.3.9.5 Callionymidae

The Callionymidae larvae collected at Pulau Sampadi (subtidal), Sungai Sibu Laut and Sungai Salak consist of all three growth stages with total length ranging from 1.38 mm to 6.00 mm (Figure 2.17). Callionymidae has a robust, moderately deep and round body in cross section; head is moderate to large and round and broad shape; snout is round and slightly pointed; mouth is small, slightly oblique and protrusible and never reaches to the mid eye; eye is round and moderate to large in size; pigmentation on the body and heavier at the ventral side.

Figure 2.16: Lateral view of Blenniidae (*Omobranchus* sp.) showing pigmented pectoral fin with a deep body and compressed trunk and tail (TL: 2.26 mm; preflexion).

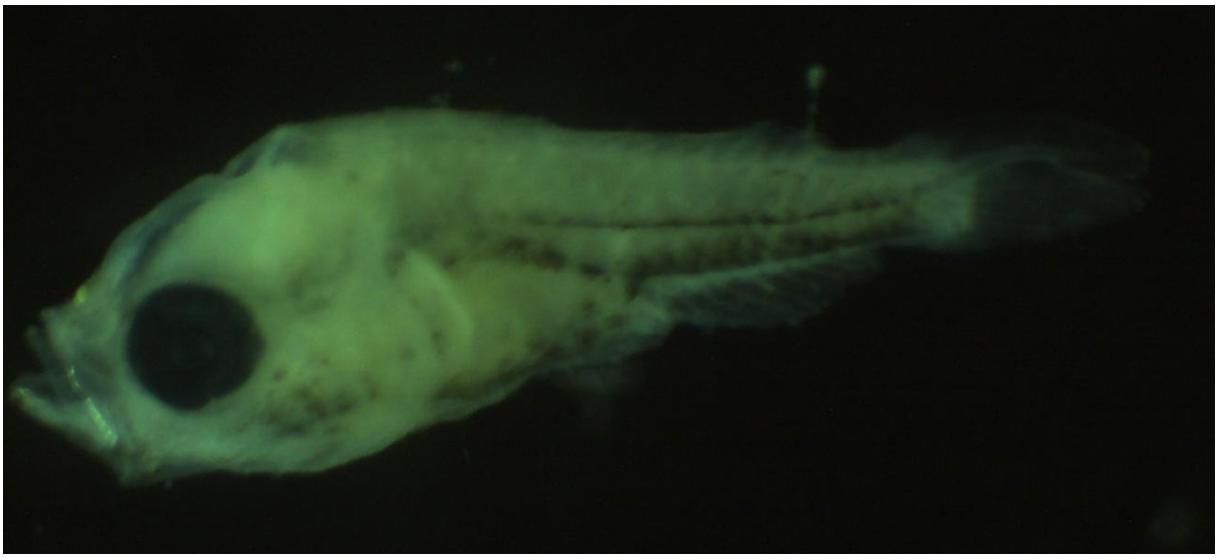


Figure 2.17: Lateral view of Callionymidae showing a robust, deep body with a large head and a heavy pigmentation at the ventral side of the body (TL: 4.34 mm; flexion).

2.3.9.6 Carangidae

Carangidae larvae were recorded at Pulau Sampadi (intertidal), Sungai Sibu Laut, Sungai Salak and Pantai Mukah which consist of all three growth stages with total length ranging from 1.26 mm to 13.00 mm (Figure 2.18). The body of Carangidae is moderate to deep; large head; snout is triangular to blunt or slightly pointed; mouth is oblique that reaches beyond the mid eye; eye is round and moderate to large in size; pigmentations are lightly or densely distributed along the head and body. Specimens under this family were identified until a few genera, namely *Kaiwarinus* and *Scomberoides* (Appendix 1).

2.3.9.7 Centrolophidae

One individual of Centrolophidae was recorded from Sungai Sibu Laut at postflexion growth stage with a total length of 5.26 mm (Figure 2.19). Centrolophidae has an elongate and deep body at postflexion; short head; pigmented eye; melanophores present on the dorsal and ventral midline of the trunk and the dorsal and anal fin with weak indistinct spines.

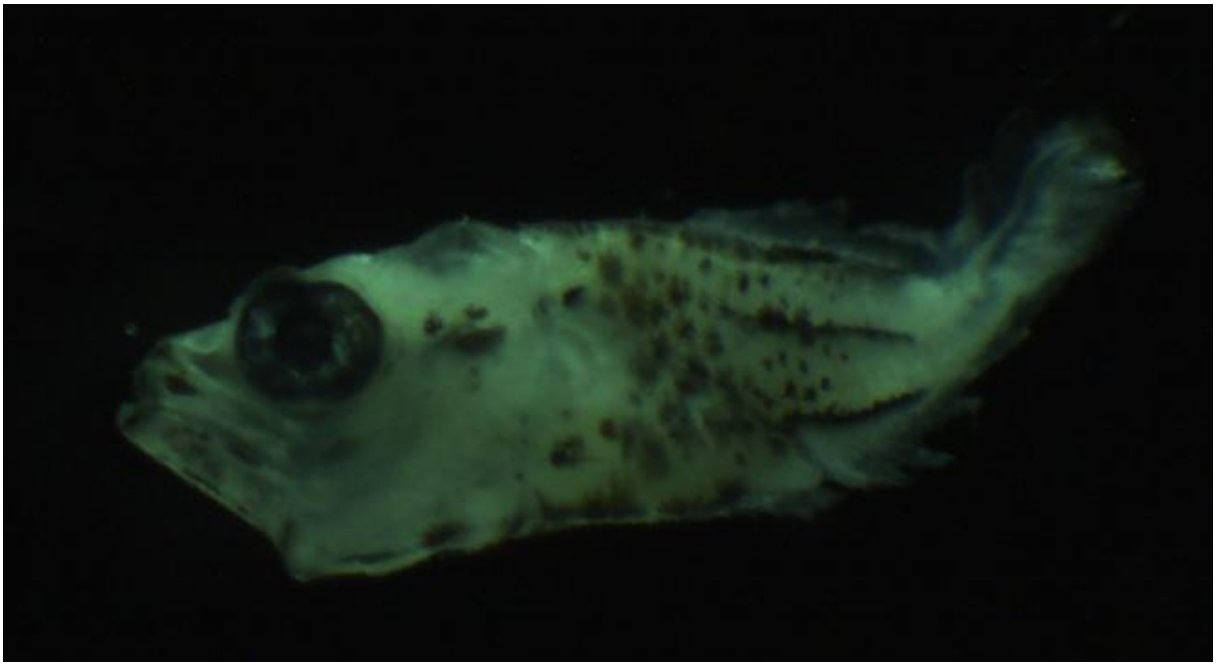


Figure 2.18: Lateral view of Carangidae showing a deep body with large head and triangular snout. Dense pigmentation on the body and light pigmentation on the head (TL: 3.70 mm; flexion).

Figure 2.19: Lateral view of Centrolophidae showing melanophores present on the dorsal and ventral midline of the trunk (TL: 5.26 mm; postflexion).

2.3.9.8 Gerreidae

The Gerreidae larvae were collected at all intertidal sampling sites and Pulau Sampadi (intertidal and subtidal). Total length ranged from 4.44 mm to 25.18 mm and all larvae are at postflexion growth stage (Figure 2.20). Gerreidae has a moderate to compressed body; large and compressed head; snout is somewhat short, triangular and compressed; mouth is slightly oblique that reaches near the mid eye; eye is large to moderate and round; pigmentations occur on the head and at the base of dorsal, anal and caudal fins. Specimen under this family was identified until genus, namely *Gerres*.

2.3.9.9 Gobiidae

The Gobiidae larvae were collected in high abundance at Sungai Sibu Laut and Sungai Salak as well as Pantai Mukah but low at Pantai Teluk Pandan, Pantai Rambungan and Pulau Sampadi (subtidal) (Figure 2.21). All three growth stages were observed with total length ranging from 1.02 mm to 14.06 mm. The body of Gobiidae is elongate to moderate in depth with round to ovoid in cross section and a long caudal peduncle; head is small to moderate in size; snout is small and pointed to rounded; mouth is oblique that reaches to beyond the anterior edge of the eye; large and rounded eye; pigmentation usually at the ventral surface of body and could be distributed throughout the body.

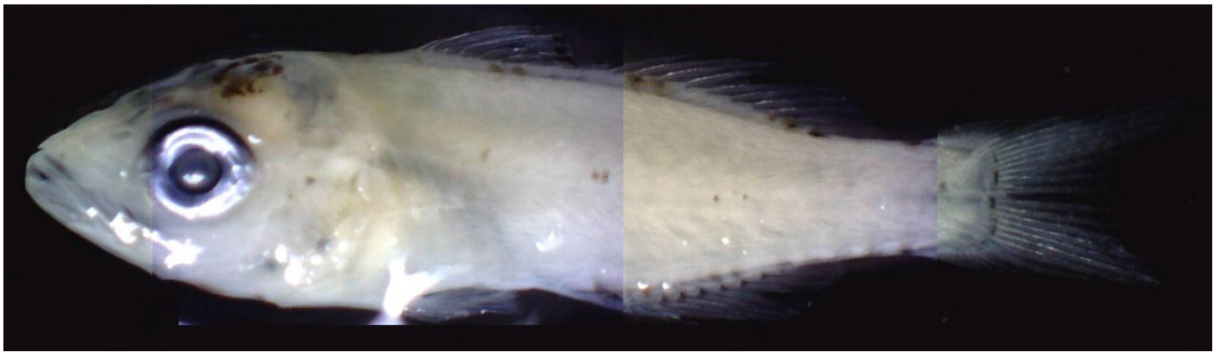


Figure 2.20: The lateral view of Gerreidae (*Gerres* sp.) showing a compressed body with large and compressed head with compressed, triangular snout (TL: 11.00 mm; postflexion).

Figure 2.21: The lateral view of Gobiidae showing a long caudal peduncle with small head and snout, and large-rounded eye (TL: 2.90 mm; preflexion).

2.3.9.10 Haemulidae

A single larva at flexion stage was collected at Sungai Sibu Laut with a total length of 6.70 mm (Figure 2.22). Haemulidae has a moderate to deep and compressed body; mostly large and hunch-backed or progressively steep head in dorsal profile; snout is moderate and somewhat pointed; mouth is oblique that reaches to the mid eye; eye is rounded and moderate in size.

2.3.9.11 Leiognathidae

The larvae collected at Sungai Sibu Laut and Sungai Salak are mostly at their preflexion and flexion stages with total length ranging from 1.36 mm to 6.18 mm (Figure 2.23), while most of Leiognathidae at Pulau Sampadi (intertidal) are at late postflexion stage to juvenile with total length ranging from 18.00 mm to 60.00 mm. The body of Leiognathidae is deep and strongly compressed; large and deeply ovate head; snout is steep, blunt and concave; mouth is small and protrusible that reaches to about the anterior margin of the eye; eye is round and moderate to large in size.

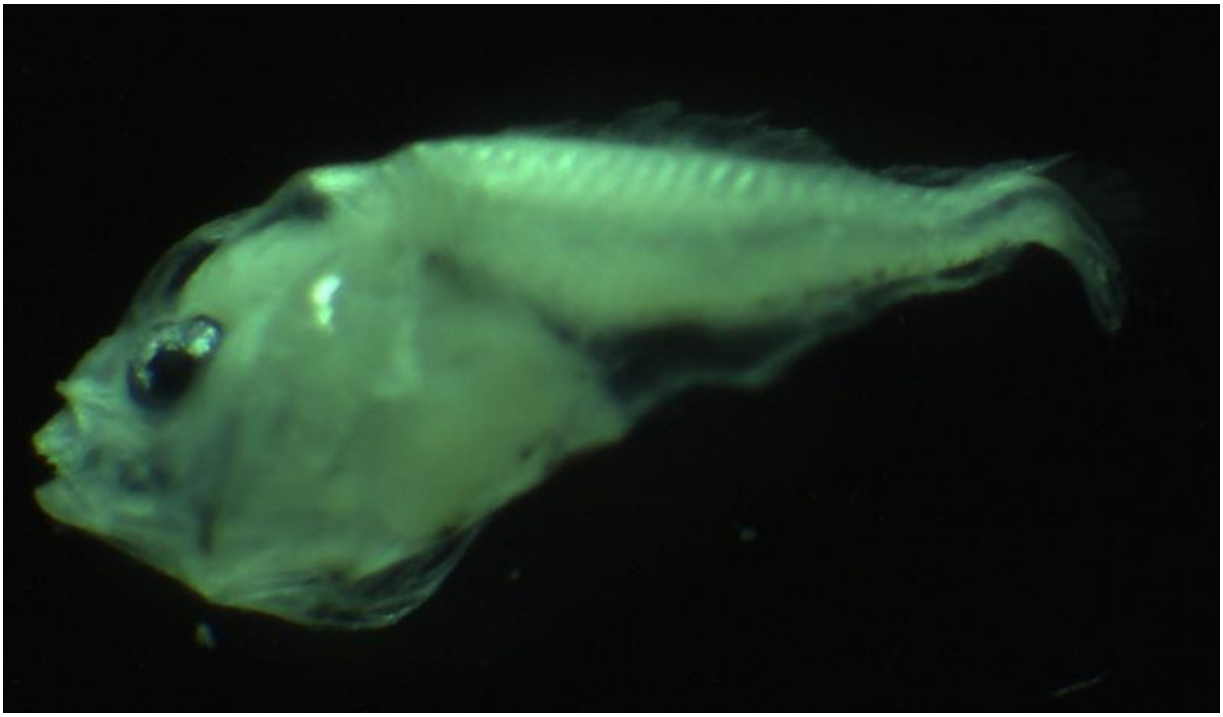


Figure 2.22: Lateral view of Haemulidae showing a deep and compressed body with large-hunch-backed head and pointed snout (TL: 6.70 mm; flexion).

Figure 2.23: Lateral view of Leiognathidae showing a large, deeply ovate head with a deep, compressed body (TL: 3.48 mm; preflexion).

2.3.9.12 Mugilidae

Larvae of Mugilidae were collected in low abundance at Pulau Sampadi (intertidal), Pulau Satang, Sungai Sibu Laut and Pantai Mukah. The larvae are at postflexion and juvenile growth stages with total length ranging from 4.70 mm to 20.82 mm (Figure 2.24). Mugilidae has a moderate and compressed body; moderate to large and round head; snout is short and slightly concave; oblique and nearly horizontal mouth that reaches to the anterior edge of the eye; eye is moderate to large and round; dorsal fin and anal fin form in the posterior half of the body; branching pigmentations occur throughout the body.

2.3.9.13 Ptereleotridae

Only one postflexion stage larva was recorded at Pulau Satang with a total length of 12.00 mm (Figure 2.25). The body of Ptereleotridae is elongate; caudal peduncle is short and of similar depth to the trunk and rest of the tail; head is small to moderate and rounded; snout is small and rounded that later become concave and pointed; mouth is moderately oblique and moderate in size that reaches nearly to the eye; eye is round and large but later become moderate.

Figure 2.24: Lateral view of Mugilidae showing moderate and compressed body with moderate and round head. The pigmentation can be seen throughout the body from the head to caudal but not on the fins (TL: 8.58 mm; postflexion).

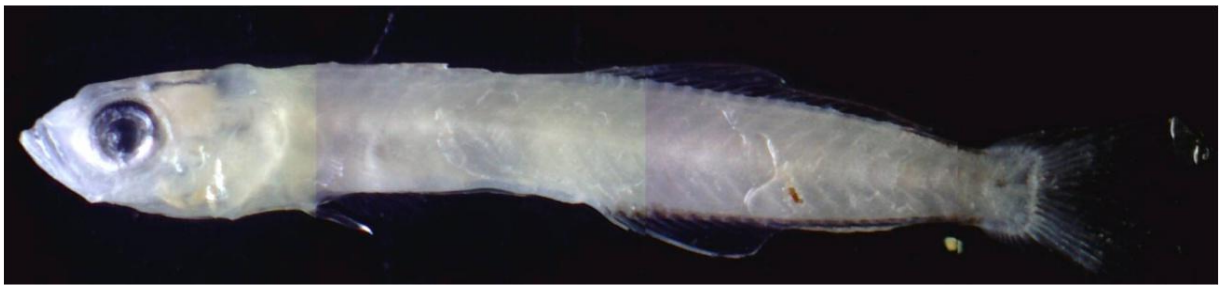


Figure 2.25: Lateral view of Ptereleotridae showing an elongate body with a short caudal peduncle (TL: 12.00 mm; postflexion).

2.3.9.14 Scatophagidae

Preflexion and postflexion larvae were collected at Sungai Sibu Laut and Sungai Salak with total length ranging from 1.72 mm to 11.62 mm, while one postflexion larva was collected at Pantai Mukah with a total length of 13.32 mm (Figure 2.26). Scatophagidae has a moderate body depth and ovate in cross section that later becomes deeper and compressed; head is large, deep and rounded; snout is blunt and uneven in profile; mouth is moderate that reaches to the anterior margin of the eye; eye is large to moderate and round in shape. Some specimen under this family was identified until genus, namely *Scatophagus*.

2.3.9.15 Sciaenidae

All three (preflexion, flexion and postflexion) growth stages larvae of Sciaenidae were collected at Sungai Sibu Laut, Sungai Salak and Pantai Mukah with total length ranging from 1.96 mm to 22.90 mm (Figure 2.27). Sciaenidae has a moderate and compressed body; large and round head; snout is short and moderate and somewhat triangular or round; mouth is large and oblique that reaches to the eye; eye is moderate and round.

2.3.9.16 Scombridae

Two individuals of Scombridae larvae were collected at Sungai Sibu Laut comprise one preflexion and one flexion growth stages with total length of 2.94 mm and 5.56 mm, respectively (Figure 2.28). The body of Scombridae is elongated to moderate in depth; head is large and rounded; mouth is moderate reaching to about the anterior edge of the eye; equal length of jaw with the upper jaw projects beyond the lower jaw; eye is round and moderate to large in size.

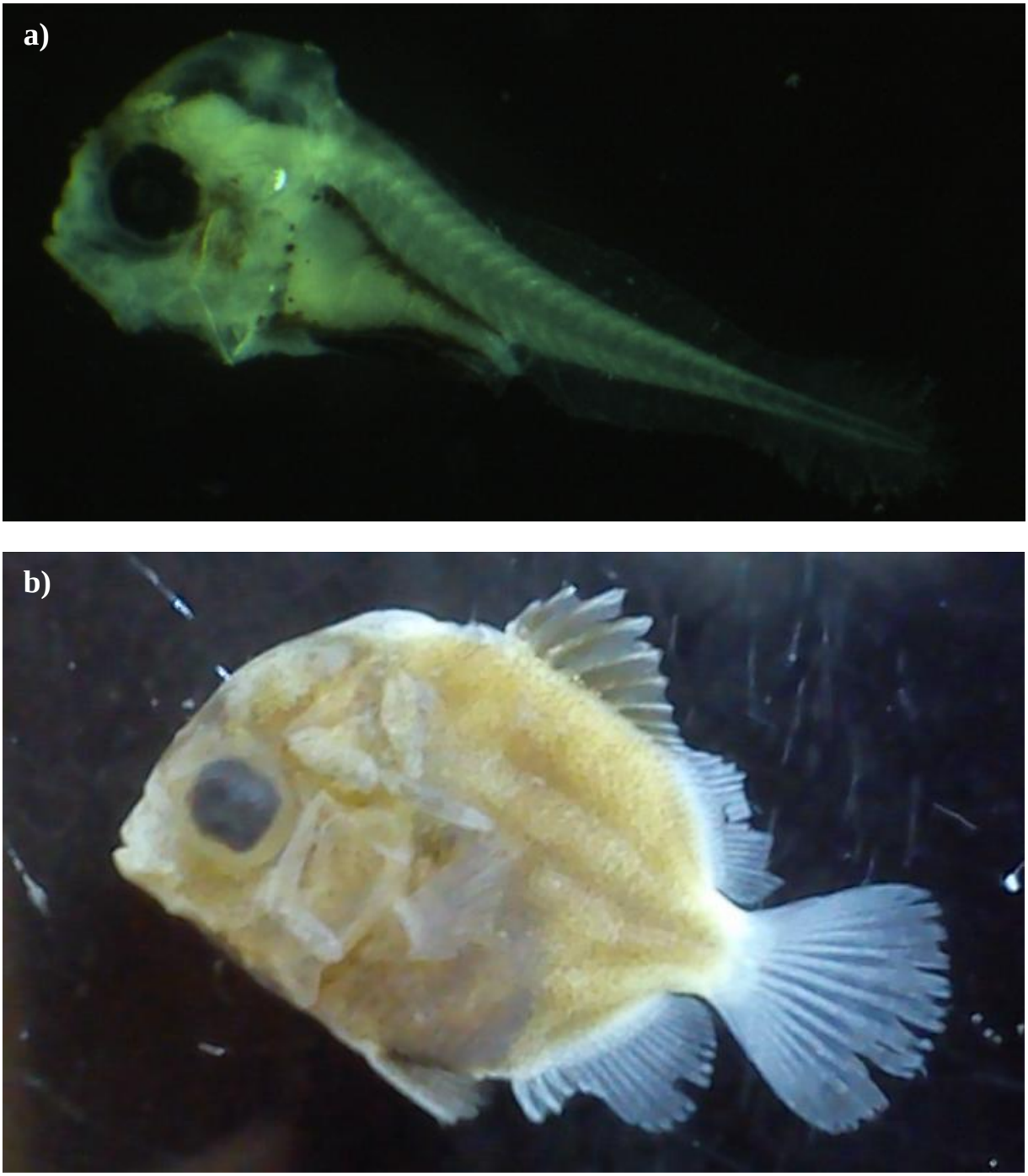


Figure 2.26: Lateral view of (a) preflexion larvae stage of Scatophagidae (*Scatophagus* sp.) showing a moderate body depth (TL: 1.82 mm) and (b) postflexion larvae stage of Scatophagidae (*Scatophagus* sp.) showing a deeper and compressed body (TL: 13.32 mm).

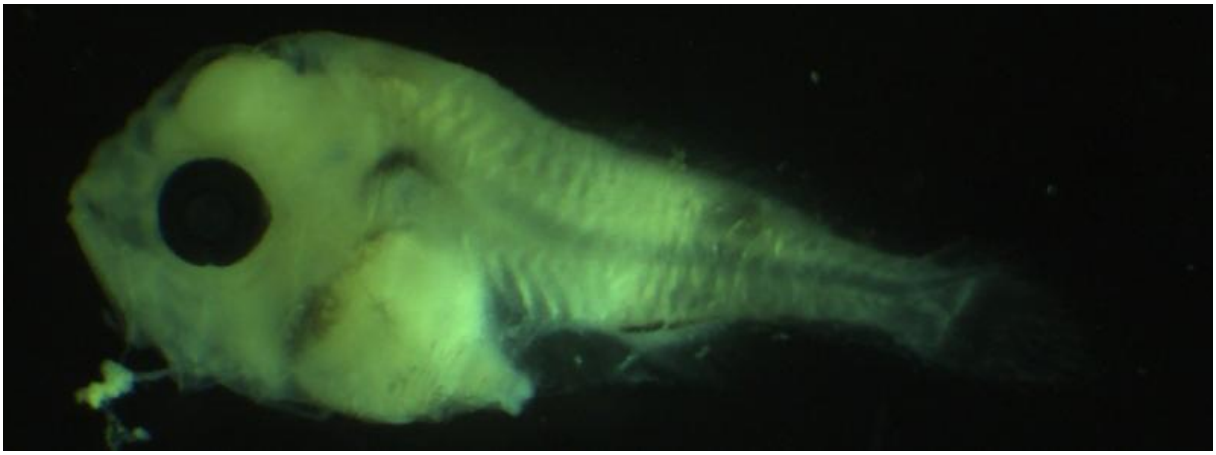


Figure 2.27: The body of Sciaenidae is moderate and compressed with a large and round head (TL: 8.02 mm; flexion).

Figure 2.28: A lateral view of Scombridae showing elongated body depth with large head and equal length protruded jaws (TL: 5.56 mm; flexion).

2.3.9.17 Serranidae

The Serranidae larvae collected at Pulau Sampadi (subtidal) and Sungai Sibu Laut are at preflexion and postflexion growth stages (Figure 2.29). The total length ranged from 1.34 mm to 8.00 mm. The body of Serranidae is moderate to deep and compressed; head is moderate to large, round and sloped in dorsal profile; snout is short to moderate and blunt; mouth is oblique that reaches to the mid eye or beyond it; eye is small to moderate and round; pigmentation at the ventral side of the body.

2.3.9.18 Sillaginidae

Only postflexion larvae were collected at Pantai Teluk Pandan, Pantai Puteri, Pulau Satang and Sungai Sibu Laut with total length ranging from 7.60 mm to 14.00 mm (Figure 2.30). The body of Sillaginidae is elongate and somewhat compressed; moderate size of head; snout is somewhat pointed and concave in profile; mouth is oblique that reaches to about the anterior margin of the eye; eye is moderate and round; lightly pigmented along the ventral midline of the trunk, tail and often on the head. Some specimen under this family was identified until genus, namely *Sillago*.

Figure 2.29: Lateral view of Serranidae showing a deep and compressed body with large, round and slope head in dorsal profile (TL: 1.78 mm; preflexion).

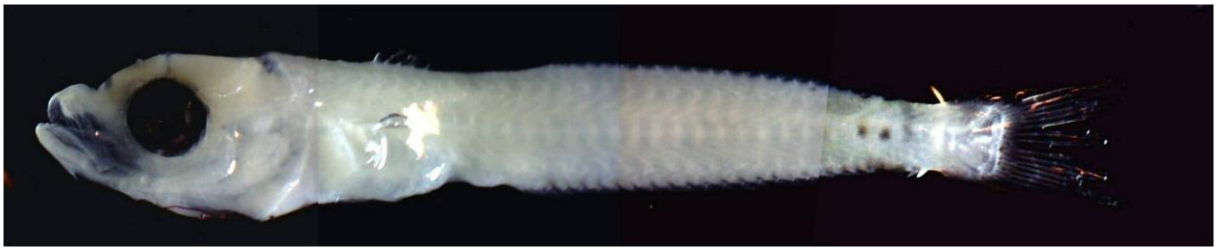


Figure 2.30: Lateral view of Sillaginidae (*Sillago* sp.) showing an elongate body with moderate size of head and little pigmentation at the edge of the caudal peduncle (TL: 14.00 mm; postflexion).

2.3.9.19 Terapontidae

Postflexion larvae and juvenile stages of Terapontidae were recorded at Pantai Rambungan, Pulau Satang and Pantai Mukah (Figure 2.31). Total length ranged from 13.00 mm to 25.22 mm. Terapontidae has an elongate to moderate and compressed body; moderate to large head; snout is short and slightly pointed; mouth is oblique that reaches to the anterior margin of the eye; eye is moderate to large and round; pigmentations occur in lines on the dorsal and lateral of the body. Some specimen under this family was identified until genus, namely *Terapon*.

2.3.9.20 Uranoscopidae

One preflexion larva of Uranoscopidae was recorded at Sungai Sibu Laut with a total length of 2.10 mm (Figure 2.32). Uranoscopidae has a large, very wide rounded head and trunk; deep, compressed tail; moderate to deep body which later elongate; snout is very short and blunt; mouth is oblique and large that reaches to mid pupil to beyond the eye; eye is moderate to large and round to slightly elongate.

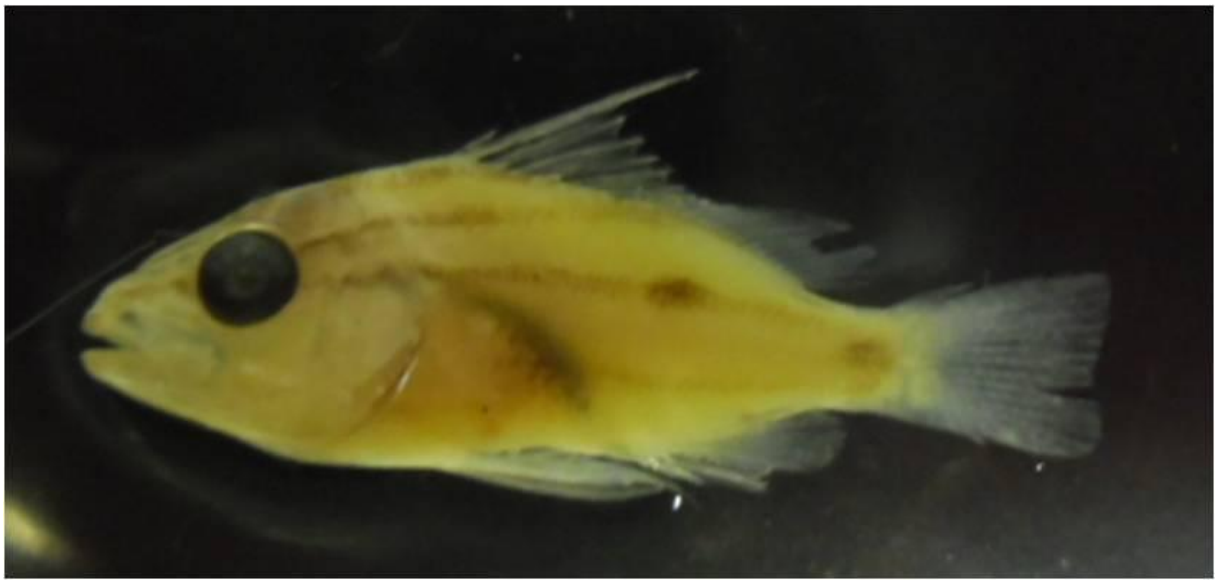


Figure 2.31: Lateral view of Terapontidae (*Terapon* sp.) showing an elongate, compressed body with moderate head and slightly pointed, short snout (TL: 25.08 mm; juvenile).

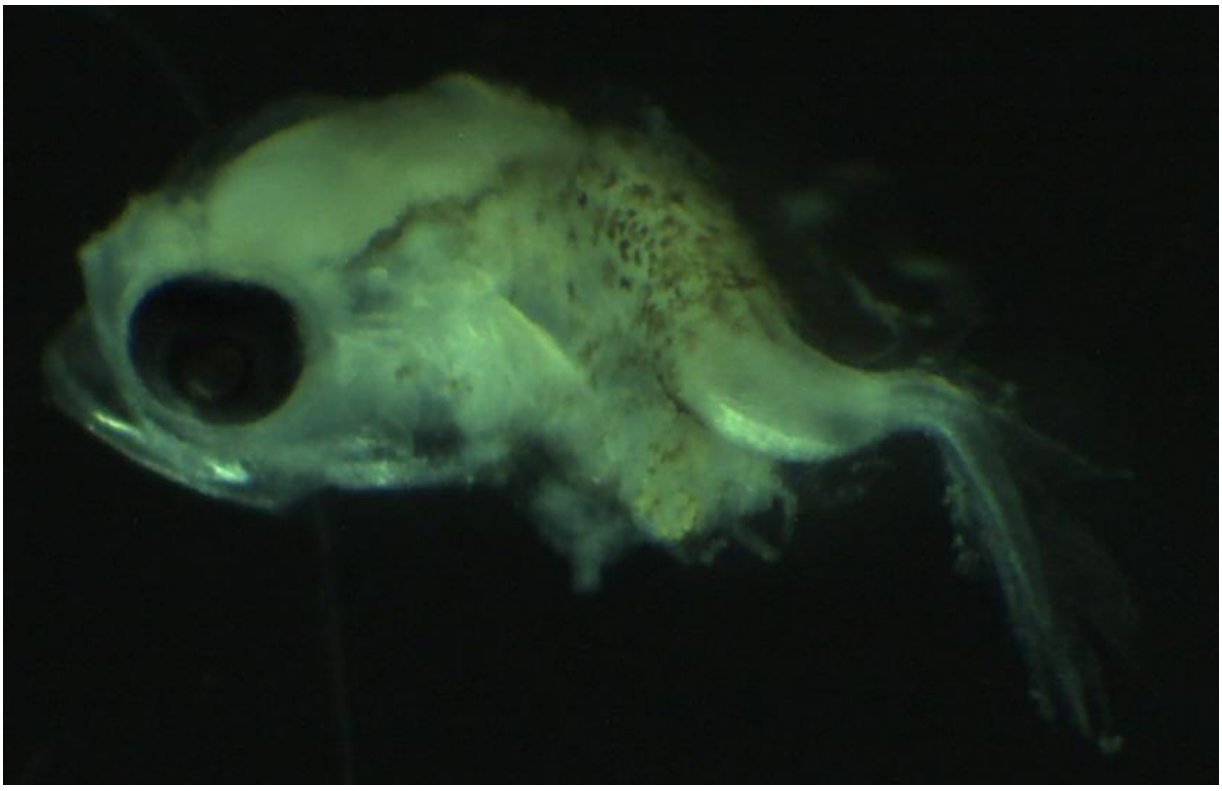


Figure 2.32: The large body of Uranoscopidae with a very wide rounded head, deep trunk and compressed tail (TL: 2.10 mm; preflexion).

2.3.10 Pleuronectiformes

Two families were recorded under Order Pleuronectiformes, namely Cynoglossidae and Paralichthyidae.

2.3.10.1 Cynoglossidae

The larvae of Cynoglossidae were recorded at Pulau Sampadi (subtidal), Sungai Sibu Laut and Sungai Salak. The larvae were observed to be at preflexion and flexion growth stages with total length ranging from 1.20 mm to 7.00 mm (Figure 2.33). Cynoglossidae has a slightly deep at the head and trunk; elongate to tapering at the tail; laterally compressed and bilaterally symmetrical body; head is small, round and deep; snout is short and convex; mouth is oblique to horizontal and terminal that reaches to the posterior margin of the eye or beyond it; eye is round and moderate with a small posterior projection and later the right eye migrate to the left body.

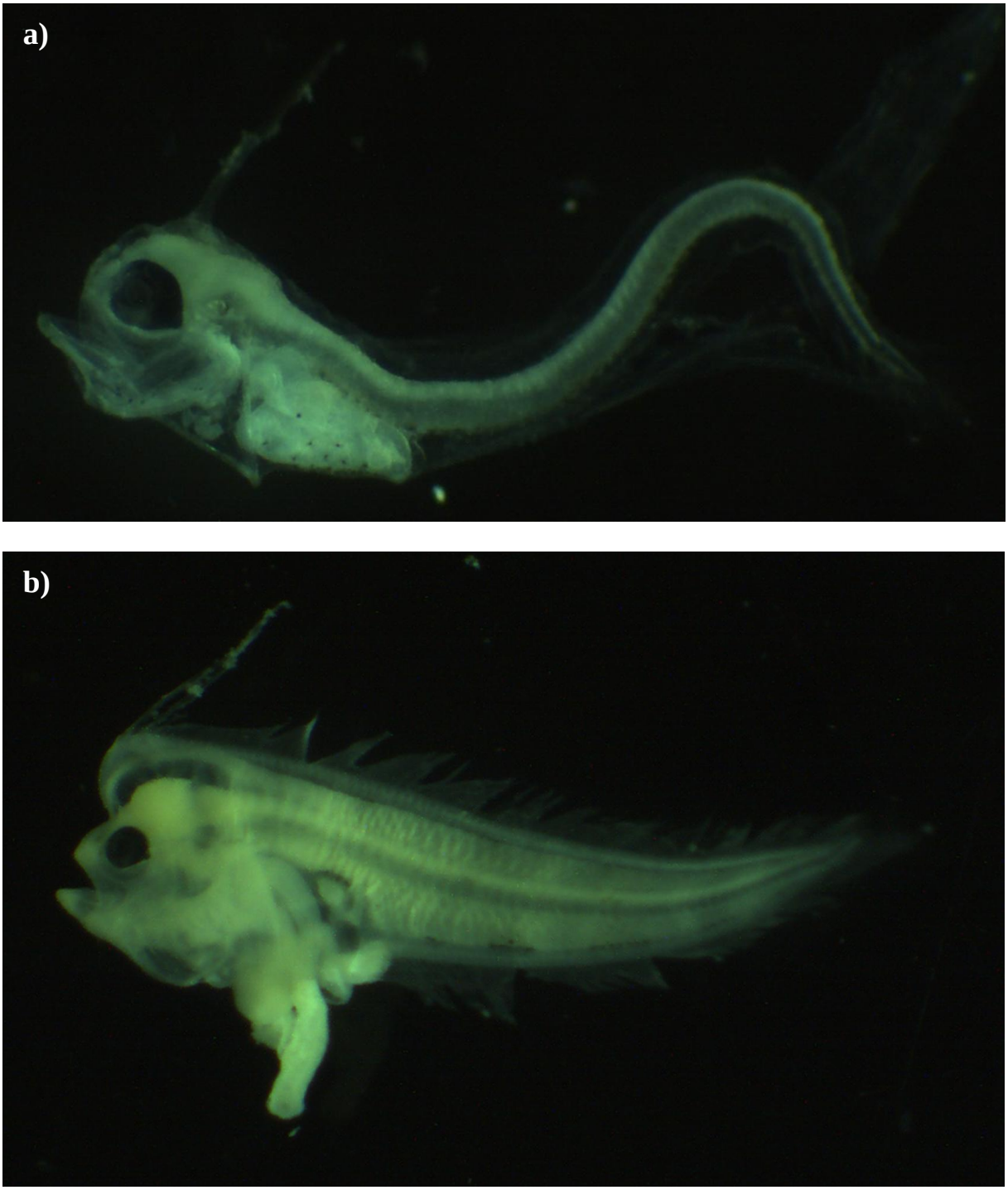


Figure 2.33: Lateral view of Cynoglossidae larvae during a) preflexion growth stage (TL: 2.64 mm) and b) flexion growth stage showing a bilaterally symmetrical body and a slightly deep at the head and trunk with elongate to tapering tail (TL: 5.88 mm).

2.3.10.2 Paralichthyidae

Only one flexion stage larva of Paralichthyidae was recorded at Sungai Sibu Laut with total length of 5.46 mm (Figure 2.34). Paralichthyidae has a moderate in depth and laterally compressed body; moderate with a steep dorsal profile head; snout is short angular; mouth is moderate to large and oblique that reaches to the mid eye; eye is moderate and round and the right eye will begins to move to the left side of the body upon growing. This single specimen was identified until genus, namely *Pseudorhombus*.

2.3.11 Scorpaenidae

2.3.11.1 Scorpaenidae

Scorpaenidae is the only family found under Order Scorpaeniformes throughout the sampling period. A few larvae collected at Pulau Sampadi (subtidal), Sungai Sibu Laut and Sungai Salak are at preflexion and flexion growth stages with total length ranging from 2.04 mm to 6.68 mm (Figure 2.35). The body of Scorpaenidae is moderate and laterally compressed; moderate and round or triangular head; snout is relatively short and steep or long and triangular; mouth is oblique that reaches to or beyond the mid eye; eye is moderate to large and round; enlarged fan-shaped pectoral fin.

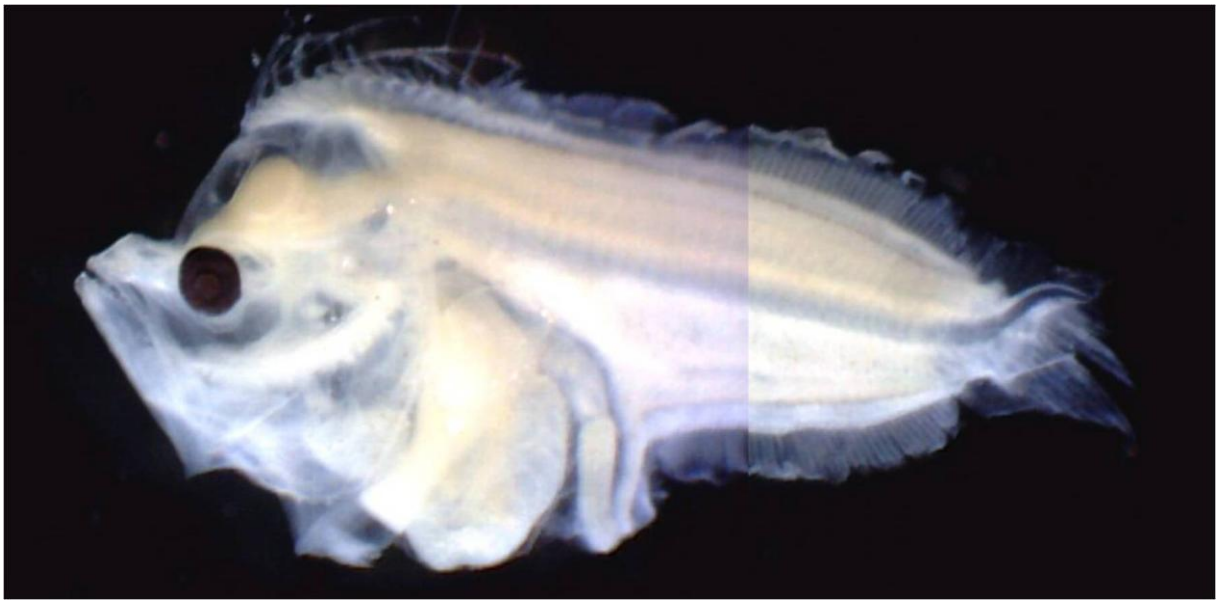


Figure 2.34: Lateral view of Paralichthyidae (*Pseudorhombus* sp.) showing moderate in depth and laterally compressed body with a steep dorsal profile head (TL: 5.46 mm; flexion).

Figure 2.35: Lateral view of Scorpaenidae showing a compressed body with round triangular head and large fan-shaped pectoral fin (TL: 5.92 mm; flexion).

2.3.12 Syngnathiformes

2.3.12.1 Syngnathidae

Syngnathidae is the only family recorded under Order Syngnathiformes throughout the sampling period at Sungai Sibu Laut and Sungai Salak (Figure 2.36). The total length ranged from 5.72 mm to 42.50 mm. The head of Syngnathidae is small; snout is longer than the distance between the posterior margin of the eye and the middle of the pectoral fin base; tail excluding the caudal fin longer than the trunk. The growth stage of this family could not be determined because no information is available in literature.

2.3.13 Tetraodontiformes

Throughout this study, three families were recorded under this order, namely Balistidae, Monacanthidae and Tetraodontidae.

2.3.13.1 Balistidae

Only one postflexion larva of Balistidae was collected at Pulau Sampadi (subtidal) with a total length of 13.20 mm (Figure 2.37). Balistidae has a deep, ovate and laterally compressed body; slender tail; head and gut are covered by spinule-like scales; head is large and round; snout is short and round to steep; mouth is small and terminal that reaches to the eye; eye is round and large.

Figure 2.36: Lateral view of Syngnathidae showing a small head and a tail longer than the trunk (TL: 10.26 mm).

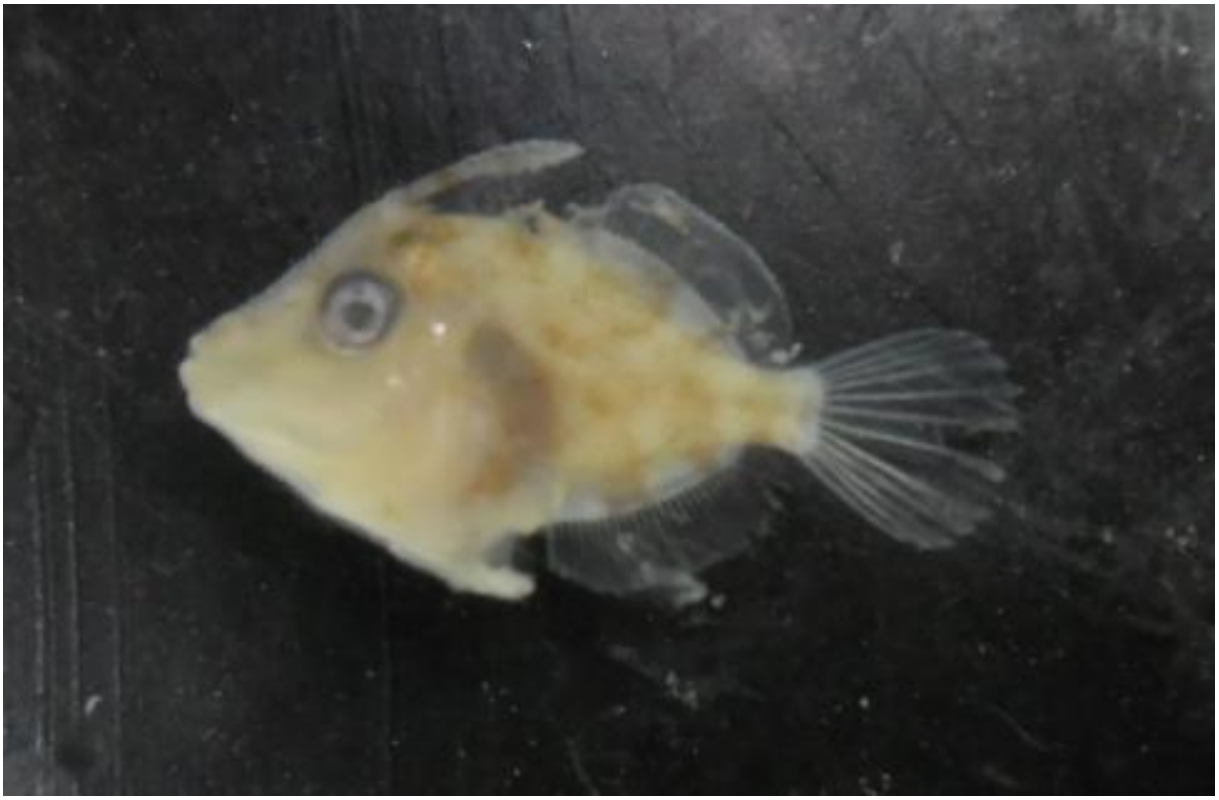


Figure 2.37: Lateral view of Balistidae showing a deep, ovate and compressed body with head and gut covered by spinule-like scales (TL: 13.20 mm; postflexion).

2.3.13.2 Monacanthidae

Preflexion larvae of Monacanthidae were collected at Pulau Sampadi (subtidal) and Sungai Sibu Laut with total length ranging from 2.04 mm to 3.28 mm (Figure 2.38). Monacanthidae has an elongate to deep and laterally compressed body; small papillae cover or extend on the body; head is moderate to large and round to triangular; snout is moderate and steep to round in dorsal profile; mouth is small and terminal that does not reach to the eye due to elongation of the snout; eye is round and large to moderate in size.

2.3.13.3 Tetraodontidae

Most of the Tetraodontidae larvae collected at Sungai Sibu Laut and Sungai Salak are at preflexion stage, while a few are at flexion and postflexion stages (Figure 2.39) with total length ranging from 1.58 mm to 8.94 mm. The body of Tetraodontidae is moderate to deep; ovoid trunk; slender, tapered tail. Later, the head and trunk become more robust and the larvae are capable of inflation; body width is less than body depth; head is moderate to large and ovoid to rotund; snout may be short and round or slightly elongate; mouth is small and does not reach to the anterior edge of the eye; round and large to very large eye.

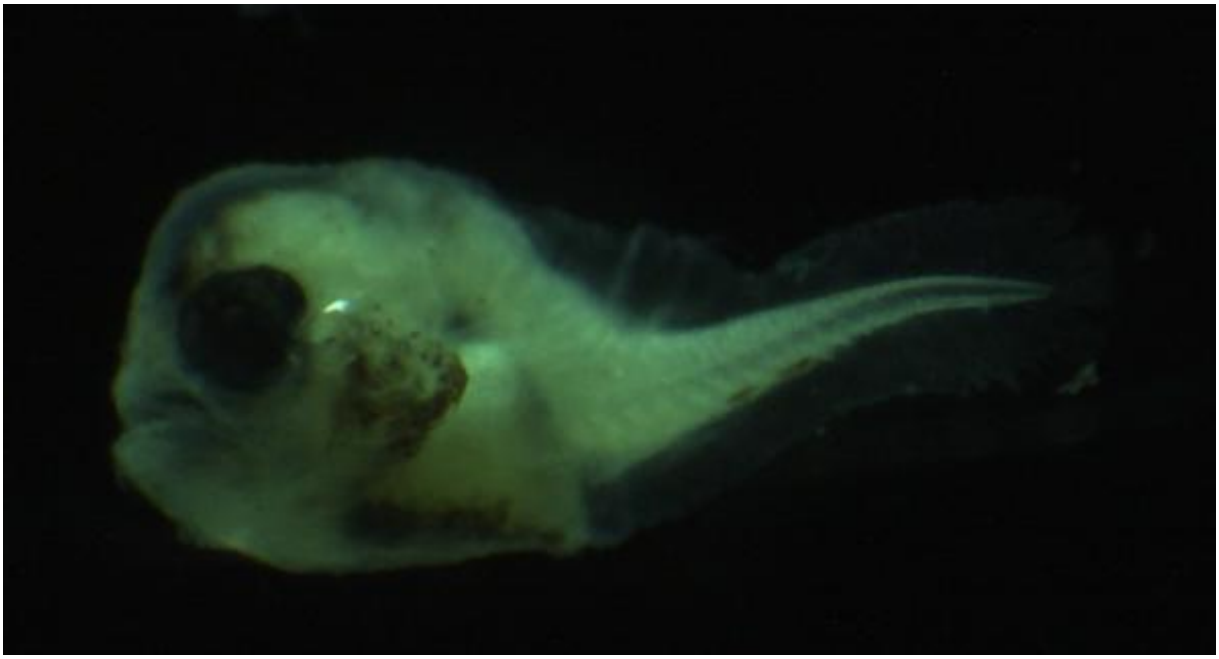


Figure 2.38: Lateral view of Monacanthidae showing deep and compressed body with a large and round head (TL: 2.04 mm; preflexion).

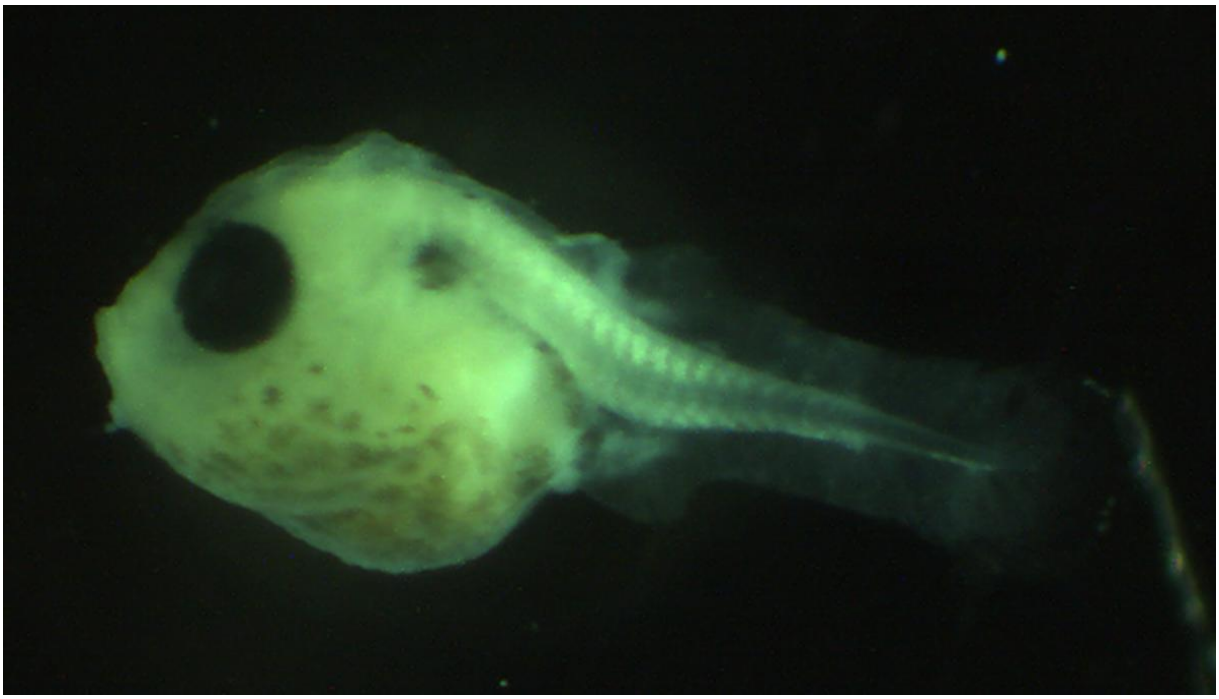


Figure 2.39: Lateral view of Tetraodontidae showing a deep body with ovoid trunk and a slender, tapered tail (TL: 2.10 mm; preflexion).

2.3.14 Fish Eggs

A total of 31,566 fish eggs were collected throughout the sampling period that can be classified into two general shapes: spherical and elliptical (Figure 2.40), where both of them collected from Sungai Sibu Laut-Sungai Salak estuaries.

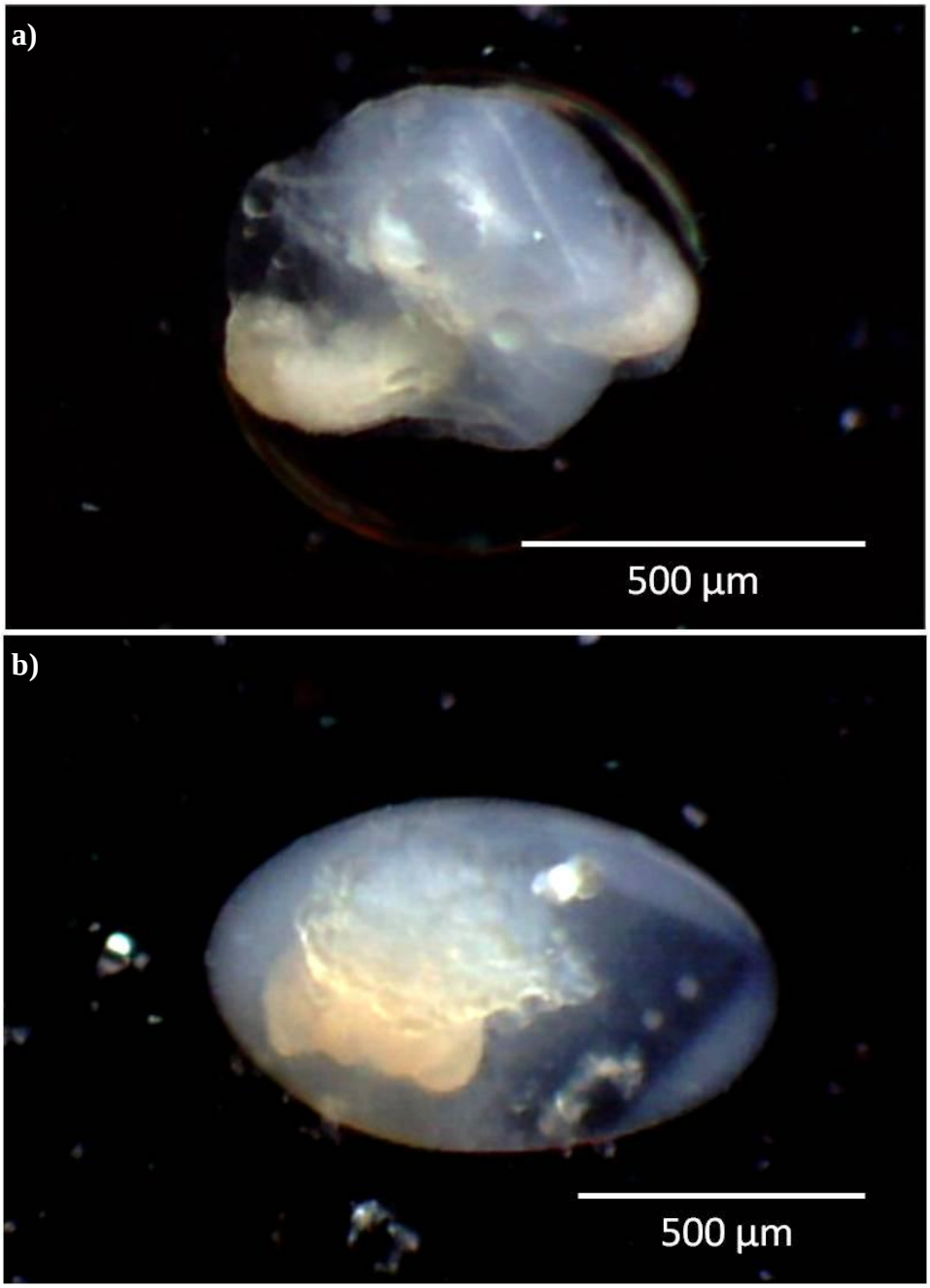


Figure 2.40: Shapes of fish eggs collected from Sungai Sibu Laut-Sungai Salak estuaries that were classified as a) spherical and b) elliptical.

2.4 Discussion

Overall, a total of 38 families were recorded throughout the sampling period which contributes to 60.30% of total Malaysia fish larvae record so far. Almost 53% of the fish larvae family was recorded under the order Perciformes. The number of fish larvae family found in this study is higher than the collections from 23 estuaries along Sabah and Sarawak that recorded 26 families (Blaber *et al*., 1997). On the other hand, the recent short survey at western part of Sarawak waters that has a few similar sampling sites recorded 19 families (Muhamad and Rahim, 2013). Other studies that were carried out in Malaysian waters recorded less than this (Table 2.3). For examples, 21 families were recorded at Sungai Pulai estuary, Johor (Ara *et al*., 2011a; 2011c) and 19 families were recorded at Sungai Pendas estuary, Johor (Arshad *et al*., 2012). In total, the above studies recorded 24 families from Johor waters. In addition, another study conducted at the east coast off Pulau Payar Marine Park, Kedah recorded 18 families of fish larvae (Mohamad-Norizam and Ali, 2009).

In comparison to the short survey at western part of Sarawak waters, three families namely Belonidae, Elopidae and Priacanthidae were not discovered in this study. Blaber *et al*. (1997) did not specify the exact location of each family recorded in Sarawak estuaries, but the five major families (Clupeidae, Engraulidae, Gobiidae, Sciaenidae and Tetraodontidae) found in that study were also recorded in this study. To date, 41 families of fish larvae were recorded from the Sarawak coastal waters with 14 new families recorded in Malaysian waters namely Acropomatidae, Balistidae, Centrolophidae, Chanidae, Exocoetidae, Haemulidae, Megalopidae, Muraenidae, Paralichthyidae, Pristigasteridae, Ptereleotridae, Scombridae, Scorpaenidae and Serranidae. In addition, 16 families of fish larvae are new records for Sarawak waters only, namely Acropomatidae, Balistidae, Centrolophidae, Chanidae,

Exocoetidae, Haemulidae, Megalopidae, Muraenidae, Paralichthyidae, Pristigasteridae, Ptereleotridae, Scatophagidae, Scombridae, Scorpaenidae, Serranidae and Uranoscopidae.

According to the comparison above, the similarity and differences in term of fish larvae family recorded between current study and the previous studies did not find out which sampling sites are more diverse compared to others but it is basically to update the checklist of fish larvae family that are recorded in Malaysian waters. Besides, the sampling approaches and characteristics of the site chosen were varied between each study might contributed to the differences.

Table 2.3: Comparison of family recorded between this study and other published articles that involved Malaysian waters.

	Family	This Study	Western part of Sarawak Survey	Sabah & Sarawak	Johor	Kedah
1	Acropomatidae	+				
2	Ambassidae	+	+	+	+	+
3	Apogonidae	+		+		+
4	Apolectidae			+		
5	Ariidae			+		
6	Atherinidae	+		+		+
7	Balistidae	+				
8	Belonidae		+		+	
9	Blenniidae	+	+	+	+	
10	Bothidae					+
11	Bregmacerotidae					+
12	Callionymidae	+	+			
13	Carangidae	+	+	+	+	+
14	Centrolophidae	+				
15	Chanidae	+				
16	Clupeidae	+	+	+	+	+
17	Cynoglossidae	+		+	+	+
18	Eleotridae			+		
19	Elopidae		+			
20	Engraulidae	+	+	+	+	
21	Exocoetidae	+				
22	Gerreidae	+	+			
23	Gobiidae	+	+	+	+	+

Table 2.3 continued

24	Haemulidae	+				
25	Harpadontidae			+		
26	Hemiramphidae	+	+	+	+	
27	Leiognathidae	+	+		+	+
28	Lutjanidae			+		+
29	Megalopidae	+				
30	Monacanthidae	+	+		+	
31	Monodactylidae				+	
32	Mugilidae	+		+		+
33	Mullidae				+	
34	Muraenidae	+				
35	Myctophidae	+	+			
36	Nemipteridae				+	+
37	Ostraciidae			+		
38	Pangasiidae			+		
39	Paralichthyidae	+				
40	Polynemidae			+		
41	Pomacentridae					+
42	Priacanthidae		+			
43	Pristigasteridae	+				
44	Ptereleotridae	+				
45	Rachycentridae				+	
46	Samaridae				+	
47	Scatophagidae	+			+	
48	Sciaenidae	+		+		+
49	Scombridae	+				
50	Scorpaenidae	+				
51	Serranidae	+				
52	Siganidae			+		+
53	Sillaginidae	+	+		+	
54	Sphyraenidae				+	+
55	Syngnathidae	+	+	+	+	
56	Synodontidae	+		+		
57	Terapontidae	+	+		+	+
58	Tetraodontidae	+	+	+		
59	Toxotidae				+	
60	Triacanthidae				+	
61	Trichiuridae			+		
62	Triglidae			+		
63	Uranoscopidae	+			+	
	Total Family	38	19	26	24	18
	Source		Muhamad and Rahim (2013)	Blaber *et al*. (1997)	Ara *et al*. (2011a; 2011c) and Arshad *et al*. (2012)	Muhamad-Norizam and Ali (2009)

From 38 families recorded in this study, the growth stage of two families (Muraenidae and Syngnathidae) cannot be determined due to unique characteristic of their tail structure. Most identification books only describe the length measurements of these two families and their maturity in adult stage. Besides, Matić-Skoko *et al*. (2011) reported that Muraenidae has a long larval retention period which is around one year, making it hard to determine the growth stage during larval period. In adult fishes of both Muraenidae and Syngnathidae, analyses of otoliths are commonly used to determine the age (Campbell and Able, 1998; Matić-Skoko *et al*., 2011).

Some fish families showed different morphological features at each larval growth stage. Among the fish families found in this study, this was observed in Scatophagidae and Cynoglossidae larvae. On the other hand, Clupeidae and Engraulidae that belong to the Order Clupeiformes shared very similar morphological characteristics during their preflexion and flexion stages, but these two families can be differentiated according to the location of dorsal and anal fins anlagen (Figure 2.41). Although myomeres count is normally used to differentiate these two families, it is not performed in this study because myomeres cannot be seen clearly under stereomicroscope. Specimens of other families that comprised all three growth stages showed similar morphological features from preflexion to postflexion stage. Therefore, only a single specimen was presented to represent those families. For families that consist of only one individual, the differences in morphology according to growth stage were not mentioned even though they have different morphological descriptions according to the guide books.

Figure 2.41: Preflexion larva of Engraulidae showing the location of dorsal fin anlage (A) and anal fin anlage (can be identified at the end of the gut) (B).

A few families of fish larvae recorded were able to be determined until genus and species with the help from the expert, Professor Dr. Izumi Kinoshita. Some of them were chosen as representative figures for each family described above while others were presented in the Appendix 1. These identified genera and species were compared with the data from published articles on the adult fishes in Sarawak waters and nearby coastal areas that are located within South China Sea (SEAFDEC, n.d.; Blaber, 1997; Blaber *et al*., 1997; Vidthayanon, 1998; Leh, 2000; Parenti and Lim, 2005; Nyanti *et al*., 2012a; Nyanti *et al*., 2012b; Nyanti *et al*., 2014; Nyanti and Bolhen, 2015) that were presented in Table 2.4. It is found that only *Omobranchus* and *Kaiwarinus* were not reported from the articles. However, *Omobranchus* sp. was recently reported in Johor Strait, Johor (Ara *et al*., 2016) while *Kaiwarinus* is a further division of the genus *Carangoides* (Konishi *et al*., 2012) which is probably being used by the expert to identified the fish larvae.

Table 2.4: List of possible genera under the family of fish larvae that were identified throughout this study.

Order	Family	Possible Genera
Anguilliformes	Muraenidae	*Gymnothorax, Encheloycore, Strophidon, Uropterygius*
Atheriniformes	Atherinidae	*Hypoatherius*
Aulopiformes	Synodontidae	*Harpadon*
Beloniformes	Exocoetidae	*Cypselurus*
	Hemiramphidae	*Hemiramphus, Rhynchorhampus*
Clupeiformes	Clupeidae	*Anodontostoma, Amblygaster, Dussumieria, Sardinella, Opisthopterus, Tenualosa*
	Engraulidae	*Coilia, Encrasicholina, Lycothrissa, Setipinna, Stolephorus, Thryssa*
	Pristigasteridae	*Ilisha*
Elopiformes	Megalopidae	*Megalops*
Gonorynchiformes	Chanidae	*Channa, Chanos*
Myctophiformes	Myctophidae	*Diaphus*
Perciformes	Acropomatidae	*Acropoma, Malakichthys, Synagrops*
	Ambassidae	*Ambassis*
	Apogonidae	*Apogon, Rhapdamia, Sphaeramia*
	Blenniidae	*Xiphasia*
	Callionymidae	*Bathycallionemus*
	Carangidae	*Alectes, Alepes, Atropus, Atule, Carangoides, Caranx, Decapterus, Gnathanodon, Megalaspis, Paratromateus, Pseuocaranx, Scombroides, Selar, Selaroides, Seriolina, Uraspis*
	Centrolophidae	*Psenopsis*
	Gerreidae	*Gerres*
	Gobiidae	*Apocryptodon, Bathygobius, Glossogobius, Gobiopterus, Pandaka, Parapocryptes, Periopthalmus, Priolepis, Trypauchen*
	Haemulidae	*Diagramma, Hapalogenys, Pomadasys*
	Leiognathidae	*Gazza, Leiognathus, Secutor*
	Mugilidae	*Liza, Mugil, Valamugil*
	Ptereleotridae	*Nemateleotris, Parioglossus, Ptereleotris*
	Scatophagidae	*Scatophagus*
	Sciaenidae	*Chrysochir, Johnius, Larimichthys, Nibea, Otolithes, Paranibea, Pennahia, Protonibea*
	Scombridae	*Auxis, Katsuwonus, Rastelliger, Scomber, Scomberomorus*
	Serranidae	*Cephalopholis, Epinephelus, Plectanthius, Plectopoma, Pseudanthius*
	Sillaginidae	*Sillago*
	Terapontidae	*Terapon*
	Uranoscopidae	*Uranoscopius*
Pleuronectiformes	Cynoglossidae	*Cynoglossus*
	Paralichthyidae	*Pseudorhombus*

Table 2.4 continued

Scorpaeniformes	Scorpaenidae	*Brachypterois, Choridactylus, Cottapistus, Inimiscus, Minous, Pterois, Scorpaenodes, Scorpaenopsis, Synanceja, Vespicula*
Syngnathiformes	Syngnathidae	*Doryichthys*
Tetraodontiformes	Balistidae	*Abalistes, Balistoides, Odonus, Sufflumen*
	Monacanthidae	*Acreichthys, Aluterus, Anacanthus, Chaetoderma, Paramonacanthus, Pseudoalutarius, Thamnaconus*
	Tetraodontidae	*Arothron, Canthigaster, Chelonodon, Chonerhinos, Lagocephalus, Tetraodon, Torquigener, Xenopterus*

The total length of fish larvae that was measured individually for each family showed overlapping values between growth stages which were observed in Acropomatidae, Callionymidae, Carangidae, Clupeidae, Engraulidae, Gobiidae and Pristigasteridae. Even within each growth stage, the length of fish larvae varied in a single sample collected. This is probably due to different species occurrence under the same family or it might be influenced by their diet, food availability or influenced from the changes in water body. It was reported that the growth of fish larvae is influenced by the changes in physico-chemical water parameters such as temperature, dissolved oxygen, pH, turbidity and salinity (Petereit *et al*., 2009; Rhody *et al*., 2010; Ye *et al*., 2010).

Among the 38 families obtained in this study, 14 families are classified as commercially important fish based on commercial fish species listed by Ismail (1992) namely Balistidae, Carangidae, Clupeidae, Cynoglossidae, Engraulidae, Gerreidae, Leiognathidae, Megalopidae, Mugilidae, Sciaenidae, Scombridae, Serranidae, Sillaginidae and Synodontidae. Majority of them were collected at two or more sampling sites chosen in this study and at their preflexion stage suggesting that they are still available and able to survive in Sarawak coastal waters (Marchetti and Moyle, 2000).

Based on the 30 identified fish larvae families, 27 families were reported to have spherical shaped eggs, while another three families have elliptical shaped eggs. Among the families that have spherical shaped eggs, three of them are known to practice parental care for their eggs, namely Apogonidae, Blenniidae and Monacanthidae (Neira, 1991; Vagelli, 1999; Jonna, 2004; Nakazono and Kawase, 1993) and one family (Scorpaenidae) is known as ovoviviparous fish (Yu *et al*., 2015). For the three families that have elliptical shaped eggs (Engraulidae, Gobiidae and Syngnathidae), only Gobiidae and Syngnathidae are known to practice parental care for their eggs (Coleman, 1991; Privileggi *et al.,* 1997). Therefore, this suggests that all elliptical shaped eggs probably belong to Engraulidae. However, it is not conclusive evidence because no detail morphological description was conducted on the fish eggs.

The selected sampling sites in this study have different habitat characteristics such as intertidal zone, seagrass beds, mangrove area, coral reef, rocky shore and estuaries which are known to be suitable habitats as nursery ground of most fishes (Breitburg *et al*., 1995; Baran, 2002; Anand and Pillai, 2005; Ara *et al*., 2011a). However, the observation of fish larvae according to the habitat characteristics will be discussed in the following chapters. The detail findings about the spatial family distribution of fish larvae will be discussed in Chapter 3, while spatio-temporal pattern of fish larvae and fish eggs at Sungai Sibu Laut-Sungai Salak estuaries will be discussed in Chapter 4.

2.5 Conclusion

Overall, 38 families were recorded and majority of the families are listed under Order Perciformes. In this study, 14 families of fish larvae are new records for Malaysian waters, while 16 families are new records for Sarawak waters. The morphological description of fish larvae under each family that were briefly described can be use as guideline for future identification purposes. However, detail information on the morphology is still needed in order to make a proper documentation. More works need to be done in order to describe the anatomy of fish eggs for the identification purposes. The genera listed could indicate the specific type of fish that might use the selected sampling sites in this study as breeding or spawning ground as the fish larvae were only identified until family. Therefore, a specific study could be made for the specific type of fish in the future. More than one third of the total family recorded are identified as commercially important fish family for Malaysian waters and a few of them have been recorded at more than half of the sampling sites namely Clupeidae, Engraulidae and Gerreidae. The selected sampling sites in this study are proven to hold ichthyoplankton. However, further research is needed to assess the situation and the condition of both sampling sites and ichthyoplankton. This study had shed some useful information about the ichthyoplankton in Sarawak waters in term of morphology and distribution that could be use as baseline data for future ichthyoplankton study in Malaysian waters.

CHAPTER 3

SPATIAL ASSEMBLAGES OF FISH LARVAE AT SELECTED COASTAL WATERS OF SARAWAK

3.1 Introduction

Fish larvae are the newly hatched fish eggs, which are part of ichthyoplankton. Most larval fishes tend to occupy the habitat with high food availability, low predation rate and stable ocean condition for growth (Freitas and Muelbert, 2004). Habitats that usually fulfill these requirements are seagrass beds, estuaries, littoral areas and reef habitats where the water is generally shallow and the larger predators will tend to avoid such environments (Breitburg *et al*., 1995; Baran, 2002; Anand and Pillai, 2005; Ara *et al*., 2011a; Ara *et al*., 2011b).

The presence of fish larvae can be an indicator of the health of aquatic environment as fish will use this area as spawning ground (Chamchang and Chayakul, 2000; Freitas and Muelbert, 2004) and suitable for their recruitment (Arkhipov, 2009). Ichthyoplankton survey is a way of generating fishery-independent stock assessment and key component in understanding function of marine ecosystem (Moser and Smith, 1993). Knowledge about larval stages including their dispersal and settlement events are important to ensure the consistent stock recruitment in improving the management of local fisheries (Baran, 2002).

Intertidal zone is known as marine shoreline which is exposed to air during low tide and submerged under seawater during high tide, causing regular changes in its environmental condition. Even with such condition, there are still some species that can tolerate and live their entire life there while others just occupy that area at certain stage of their life (Gibson, 1982). In term of fish, some species were categorised as resident and transient species. Resident fish or called as intertidal fish fully occupy intertidal zone throughout their life cycle, while transient fish occupy intertidal zone mostly during their planktonic larval stage

and move to other places later on. This type of fish is also known as tidal visitor (Gibson, 1982).

Even though intertidal area which is known to have constant changes in its environmental condition, fish larvae can still be found in that area. In Malaysia, there is not much information that can be obtained about fish larvae at intertidal zone. Most available data were collected at subtidal area and offshore (Muhamad-Norizam and Ali, 2009; Ara *et al*., 2011a; Ara *et al*., 2011c). The only information available on intertidal fish larvae is a survey done by Muhamad and Rahim (2013). Therefore, it is timely to obtain current information on assemblages of fish larvae at intertidal areas of Sarawak coastal waters.

The main objective of this study was to obtain spatial composition and abundance of fish larvae at selected intertidal areas of Sarawak coastal waters. The second objective of this study was to observe similarities and differences between fish larvae assemblages from two different zones (intertidal and subtidal) of Pulau Sampadi.

3.2 Materials and Methods

3.2.1 Sampling Sites

A total of six sampling sites were chosen along shoreline areas of Sarawak from April 2012 until March 2013 (Figure 3.1). Each sampling site has a different characteristic that was explained earlier in Chapter 2 (Table 2.1) that causes the differences in the number of replicates (Table 3.1). However, the data collected was standardised using catch per unit effort (CPUE) which will be explained further in data analyses.

Table 3.1: List of sampling sites, dates of sample collection, sampling area and number of replicates. Pantai = beach; Pulau = island.

Sampling Site	Date of Collection	Sampling Zone	Number of Replicates
Pantai Teluk Pandan	April 2012	Intertidal	5
Pantai Rambungan	May 2012	Intertidal	5
Pantai Puteri	May 2012	Intertidal	7
Pulau Sampadi	July 2012	Subtidal	5
	November 2012	Intertidal	8
Pulau Satang	September 2012	Intertidal	8
Pantai Mukah	March 2013	Intertidal	5

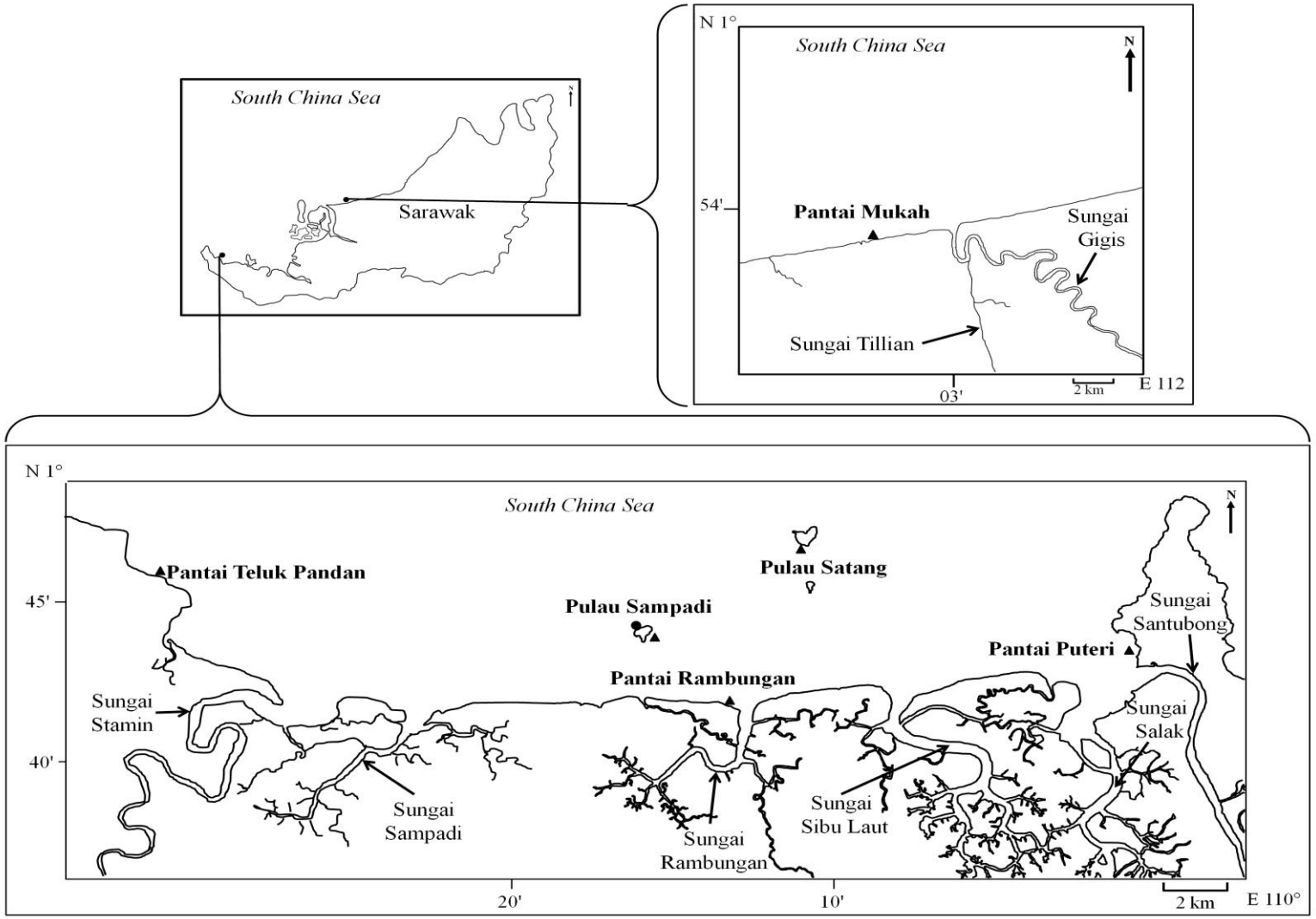


Figure 3.1: The location of six sampling sites is indicated by triangle for intertidal zone and one circle for subtidal sampling at Sampadi Island. Pantai = beach; Pulau = island; Sungai = river.

3.2.2 Sample Collection

Fish larvae were collected using a modified seine net with bag (about 4 m × 1 m area; 1 mm mesh size), pulled by two people along the intertidal zone for about two minutes with normal walking speed (Brazner, 1997). The bottom of the net was maintained as close as possible to the floor during sample collection. In order to make comparison between intertidal and subtidal fish larvae at Pulau Sampadi, a plankton net (one metre opening diameter; 0.5 mm mesh size) was towed obliquely by boat for about 10 minutes (Muhamad-Norizam and Ali, 2009 at subtidal zone of Pulau Sampadi.

All samples were then preserved in the field using 10% buffered formalin seawater and later transferred into 75% ethanol upon sorting in the laboratory. During sampling, water physico-chemical parameters were recorded *in-situ*: water temperature and dissolved oxygen were recorded using multiprobe (Eu-Tech Cyberscan 600 PCD650), while water turbidity and salinity were recorded using turbidity meter (Eu-Tech TN100) and salinometer (Milwaukee MA887), respectively. However, no water parameter data were recorded for Pulau Satang and subtidal zone of Pulau Sampadi, while no dissolved oxygen reading for Pantai Teluk Pandan and no salinity reading for Pantai Mukah due to technical problem.

3.2.3 Data Analyses

The identification was done and was described in Chapter 2. Samples collected from all intertidal zones were standardised using CPUE by calculating number of individuals per replicate (Marchetti and Moyle, 2000). The abundance of fish larvae according to family at each sampling site was expressed in percentage. The assemblage of fish larvae was expressed using Shannon-Wiener diversity index (Shannon and Weaver, 1963), Pielou's evenness index (Pielou, 1966) and Margalef richness index (Margalef, 1958). The equations were shown in

Appendix 2. Two way ANOVA with post-hoc Tukey test (p=0.05) was used to compare mean physico-chemical water parameters among sampling sites. The relationships between intertidal fish larvae family abundance and water parameters (temperature, dissolved oxygen, turbidity and salinity) were analysed through Principle Component Analysis (p=0.05) using software PC-ORD, 5.10. If there is unavailable reading of any water parameter, the value was replaced with mean values in order to run this analysis.

For samples collected from both intertidal and subtidal zones of Pulau Sampadi, the actual number of individuals was used instead because the use of different sampling gears during sample collection. The abundance of fish larvae according to family at each sampling site was expressed in percentage. The assemblage of fish larvae was expressed using Shannon-Wiener diversity index (Shannon and Weaver, 1963), Pielou's evenness index (Pielou, 1966) and Margalef richness index (Margalef, 1958). For the family that were collected from both zones, total length was measured to the nearest ± 0.02 mm using a dial calliper (Mitutoyo, D15HA) and was compared using paired sample t-test analysis (p=0.05) in order to see the differences of fish larvae of the same family between both zones. All statistical analyses above were conducted using SPSS Version 22.

3.3 Results

A total of 3,421 fish larvae were collected from all sampling stations belonging to 27 families (Table 3.2). Fish larvae that were collected at intertidal zone comprise 3,300 individuals belonging to 18 families, whereby subtidal zone of Pulau Sampadi consists of 121 individuals belonging to 16 families. Ambassidae was found to be the dominant family throughout this study, contributing 46.62% from the total fish larvae and followed by Gobiidae (16.37%), Clupeidae (11.14%), Engraulidae (10.14%) and Gerreidae (6.96%). Other families contributed 8.77% in which six families recorded only one individual (Balistidae, Exocoetidae, Hemiramphidae, Myctophidae, Ptereleotridae and Scatophagidae). Seven families were observed to inhabit both intertidal and subtidal zones, namely Ambassidae, Atherinidae, Blenniidae, Chanidae, Clupeidae, Gerreidae and Gobiidae.

Table 3.2: List of fish larvae family according to the number of individuals (N), their abundance (%) and collection zone.

	Family	N	%	Intertidal	Subtidal
1	Ambassidae	1,595	46.62	+	+
2	Apogonidae	15	0.44		+
3	Atherinidae	10	0.29	+	+
4	Balistidae	1	0.03		+
5	Blenniidae	9	0.26	+	+
6	Callionymidae	31	0.91		+
7	Carangidae	6	0.18	+	
8	Chanidae	7	0.20	+	+
9	Clupeidae	381	11.14	+	+
10	Cynoglossidae	2	0.06		+
11	Engraulidae	347	10.14	+	
12	Exocoetidae	1	0.03		+
13	Gerreidae	238	6.96	+	+
14	Gobiidae	560	16.37	+	+
15	Hemiramphidae	1	0.03	+	
16	Leiognathidae	5	0.15	+	
17	Megalopidae	4	0.12	+	
18	Monacanthidae	3	0.09		+
19	Mugilidae	18	0.53	+	
20	Myctophidae	1	0.03		+
21	Ptereleotridae	1	0.03	+	
22	Scatophagidae	1	0.03	+	
23	Sciaenidae	94	2.75	+	
24	Scorpaenidae	3	0.09		+
25	Serranidae	8	0.23		+
26	Sillaginidae	68	1.99	+	
27	Terapontidae	11	0.32	+	
	Total	3,421		18	16

3.3.1 Composition and Abundance of Fish Larvae at Intertidal Zone

Family composition and abundance of fish larvae were compared between six intertidal sampling sites (Table 3.3). Pulau Satang showed the highest number of fish larvae collected and has the highest CPUE value, while Pantai Rambungan had the lowest number of fish larvae and the lowest CPUE value. The highest number of family was found at two sampling sites i.e., Pulau Satang and Pantai Mukah, while the lowest number of family was recorded at Pantai Rambungan.

Among intertidal sampling sites, Clupeidae was dominant at three sites, namely Pantai Teluk Pandan (53.33%), Pantai Rambungan (81.82%) and Pantai Puteri (70.59%). In contrast, the dominant family at Pulau Satang, Pulau Sampadi and Pantai Mukah were Ambassidae (87.79%), Engraulidae (81.39%) and Gobiidae (72.62%), respectively.

Among the families found, Clupeidae and Gerreidae were present at all sampling sites although they were not the most dominant family. However, some families were recorded only at one location. For instance, Hemiramphidae, Megalopidae and Ptereleotridae were only found at Pulau Satang. Chanidae and Leiognathidae were collected at Pulau Sampadi, while Scatophagidae and Sciaenidae were collected at Pantai Mukah only.

Table 3.3: Composition and abundance of fish larvae family at intertidal zone of each sampling site (N = number of fish larvae for each family; % = percentage of family of fish larvae at each sampling site).

	Family	Pantai Teluk Pandan		Pantai Rambungan		Pantai Puteri		Pulau Satang		Pulau Sampadi		Pantai Mukah	
		N	%	N	%	N	%	N	%	N	%	N	%
1	Ambassidae	-	-	-	-	-	-	1,575	87.79	1	0.25	9	1.21
2	Atherinidae	-	-	-	-	-	-	1	0.06	1	0.25	-	-
3	Blenniidae	-	-	-	-	1	0.67	1	0.06	-	-	1	0.13
4	Carangidae	-	-	-	-	4	2.68	-	-	1	0.25	1	0.13
5	Chanidae	-	-	-	-	-	-	-	-	3	0.74	-	-
6	Clupeidae	72	53.33	63	84.00	108	72.48	3	0.17	49	12.16	77	10.35
7	Engraulidae	1	0.74	-	-	7	4.70	-	-	328	81.39	11	1.48
8	Gerreidae	57	42.22	5	6.67	20	13.42	140	7.80	8	1.99	4	0.54
9	Gobiidae	3	2.22	1	1.33	-	-	-	-	-	-	541	72.72
10	Hemiramphidae	-	-	-	-	-	-	1	0.06	-	-	-	-
11	Leiognathidae	-	-	-	-	-	-	-	-	5	1.24	-	-
12	Megalopidae	-	-	-	-	-	-	4	0.22	-	-	-	-
13	Mugilidae	-	-	-	-	-	-	10	0.56	7	1.74	1	0.13
14	Ptereleotridae	-	-	-	-	-	-	1	0.06	-	-	-	-
15	Scatophagidae	-	-	-	-	-	-	-	-	-	-	1	0.13
16	Sciaenidae	-	-	-	-	-	-	-	-	-	-	94	12.63
17	Sillaginidae	2	1.48	-	-	9	6.04	57	3.18	-	-	-	-
18	Terapontidae	-	-	6	8.00	-	-	1	0.06	-	-	4	0.54
	Total	135		75		149		1,794		403		744	
	CPUE	27.00		15.00		21.29		224.25		50.38		148.80	
	Total family	5		4		6		11		9		11	

Diversity, evenness and richness indices of fish larvae at all intertidal sampling sites are shown in Figure 3.2. The Shannon-Wiener Diversity index (H') values ranged from 0.50 to 0.95, while Pielou's Evenness index (J) values ranged from 0.11 to 0.29 and Margalef's Richness index (D) values ranged from 0.26 to 0.49. According to sampling sites, Pantai Puteri has the highest diversity indices (H' = 0.95, J = 0.29, D = 0.49) while Pulau Satang showed the lowest diversity indices (H' = 0.50, J = 0.11, D = 0.26).

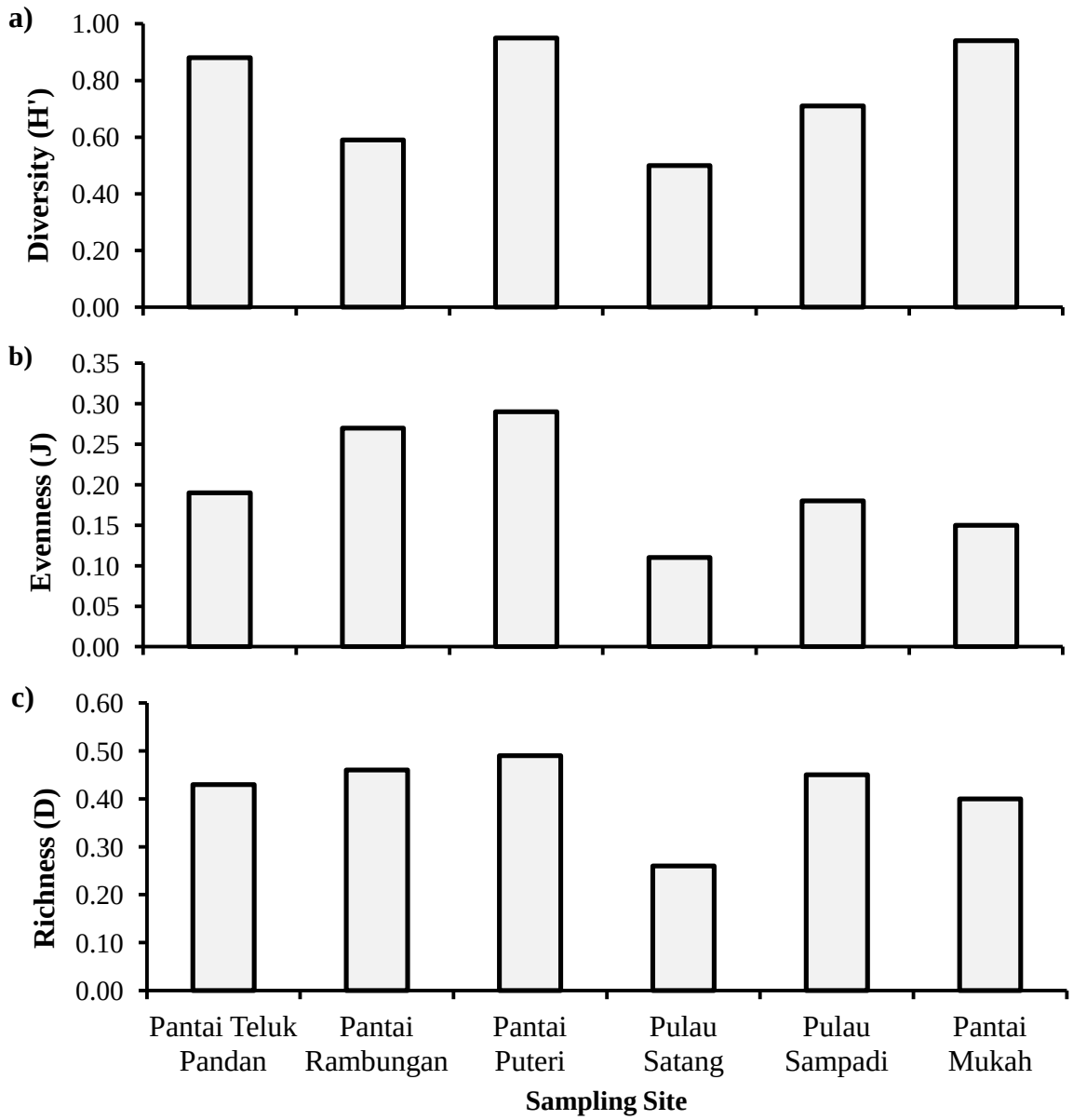


Figure 3.2: Values of diversity, evenness and richness indices according to sampling sites.

3.3.1.1 Relationship between Intertidal Fish Larvae Family Abundance and Physico-chemical Parameters of Water

Mean values of physico-chemical parameters of water recorded were compared among intertidal sampling sites (Table 3.4). All of the parameters recorded varied significantly ($p<0.05$) among sampling sites. Pantai Mukah showed significantly higher ($p<0.05$) in mean temperature and mean turbidity than other sampling sites with the value of 32.30 ± 0.00 °C and 767.33 ± 80.87 NTU, respectively. On the other hand, Pulau Sampadi showed significantly higher ($p<0.05$) in mean salinity and mean dissolved oxygen than other sampling sites with the value of 31.25 ± 0.50 PSU and 6.80 ± 0.04 mg/L, respectively.

Mean temperature and mean salinity recorded at Pantai Puteri showed significantly lower ($p<0.05$) than other sampling sites with the value of 29.40 ± 0.76 °C and 28.80 ± 1.30 PSU, respectively. Meanwhile, mean turbidity at Pantai Rambungan showed significantly lower ($p<0.05$) than other sampling sites with the value of 3.50 ± 0.51 NTU. On the other hand, mean dissolved oxygen at Pantai Mukah showed significantly lower ($p<0.05$) than other sampling sites with the value of 5.18 ± 0.47 mg/L.

Table 3.4: Mean values of physico-chemical parameters of water for each sampling site. ('–' = no data).

Sampling site	Temperature (°C)	Turbidity (NTU)	Salinity (PSU)	Dissolved oxygen (mg/L)
Teluk Pandan	29.97 ± 0.06^{ab}	15.16 ± 0.59^{ab}	31.33 ± 1.15^{ab}	-
Rambungan	31.96 ± 0.37^{cd}	3.50 ± 0.51^{a}	31.00 ± 1.87^{ab}	6.09 ± 0.21^{b}
Puteri	29.40 ± 0.76^{a}	71.51 ± 26.91^{b}	28.80 ± 1.30^{a}	6.44 ± 0.21^{b}
Pulau Sampadi	29.28 ± 0.26^{bc}	4.03 ± 0.88^{ab}	31.25 ± 0.50^{b}	6.80 ± 0.04^{c}
Mukah	32.30 ± 0.00^{e}	767.33 ± 80.87^{c}	-	5.18 ± 0.47^{a}

It was observed that there is no direct relationship between fish larvae family abundance and physico-chemical parameters of water ($p>0.05$). However, when the analysis was done separately between physico-chemical parameters of water (Table 3.5; Figure 3.3a) and fish larvae family abundance (Table 3.5; Figure 3.3b), it was observed that Chanidae and Engraulidae can adapt to low temperature while Sciaenidae and Scatophagidae can adapt to high turbidity. On the other hand, it was observed that Atherinidae can tolerate high salinity.

Table 3.5: Principal component analysis ($p=0.05$) for physico-chemical parameters of water and fish larvae family abundance at intertidal zones.

	Axis	**Eigenvalue**	**% of Variance**	**Cumulative % of Variance**	***p* value**
Physico-chemical water parameters	1	62.813	54.227	54.227	0.000999
	2	33.122	28.594	82.822	0.273726
Family abundance	1	1.319	19.626	19.626	0.452547
	2	1.15	17.116	36.743	0.211788

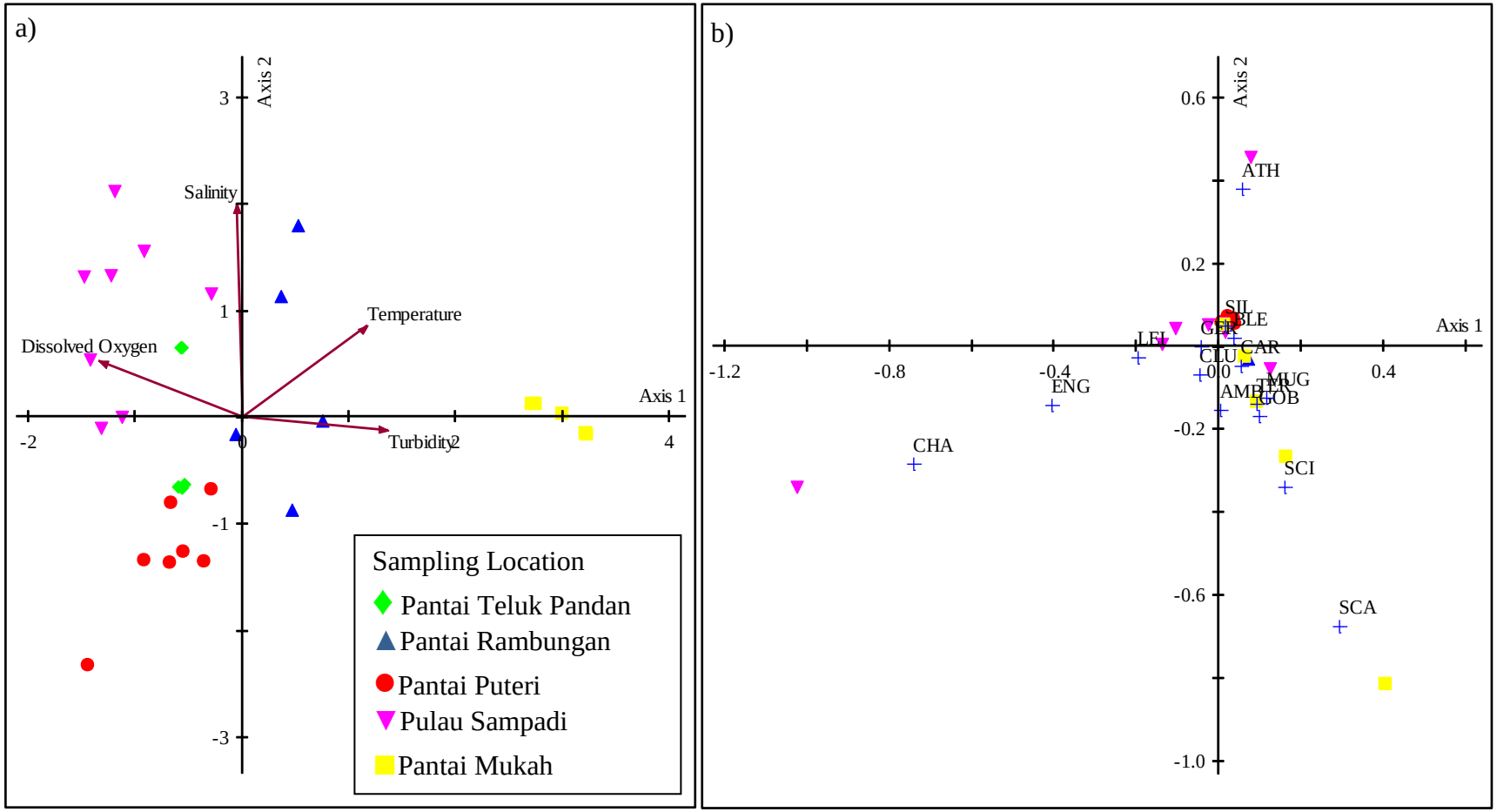


Figure 3.3: Relationship between: a) physico-chemical parameters of water and b) fish larvae family abundance (as indicated with '+') at intertidal zones from principal component analyses. Key: AMB-Ambassidae, ATH-Atherinidae, BLE-Blenniidae, CAR-Carangidae, CHA-Chanidae, CLU-Clupeidae, ENG-Engraulidae, GER-Gerreidae, GOB-Gobiidae, HEM-Hemiramphidae, LEI-Leiognathidae, MEG-Megalopidae, MUG-Mugilidae, PTE-Ptereleotridae, SCA-Scatophagidae, SCI-Sciaenidae, SIL-Sillaginidae, TER-Terapontidae.

3.3.2 Comparison of Fish Larvae Composition and Abundance at Intertidal and Subtidal Zones of Pulau Sampadi

Comparison between the intertidal and subtidal fish larvae family composition and abundance were made only for Pulau Sampadi (Table 3.6). In total, 524 individuals of fish larvae were collected from both intertidal and subtidal zones which comprised of 20 families. Nine families of fish larvae were observed at intertidal zone and was dominated by Engraulidae (81.39%), while 16 families of fish larvae were observed at subtidal zone that was dominated by Callionymidae (25.62%). Five families were observed at both zones, namely Ambassidae, Atherinidae, Chanidae, Clupeidae and Gerreidae. Overall, Engraulidae was dominant at Pulau Sampadi (62.60%), followed by Clupeidae (11.07%) and Callionymidae (5.92%) while the other 17 families contributed 20.41%.

Comparison of the mean total length was made for five families of fish larvae that inhabit both intertidal and subtidal zones (Table 3.7). It was observed that the size of fish larvae at intertidal zone is larger than subtidal zone for all five families. According to paired sample t-test analysis, there is a significant different ($p<0.05$) in mean total length between intertidal and subtidal fish larvae for Chanidae, Clupeidae and Gerreidae. Figure 3.4 showed the size differences of Clupeidae larvae collected at a) intertidal zone and b) subtidal zone.

Table 3.6: Composition and abundance of fish larvae family at intertidal and subtidal zones of Pulau Sampadi.

	Family	Intertidal		Subtidal		Total	%
		N	%	N	%		
1	Ambassidae	1	0.25	10	8.26	11	2.10
2	Apogonidae	-	-	15	12.40	15	2.86
3	Atherinidae	1	0.25	8	6.61	9	1.72
4	Balistidae	-	-	1	0.83	1	0.19
5	Blenniidae	-	-	6	4.96	6	1.15
6	Callionymidae	-	-	31	25.62	31	5.92
7	Carangidae	1	0.25	-	-	1	0.19
8	Chanidae	3	0.74	4	3.31	7	1.34
9	Clupeidae	49	12.16	9	7.44	58	11.07
10	Cynoglossidae	-	-	2	1.65	2	0.38
11	Engraulidae	328	81.39	-	-	328	62.60
12	Exocoetidae	-	-	1	0.83	1	0.19
13	Gerreidae	8	1.99	4	3.31	12	2.29
14	Gobiidae	-	-	15	12.40	15	2.86
15	Leiognathidae	5	1.24	-	-	5	0.95
16	Monacanthidae	-	-	3	2.44	3	0.57
17	Mugilidae	7	1.74	-	-	7	1.34
18	Myctophidae	-	-	1	0.83	1	0.19
19	Scorpaenidae	-	-	3	2.44	3	0.57
20	Serranidae	-	-	8	6.61	8	1.53
	Total number of fish larvae	403		121		524	
	Total family	9		16			

Table 3.7: Comparison of fish larvae size (mean total length or total length) from the same family obtained from both intertidal and subtidal zones of Pulau Sampadi with their total number of individuals (N) and the paired sample t-test analysis (p=0.05).

Family	Mean total length (mm)				
	Intertidal zone	N	Subtidal zone	N	*p* value
Ambassidae	5.00	1	2.86 ± 1.04	10	-
Atherinidae	6.00	1	2.85 ± 0.42	8	-
Chanidae	11.67 ± 0.58	3	3.85 ± 1.50	4	0.023
Clupeidae	20.53 ± 0.87	49	3.21 ± 1.17	9	0.000
Gerreidae	12.75 ± 0.71	8	3.40 ± 1.17	4	0.014

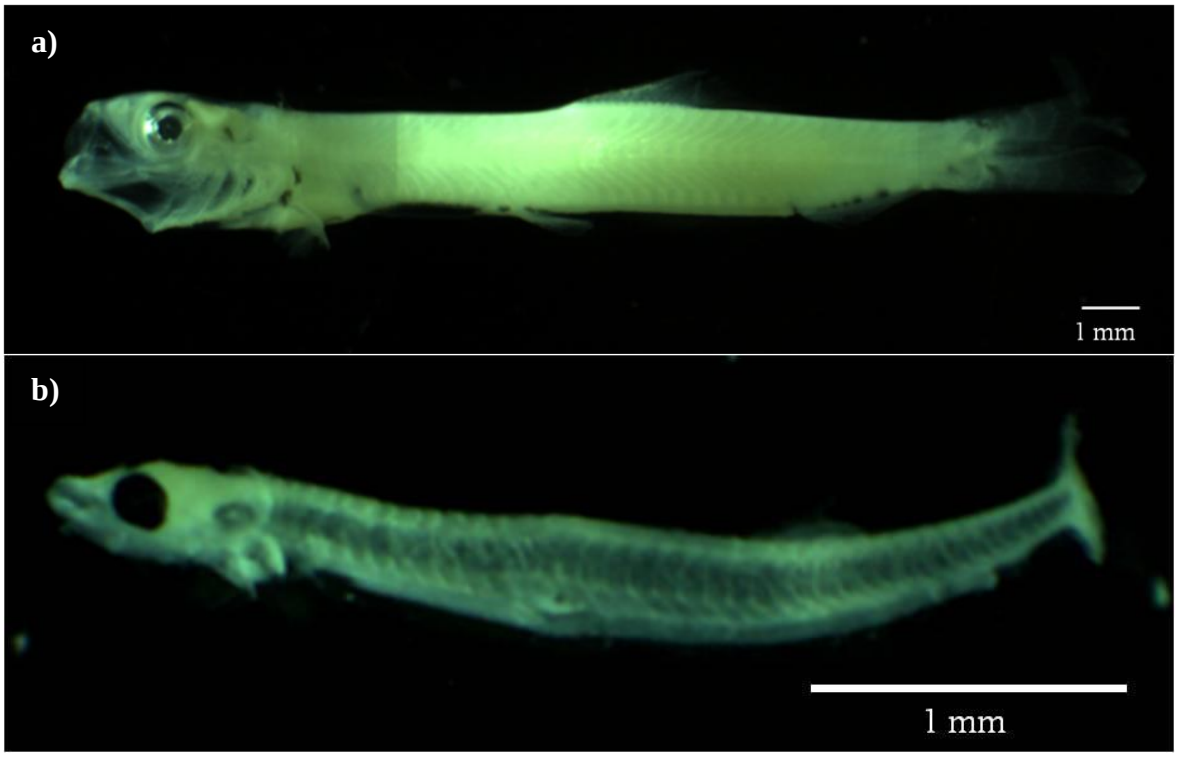


Figure 3.4: Size differences of Clupeidae larvae that were caught at a) intertidal and b) subtidal zones of Pulau Sampadi.

Diversity indices of fish larvae for both zones were also compared (Figure 3.5) and it was observed that subtidal zone showed higher diversity indices compared to intertidal zone. Shannon-Wiener Diversity index (H') value at intertidal zone is 0.71 while at subtidal zone is 2.37. Pielou's Evenness index (J) value at intertidal zone is 0.18 while at subtidal zone is 0.50. Margalef's Richness index (D) value at intertidal zone is 0.45 while at subtidal zone is 1.45.

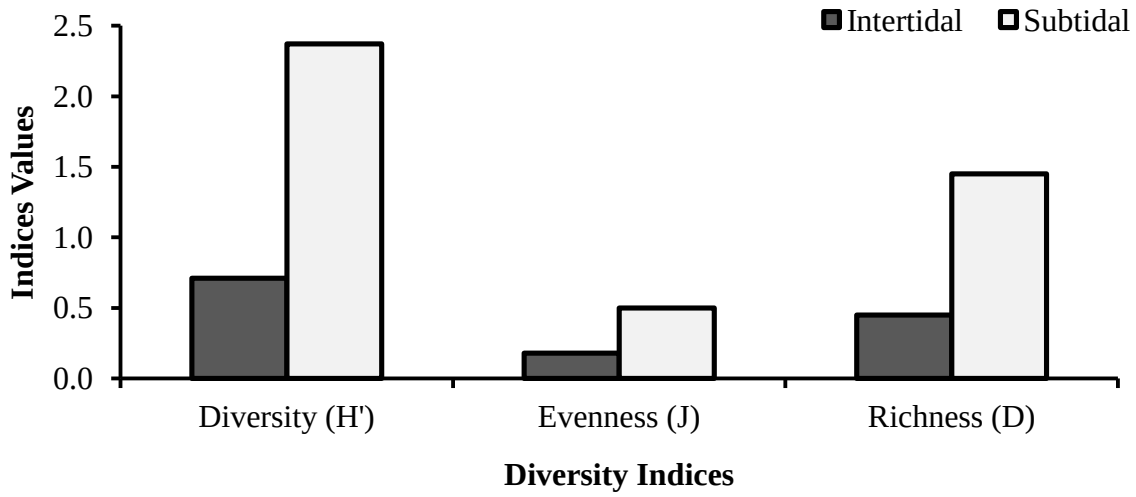


Figure 3.5: Comparison on diversity indices of fish larvae family between intertidal and subtidal zones of Pulau Sampadi.

3.4 Discussion

Throughout this study, the larval fish assemblage comprised 27 families in which 96.46% of fish larvae were collected at intertidal zones, while 3.54% were collected from subtidal zone of Pulau Sampadi. This is higher than the previous study done at 23 estuaries along Sabah and Sarawak that recorded 26 families (Blaber *et al*., 1997) and the recent short survey at western part of Sarawak that recorded 19 families (Muhamad and Rahim, 2013). This finding is also higher than the current records in Peninsular Malaysia waters in which 24 families were recorded from coastal waters of Johor (Ara *et al*., 2011a; 2011c; Arshad *et al*., 2012) and 18 families at coastal waters of Kedah that is located close to Andaman Sea (Mohamad-Norizam and Ali, 2009).

In this study, two families of fish larvae namely Clupeidae and Gerreidae were found at all intertidal sampling sites suggesting that these two families have a wide larval distribution. Compared with other studies that were conducted at intertidal zone of Malaysian waters (Table 3.8), Clupeidae was recorded at western part of Sarawak (Muhamad and

Rahim, 2013) and intertidal zone at Southwestern part of Johor (Ara *et al*., 2011a; 2011c). In contrast, Gerreidae was only recorded at western part of Sarawak (Muhamad and Rahim, 2013) suggesting that the distribution of Gerreidae larvae is confined to Sarawak coastal waters only. It is because Gerreidae was reported to inhabit various types of habitat (shallow bays, estuaries and coastal lagoons) and can tolerate wide range of salinity and turbidity (Carpenter and Niem, 2001) and yet, it was not recorded by other studies in Peninsular Malaysia. In contrast, seven families were recorded at one sampling site only (Pulau Satang, Pulau Sampadi and Pantai Mukah), indicating that these larvae may have specific habitat preference. However, due to one time sampling at each sampling site, this is not yet conclusive.

Table 3.8: Comparison of family recorded between this study at intertidal zones and other intertidal areas in Malaysian waters.

	Family	This Study	Western part of Sarawak Survey	Johor
1	Ambassidae	+	+	+
2	Atherinidae	+		
3	Blenniidae	+		+
4	Carangidae	+		+
5	Chanidae	+		
6	Clupeidae	+	+	+
7	Cynoglossidae			+
8	Elopidae		+	
9	Engraulidae	+	+	+
10	Gerreidae	+	+	
11	Gobiidae	+	+	+
12	Hemiramphidae	+	+	+
13	Leiognathidae	+		+
14	Megalopidae	+		
15	Monacanthidae			+
16	Monodactylidae			+
17	Mugilidae	+		
18	Mullidae			+
19	Nemipteridae			+
20	Ptereleotridae	+		
21	Rachycentridae			+

Table 3.8 continued

22	Samaridae			+
23	Scatophagidae	+		+
24	Sciaenidae	+		
25	Sillaginidae	+	+	+
26	Terapontidae	+	+	+
27	Toxotidae			+
28	Triacanthidae			+
	Total	18	9	20
	Source		Muhamad and Rahim (2013)	Ara *et al*. (2011a; 2011c)

At intertidal zones, seven families of fish larvae were collected in large group, suggesting that those fish larvae aggregate in a group called shoal. It has been reported that adults of these seven families namely Ambassidae, Clupeidae, Engraulidae, Gerreidae, Gobiidae, Sciaenidae and Sillaginidae are known to live in shoals (Longhurst, 1971; Ryan, 1991; Sasekumar *et al*., 1992; Jenkins and May, 1994; Kingsford and Suthers, 1994; Araújo and Santos, 1999). Shoaling behaviour could reduce the predation rate by confusing the predator from detecting the fish (prey) (Spooner, 1931; Partridge, 1982).

The intertidal of Pulau Satang was observed to have high abundance of fish larvae, CPUE value and family composition. This could be due to the habitat characteristics of Pulau Satang itself, which consist of fringing corals, seaweed patches and rocky shores that are known to be suitable habitat for breeding and refuge for fish larvae (Joseph, 1973; Breitburg *et al.*, 1995; Freitas and Muelbert, 2004). Pantai Mukah showed equal number of family composition with Pulau Satang and has six similar families recorded, namely Ambassidae, Blenniidae, Clupeidae, Gerreidae, Mugilidae and Terapontidae although this site has different type of habitat compared to Pulau Satang. These results could be due to the input of nutrients from the nearby Sungai Gigis, enhance the growth of phytoplankton that feeds by

zooplankton which is later became the food source for ichthyoplankton that (Herbert and Ontario, 2008).

Although Pulau Satang recorded high number of fish larvae abundance and family among the sampling sites, the fish larvae diversity is low as the individuals of fish larvae in Pulau Satang community were not distributed equitably where one family (Ambassidae) consist of high number of individuals (87.78%). On the other hand, Pantai Puteri recorded the highest fish larvae diversity where the individuals of fish larvae in Pantai Puteri community were distributed more equitably compared to other sampling sites. However, the fact that Pulau Satang has higher CPUE and number of family compared to Pantai Puteri shows diversity analysis in this study has some weakness in term of time and space.

Physico-chemical water parameters showed no direct relationship with fish larvae family abundance. However, it was reported that these water parameters could affect the growth of fish larvae (Petereit *et al*., 2009; Rhody *et al*., 2010; Ye *et al*., 2010). Since the study was conducted in tropical environment, the fluctuation in environment is fairly small as observed in this study. Some families are shown to have the ability to survive in certain kind of environment like lower temperature (Chanidae and Engraulidae), high turbidity (Sciaenidae and Scatophagidae) and high salinity (Atherinidae). However, the range of temperature and salinity were narrow and not highly fluctuated among the sites. Therefore, temporal study is needed in order to obtain more accurate results.

Fish larvae obtained from the intertidal and subtidal zones of Pulau Sampadi contributed 15.32% from the total fish larvae collected and belong to 20 identified families. Based on the family recorded, Engraulidae was the most abundant larvae (62.60%) but it was confined at intertidal zone only. Fish larvae family at subtidal zone was higher than the intertidal zone but lower in term of abundance. Fish larvae diversity of Pulau Sampadi is

higher at subtidal zone than intertidal zone. This shows that the individuals of fish larvae at subtidal zone community were distributed equitably compared to subtidal zone. Meanwhile, one family (Engraulidae) at intertidal zone consist of high number of individuals (81.39%) resulting in lower diversity of fish larvae. These results are still preliminary because of one time sampling was taken at both zones and variations in methods of sampling (seine net at intertidal; plankton net at subtidal), time of sampling, and sampling effort (replicates) making it impossible to reflect the actual situation and make a fair comparison.

Comparison on the total length of fish larvae of five families collected in both zones at Pulau Sampadi showed that fish larvae of intertidal zone have larger body size compared to subtidal zone. Moreover, the physical appearance of postflexion fish larvae at intertidal zone nearly resembled their adult with all the swimming appendages are well developed compared to subtidal fish larvae which were still at preflexion stage with undeveloped swimming appendages. Therefore, this probably the reason why the larger fish larvae could retain at intertidal zone compared to subtidal area. In addition, the mesh size of sampling gear for intertidal collection is larger than subtidal sampling gear which might contribute to no small fish larvae collected at intertidal zone.

3.5 Conclusion

In this study, a total of 27 families of fish larvae were identified with Ambassidae as the dominant family. Based on intertidal sampling sites, 18 families of fish larvae were recorded with Clupeidae and Gerreidae showed a wide distribution, while the highest number of family (11 families) recorded at both Pulau Satang and Pantai Mukah. However, fish larvae diversity is low due to the uneven family abundance with the present of dominant family within each sampling site. Physico-chemical water parameters did not show any direct influenced towards abundance of fish larvae family and probably due to not enough data collection. Meanwhile, intertidal and subtidal zones of Pulau Sampadi recorded 20 families of fish larvae with five families inhabited both zones, namely Ambassidae, Atherinidae, Chanidae, Clupeidae and Gerreidae. The subtidal zone of Pulau Sampadi holds higher diversity of fish larvae compared to its intertidal zone. Different growth stages were observed at different zones of Pulau Sampadi. Overall, availability of heterogeneous habitats at Pulau Satang and Pulau Sampadi and turbid water at Pantai Mukah support high abundance of fish larvae and high number of family while low abundance of fish larvae and number of family can be found at intertidal zone which are located at Pantai Teluk Pandan, Pantai Rambungan and Pantai Puteri. In future, it is strongly suggested that temporal variation in water physico-chemical parameter and surface current need to be taken into account as this is only one time sampling with different sampling dates. In short, these findings had provided some ecological information regarding the spatial distribution of fish larvae at several intertidal zones of Sarawak coastal waters and the growth stage of fish larvae at two different zones that could act as baseline data for future studies.

CHAPTER 4

SPATIO-TEMPORAL PATTERN OF ICHTHYOPLANKTON AT KUCHING WETLAND NATIONAL PARK ESTUARIES

4.1 Introduction

Ichthyoplankton survey is a way of generating fishery-independent stock assessment and key component in understanding the function of marine ecosystem (Moser and Smith, 1993) as well as the ecological processes involved not just in that particular habitat (Espinosa-Fuentes *et al*., 2009) but could cover a wide range of areas (Deepananda and Arsecularatne, 2013). Distribution patterns of marine fish larvae can determine the ecological processes of that particular fish and has crucial implications in the assessment of abundance (Brodeur and Rugen, 1994). Besides that, it could be used as guideline for the fisheries industries to control or manage their fishing activities especially during spawning season (Greve *et al*., 2005).

Spawning time of a particular fish could possibly be determined through the understanding of fisheries biology regarding information on the occurrence of fish eggs and larvae (Deepananda and Arsecularatne, 2013). The abundance of ichthyoplankton can be used to estimate the recruitment of fish population (Zhou *et al*., 2011) and to understand the marine fish recruitment mechanism (Köster *et al*., 2001). In order to obtain the recruitment pattern of fishes, temporal diversity of ichthyoplankton need to be conducted (Franco-Gordo *et al*., 2003).

Most larval fishes prefer to inhabit places in estuaries because it provides food, shelter and less impact from water current (Joseph, 1973; Freitas and Muelbert, 2004). Hence, ichthyoplankton can be an indicator of the health of aquatic environment as fish will use this area as the spawning grounds (Chamchang and Chayakul, 2000; Freitas and Muelbert, 2004;

Deepananda and Arsecularatne, 2013). This study was conducted in estuaries of Sungai Sibu Laut-Sungai Salak that are located within a protected area known as Kuching Wetland National Park (KWNP). Kuching Wetlands National Park occupies 6,610 hectares of estuarine forest including the Sungai Sibu Laut and Sungai Salak. It was gazetted as national park in July 2002 which later nominated as Ramsar site in November 2005. Study on ichthyoplankton has not been carried out before and therefore, this study is important to indicate the status of aquatic environment inside the park.

Detail information on ichthyoplankton regarding spatio-temporal study is still not available for the above mentioned study sites. Therefore, this study aimed to: 1) determine the spatio-temporal of fish larvae assemblages at Sungai Sibu Laut-Sungai Salak estuaries; 2) determine the spatio-temporal abundance and distribution of fish larvae and fish eggs at Sungai Sibu Laut-Sungai Salak estuaries; and 3) relate the spatio-temporal abundance of fish larvae and fish eggs with the environmental parameters of the Sungai Sibu Laut-Sungai Salak estuaries.

4.2 Materials and Methods

4.2.1 Sampling Sites

Ichthyoplankton samples were collected monthly at five stations along the Sungai Sibu Laut and Sungai Salak from October 2012 until September 2013 (Table 4.1; Figure 4.1). Three stations are located at the river upstream, namely Station 1 and Station 2 at Sungai Sibu Laut and Station 5 at Sungai Salak, while the other two stations i.e. Station 3 and Station 4 are located near Telaga Air jetty and Sungai Sibu Laut river mouth, respectively.

Sungai Sibu Laut and Sungai Salak are considered as estuary habitat with less impact from waves and winds but with semidiurnal tidal influence. The rivers are being used by local

people in daily transportation by boat and as fishing ground especially at Station 3 and Station 4. Most fishermen set up a drift net during high tide and some use hook and line to catch fish. Traditional fishing method called selambau is also use by fisherman to catch shrimp at few locations along the upstream of Sungai Sibu Laut before reaching Station 1 and Station 2. Meanwhile, there is quarry activity at Pulau Salak and near to Station 5. In addition, these two rivers are interconnected with each other through a few small networks of streams. Therefore, these selected stations are enough to cover the whole area. Moreover, the sampling process is restricted to time and tide that influenced the number of sampling stations. This study involves planktonic organisms, therefore time is limited to process many samples.

Table 4.1: List of coordinates for each sampling station at Sungai Sibu Laut – Sungai Salak estuaries recorded using Global Positioning System (GARMIN 60CSx) and their locations in those rivers.

Sampling Station	Location In The River	Coordinates
Station 1	Upstream of Sungai Sibu Laut	N 01° 38' 32.9" E 110° 15' 07.7"
Station 2	Upstream of Sungai Sibu Laut	N 01° 38' 59.4" E 110° 13' 13.9"
Station 3	Upstream of Sungai Sibu Laut	N 01° 40' 21.9" E 110° 14' 01.7"
Station 4	River mouth of Sungai Sibu Laut	N 01° 41' 34.3" E 110° 12' 05.2"
Station 5	Downstream of Sungai Salak	N 01° 39' 08.0" E 110° 17' 55.2"

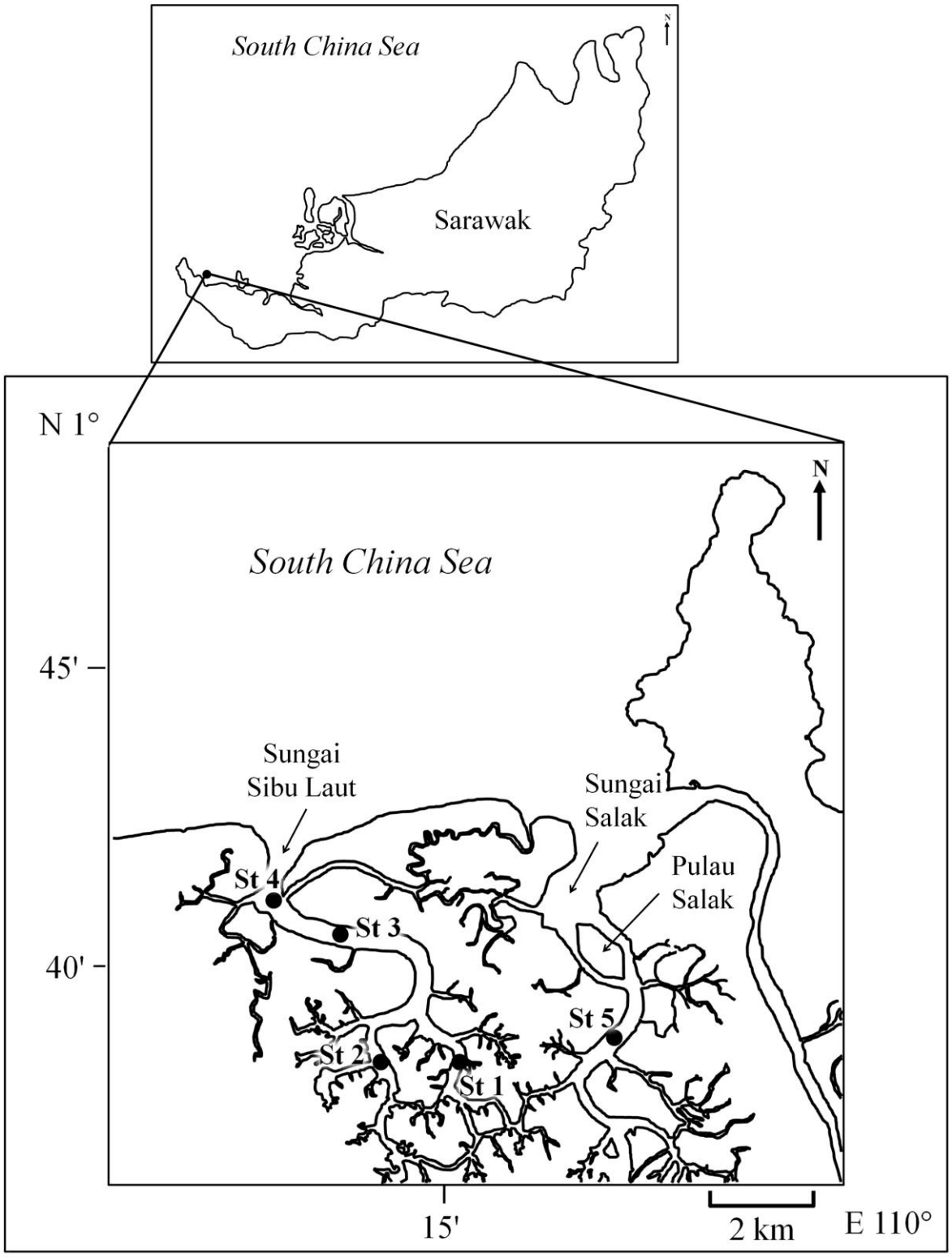


Figure 4.1: Sampling stations are indicated by the dark circles with Stations 1, 2, 3 and 4 are located at Sungai Sibu Laut, while Station 5 is located at Sungai Salak. St = Station; Sungai = river; Pulau = Island.

4.2.2 Sample Collection

Ichthyoplankton samples were collected using a plankton net (0.5 mm mesh size with 1 m diameter opening) attached with calibrated mechanical flowmeter (GO Environmental) (40 rotations = 1 m distance) at the opening ring to calculate the volume of water filtered. The flowmeter was calibrated at calm water to reduce the error when estimating the rotation of the propeller. The volume of filtered water was calculated using the volume of cylinder ($\pi r^2 h$) where:

r = the radius value which refers to half of the opening diameter of the plankton net

h = the distance of the net travelled during sample collection which were measured using the flowmeter

flowmeter reading = final reading (after towing) – initial reading (before towing)

The plankton net was towed obliquely by boat for about 10 minutes against the water current. Before towing the plankton net by boat, the net was released and let to submerge until the desired depth which was based on the water depth at each site that was measured beforehand using Depthmate Portable Sounder (Speedtech Instruments). The 10 minutes timing was counted when the boat started to move with gradual speed increment until it reached 2 knot (maximum speed) in order to make oblique tow that covered various depths.

All ichthyoplankton samples were preserved with 10% buffered formalin seawater directly in the field. Simultaneously, environmental parameters were recorded *in-situ* such as subsurface water temperature and dissolved oxygen were recorded using multiprobe (Eu-Tech Cyberscan 600 PCD650). Water turbidity and salinity were recorded using turbidity meter (Eu-Tech TN100) and salinometer (Milwaukee MA887), respectively. In the laboratory, the fish larvae were sorted out and preserved with 75% ethanol, while the sorted fish eggs

remained in 10% buffered formalin seawater. This is because ethanol can shrink the fish eggs and disrupt the transparent outer layer of fish eggs causing it not possible to observe the interior part of fish eggs which is needed for identification purposes (Ahlstrom, 1976). However, this study did not perform the detail description on the fish eggs.

4.2.3 Data Analyses

The identification was done and was described in Chapter 2. Total length of all fish larvae collected was measured to the nearest ± 0.02 mm using dial caliper (Mitutoyo, D15HA). The growth stage (preflexion, flexion or postflexion) of fish larvae was determined for the most common family recorded throughout the year. All fish larvae and fish eggs were counted and the density was expressed as number of individuals per 100 m^3.

Fish larvae recorded were analysed separately from the fish eggs. In this study, fish eggs were analysed in terms of their abundance and general shapes. No detail identification was made for fish eggs. Meanwhile, the assemblage of fish larvae was expressed by Shannon-Wiener Diversity index (Shannon and Weaver, 1963), Pielou's Evenness index (Pielou, 1966) and Margalef's Richness index (Margalef, 1958).

One way ANOVA and Two way ANOVA with post-hoc Tukey test (p=0.05) were used to compare means density of fish larvae, density of fish eggs, diversity indices of fish larvae and physico-chemical water parameters among stations and among months. Meanwhile, Pearson correlation coefficients (two-tailed, p=0.05) were performed to find correlation of fish larvae data (density of fish larvae, diversity of fish larvae, family of fish larvae) and fish eggs data (density of fish eggs) against physico-chemical water parameters (dissolved oxygen, temperature, turbidity, salinity and pH) and depth of sampling sites. All statistical analyses were calculated using SPSS Version 22.

4.3 Results

A total of 21,876 fish larvae belonging to 30 families were collected (Table 4.2). Gobiidae was found to be the dominant family that contributed 76.76% from the total fish larvae collected. This was followed by Engraulidae (7.23%), Clupeidae (3.71%) and Blenniidae (2.89%). Other 26 families made up the rest (9.41%), with seven families recorded only one individual throughout the sampling period, namely Centrolophidae, Haemulidae, Muraenidae, Paralichthyidae, Sillaginidae, Synodontidae and Uranoscopidae. The smallest mean total length of fish larvae is recorded in Serranidae (1.96 mm) while the biggest fish larvae belongs to Muraenidae with a total length of 47.20 mm.

Table 4.2: List of fish larvae families with their total number (N), abundance (%), range and mean total length (mm). ('*' indicates single individual).

	Family	N	%	Total Length (mm)	
				Range	Mean ± SD
1	Acropomatidae	298	1.36	1.02 – 5.68	2.95 ± 0.97
2	Ambassidae	49	0.22	3.84 – 8.50	6.37 ± 1.31
3	Apogonidae	199	0.91	1.32 – 2.90	2.11 ± 0.35
4	Atherinidae	3	0.01	2.48 – 3.90	3.79 ± 1.30
5	Blenniidae	632	2.89	1.96 – 4.32	2.90 ± 0.64
6	Callionymidae	283	1.29	1.38 – 6.08	3.61 ± 1.44
7	Carangidae	349	1.60	1.26 – 20.00	3.68 ± 3.51
8	Centrolophidae	1	0.00	5.26*	-
9	Clupeidae	811	3.71	1.78 – 21.50	6.85 ± 5.32
10	Cynoglossidae	95	0.43	1.20 – 7.00	3.77 ± 1.50
11	Engraulidae	1,581	7.23	2.18 – 28.21	8.14 ± 5.60
12	Gobiidae	16,791	76.76	1.02 – 14.06	4.61 ± 2.41
13	Haemulidae	1	0.00	6.70*	-
14	Hemiramphidae	3	0.01	7.76 – 27.98	22.69 ± 13.12
15	Leiognathidae	142	0.65	1.36 – 6.18	2.61 ± 1.10
16	Monacanthidae	4	0.02	2.04 – 3.28	2.75 ± 0.64
17	Mugilidae	2	0.01	3.10 – 4.70	3.90 ± 1.13
18	Muraenidae	1	0.00	47.20*	-
19	Paralichthyidae	1	0.00	5.46*	-
20	Pristigasteridae	74	0.34	4.70 – 17.74	7.58 ± 2.66
21	Scatophagidae	8	0.04	1.72 – 11.62	3.60 ± 3.94
22	Sciaenidae	55	0.25	1.96 – 22.90	6.10 ± 3.70
23	Scombridae	2	0.01	2.94 – 5.56	4.23 ± 1.85
24	Scorpaenidae	78	0.36	2.04 – 6.68	3.61 ± 1.41
25	Serranidae	28	0.13	1.34 – 2.60	1.96 ± 0.39
26	Sillaginidae	1	0.00	14.00*	-
27	Syngnathidae	216	0.99	5.72 – 42.50	10.91 ± 5.52
28	Synodontidae	1	0.00	38.70*	-
29	Tetraodontidae	166	0.76	1.58 – 8.94	2.33 ± 1.08
30	Uranoscopidae	1	0.00	2.10*	-
	Total	21,876			

4.3.1 Spatio-temporal Pattern of Fish Larvae Density

Overall mean density of fish larvae were compared among stations and among months (Figure 4.2). According to station, the highest mean density was observed at Station 4 (174.68 ± 133.59 individuals/100 m^3), while the lowest mean density was observed at Station 2 (21.02 ± 26.87 individuals/100 m^3). Based on One way ANOVA, there is no significant difference among stations ($p>0.05$) for overall mean density of fish larvae. According to monthly variation, mean density of fish larvae showed five peaks that occurred in November 2012, January 2013, April 2013, July 2013 and September 2013, with the highest peak was observed in July 2013 (273.46 ± 273.23 individuals/100 m^3). The peaks refer to each highest mean density of fish larvae before it falls in the next month. However, there is no significant difference among months using One way ANOVA ($p>0.05$).

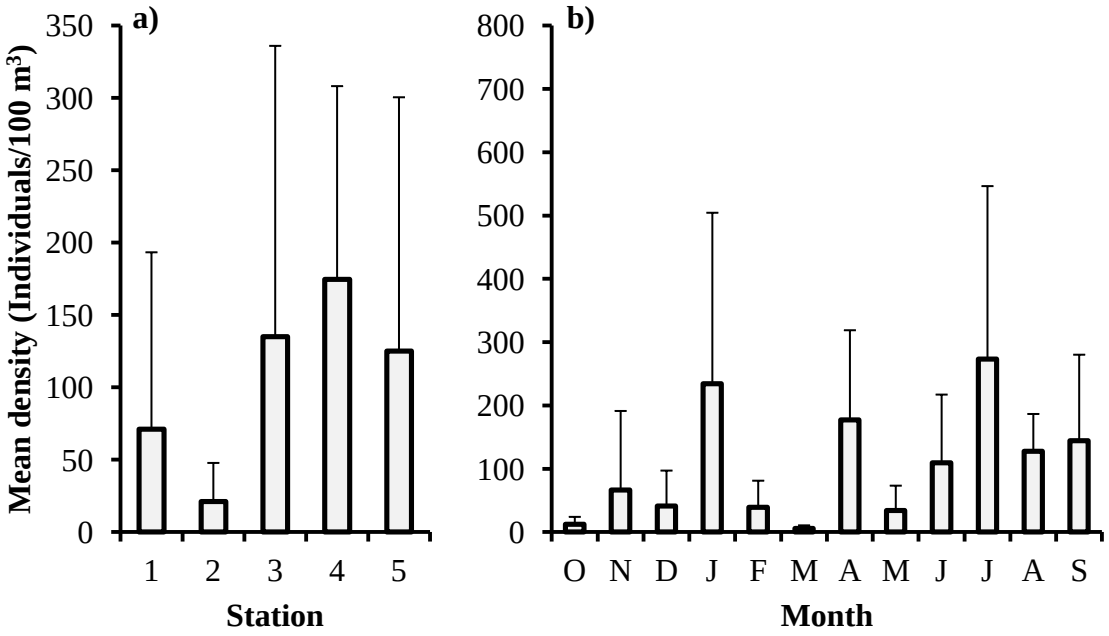


Figure 4.2: Mean density of fish larvae according to a) stations and b) months.

The fish larvae density for each station was observed to have three to five peaks within the one year period (Figure 4.3). Throughout the study period, the fish larvae density at Station 1 ranged from 0.00 individuals/100 m^3 to 415.22 individuals/100 m^3 in which no larvae was observed in October 2012, while the highest density was observed in April 2013. At Station 2, fish larvae density recorded ranged from 0.00 individuals/100 m^3 to 83.37 individuals/100 m^3 in which no larvae was observed in October 2012, November 2012 and February 2013, while the highest density was observed in June 2013. Fish larvae density at Station 3 ranged from 2.88 individuals/100 m^3 to 702.26 individuals/100 m^3 in which November 2012 showed the lowest density, while June 2013 showed the highest density. At Station 4, fish larvae density ranged from 13.80 individuals/100 m^3 to 379.01 individuals/100 m^3 in which March 2013 showed the lowest density, while January 2013 showed the highest density. Fish larvae density at Station 5 ranged from 0.46 individuals/100 m^3 to 642.53 individuals/100 m^3 in which March 2013 showed the lowest density, while January 2013 showed the highest density.

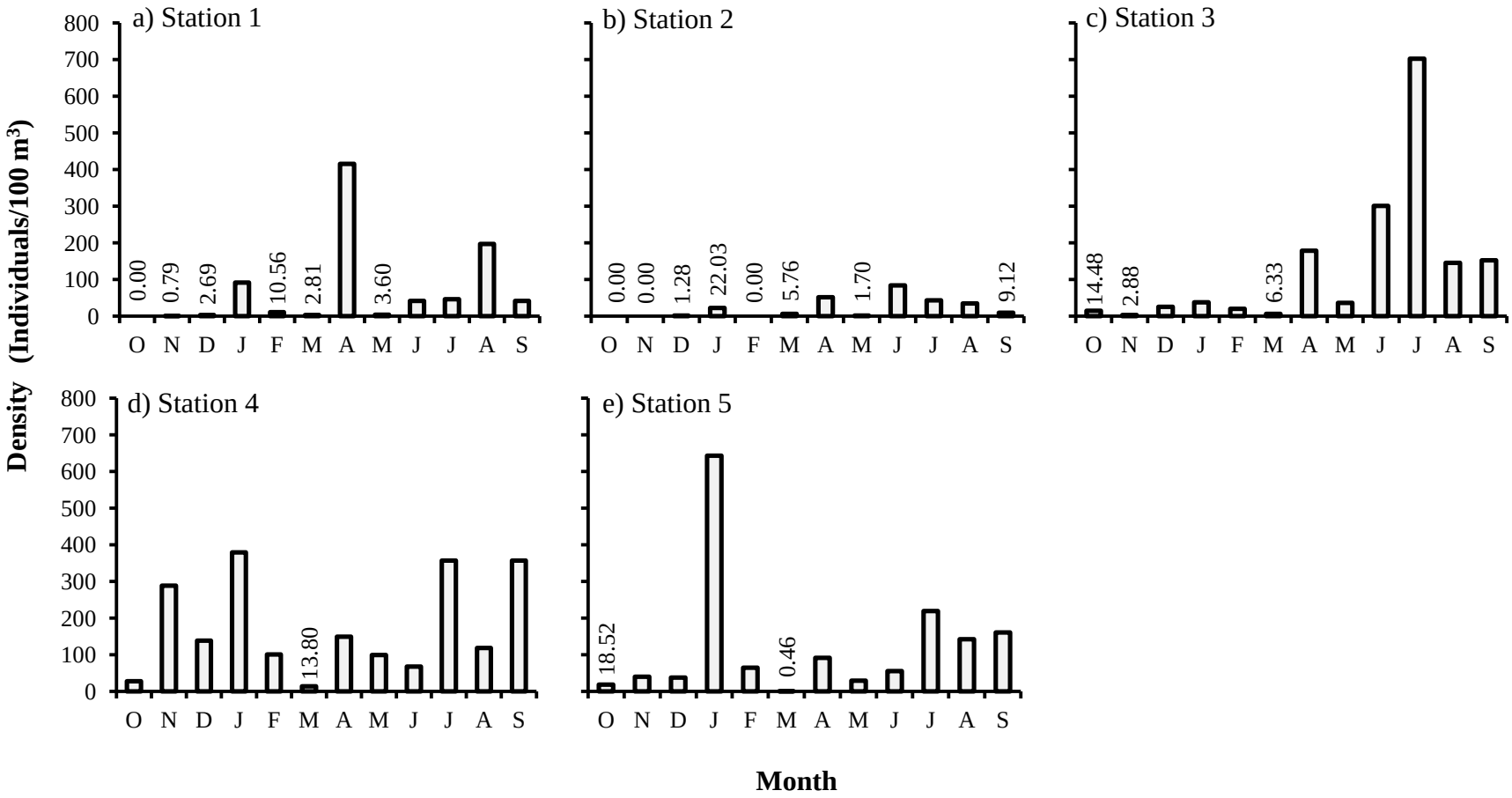


Figure 4.3: Temporal variation in density of fish larvae at each station throughout this study.

4.3.2 Spatio-temporal Pattern of Fish Larvae Diversity Indices

Mean values of Shannon-Wiener Diversity index (H'), Pielou's Evenness index (J) and Margalef's Richness index (D) were calculated and compared among stations and among months (Figure 4.4). For H', it is found that the mean H' values varied significantly among stations ($p<0.05$). Station 4 showed significantly higher than other sampling stations with the value of 1.147 ± 0.439, while Station 2 showed significantly lower than other sampling stations with the value of 0.564 ± 0.507 (Figure 4.4a). According to months, H' values ranged from 0.509 to 1.375 with the highest peak was recorded in June 2013 (1.375 ± 0.189) (Figure 4.4b). However, there is no significant difference in mean H' values among months ($p>0.05$).

For J, the highest mean J value was observed at Station 1 (0.451 ± 0.341) while the lowest J value was observed at Station 5 (0.303 ± 0.232) (Figure 4.4c). However, there is no significant difference in mean J values among stations ($p>0.05$). According the month, mean J values ranged from 0.192 to 0.982. It is found that mean J value in December 2012 is significantly higher than other stations with the value of 0.982 ± 0.446 (Figure 4.4d). Meanwhile, mean J values in January 2013 is significantly lower than other stations with the value of 0.192 ± 0.091.

For D, the highest mean D value was observed at Station 1 (0.773 ± 0.470) while the lowest D value was observed at Station 2 (0.471 ± 0.330) (Figure 4.4e). However, there is no significant difference in mean D values among stations ($p>0.05$). According to months, mean D values ranged from 0.383 to 1.028 with the highest peak recorded in March 2013 (1.028 ± 0.372) (Figure 4.4f). However, there is no significant difference in mean D values among months ($p>0.05$).

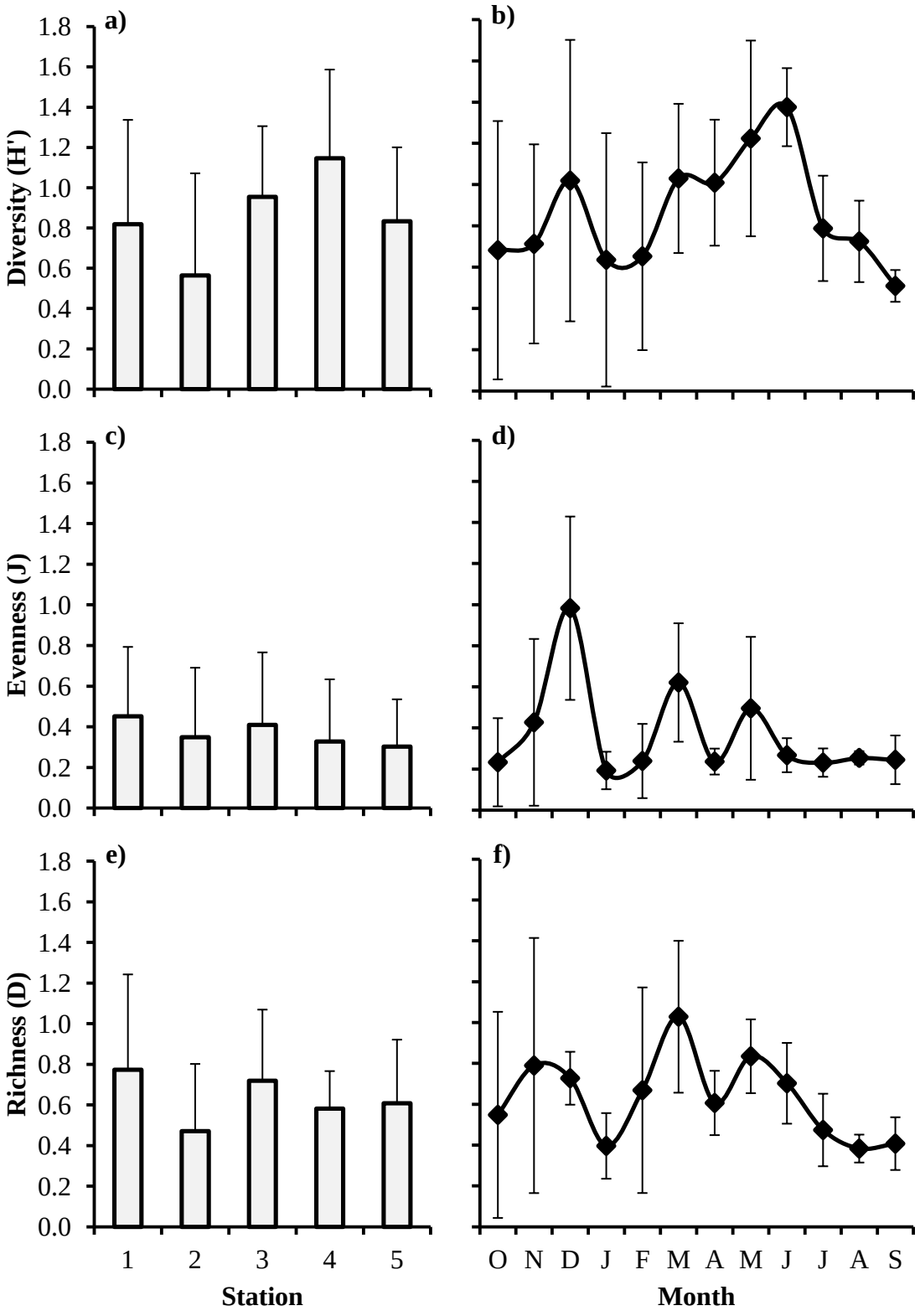


Figure 4.4: Spatio-temporal variation of diversity, evenness and richness of fish larvae. Mean values derived from 12 months sampling period for a), c) and e). Meanwhile, mean values derived from 5 sampling stations for b), d) and f).

4.3.3 Spatio-temporal Variation in Fish Larvae Family Occurrence

Station 4 showed the highest number of fish larvae family (26 families) while the lowest number of family was recorded at Station 1 and Station 2 with both having 17 families (Figure 4.5). According to months, the highest fish larvae family was recorded in June 2013 (20 families), while the lowest family was recorded in October 2012 (10 families). The temporal trend of fish larvae family showed three peaks throughout the year that occurred in November 2012, January 2013 and June 2013.

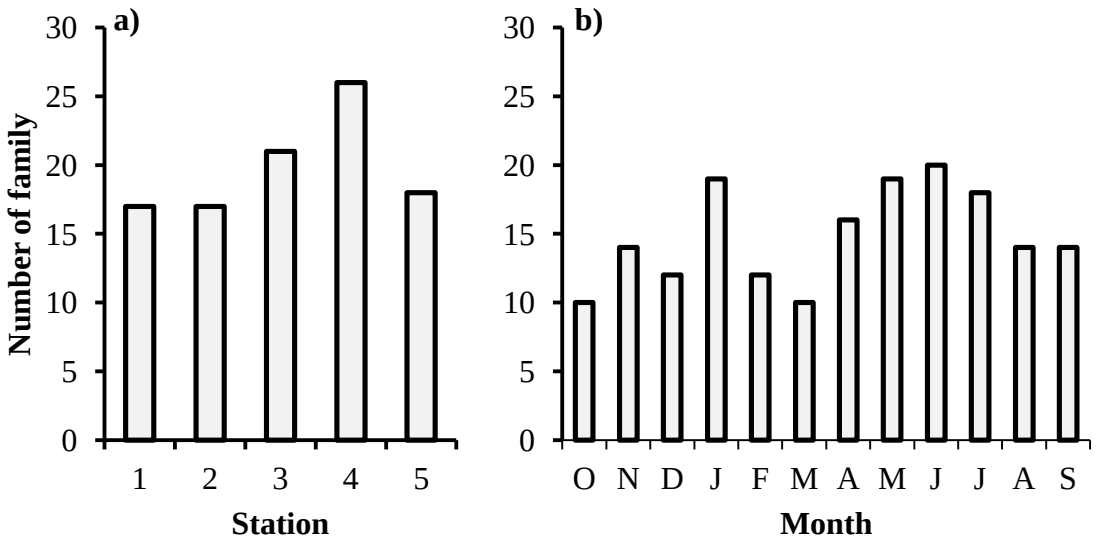


Figure 4.5: Variation in number of fish larvae family according to a) stations and b) months.

Throughout this study, 14 families were recorded at all five stations namely Acropomatidae, Ambassidae, Apogonidae, Blenniidae, Callionymidae, Carangidae, Clupeidae, Cynoglossidae, Engraulidae, Gobiidae, Sciaenidae, Scorpaenidae, Syngnathidae and Tetraodontidae, while eight families were recorded at one station only (Table 4.3).

Scombridae and Uranoscopidae were recorded only at Station 3, while Centrolophidae, Haemulidae, Muraenidae, Paralichthyidae, Sillaginidae and Synodontidae were recorded only at Station 4. Gobiidae was observed to be the dominant family at all sampling stations with the abundance ranging from 51.94% to 87.37% from the total fish larvae collected at each station.

Throughout the one year sampling period, four families were recorded every month, namely Blenniidae, Carangidae, Engraulidae and Gobiidae, while nine families were recorded only one time, namely Uranoscopidae that was collected in October 2012; Haemulidae, Muraenidae, Sillaginidae and Synodontidae that were collected in January 2013; Paralichthyidae that was collected in March 2013; Centrolophidae that was collected in May 2013; and lastly Mugilidae and Scombridae that were collected in June 2013 (Table 4.3). It was observed that Gobiidae was the dominant family in each month except in March 2013 where it was dominated by Carangidae (44.72%).

Table 4.3: Spatio-temporal variation of fish larvae family according to abundance (%).

	Family	Station					2012			2013								
		1	2	3	4	5	O	N	D	J	F	M	A	M	J	J	A	S
1	Acropomatidae	1.44	0.72	0.46	2.89	0.48	1.08	2.97	1.85	2.93		0.81	0.83	2.01	2.25	0.13	2.30	
2	Ambassidae	0.41	0.57	0.19	0.33	0.02		0.27		0.09	1.58	5.69	0.14	2.16		0.10		0.13
3	Apogonidae	0.45	0.72	1.43	0.89	0.62	2.69	0.54	0.62	0.20	0.18		2.45	0.29	0.70	1.49	1.07	0.23
4	Atherinidae		0.14			0.03					0.18			0.14	0.07			
5	Blenniidae	0.90	22.96	1.26	3.87	1.76	3.23	2.83	3.86	0.77	1.41	6.50	3.00	21.41	11.45	0.94	2.47	1.39
6	Callionymidae	2.18	0.43	2.22	0.72	0.79		0.27	2.32	0.02	0.53		0.18	3.88	7.66	0.96	1.07	1.48
7	Carangidae	1.07	5.02	1.2	2.4	0.84	3.23	3.24	8.35	0.22	0.35	44.72	1.71	13.94	2.25	0.27	0.53	0.16
8	Centrolophidae				0.01									0.14				
9	Clupeidae	0.21	7.32	0.75	9.59	0.60	36.02	0.13	0.15	0.63	0.18		3.14	10.78	7.94	7.03	1.97	1.32
10	Cynoglossidae	0.21	0.14	0.48	0.69	0.21		0.13	0.31	0.90			0.28	0.72	2.53	0.04	0.08	
11	Engraulidae	16.92	6.46	4.68	7.22	5.84	2.69	4.45	32.61	7.72	8.96	4.07	20.49	1.44	1.69	5.59	1.89	3.45
12	Gobiidae	73.39	51.94	84.02	65.55	87.37	44.09	83.4	39.72	83.18	82.78	34.96	63.77	37.93	56.43	80.57	85.73	89.61
13	Haemulidae				0.01					0.02								
14	Hemiramphidae		0.14		0.01	0.02								0.14		0.02	0.04	
15	Leiognathidae	0.12		0.34	1.60	0.10				1.33			0.46	3.02	1.41	0.29	0.29	0.26
16	Monacanthidae			0.05	0.01									0.14	0.21			
17	Mugilidae	0.04		0.02											0.14			
18	Muraenidae				0.01					0.02								
19	Paralichthyidae				0.01							0.81						
20	Pristigasteridae			0.02	1.04					1.09			0.05			0.44		
21	Scatophagidae		0.14		0.07	0.02				0.11					0.14			0.03
22	Sciaenidae	0.29	0.29	0.07	0.30	0.36		0.27	1.08		0.88	0.81	0.23	1.01	0.77	0.27		0.10
23	Scombridae			0.03											0.14			
24	Scorpaenidae	0.53	0.72	0.43	0.41	0.10	1.61	0.13				0.81	1.15	0.14	1.48	0.29	0.25	0.16
25	Serranidae	0.16		0.39	0.01									0.43	1.48	0.08		
26	Sillaginidae				0.01					0.02								
27	Syngnathidae	1.03	1.29	1.04	1.25	0.57	4.84	0.94	1.24	0.31	2.46		0.97	0.29	0.98	0.78	1.77	1.39
28	Synodontidae				0.01					0.02								
29	Tetraodontidae	0.66	1.00	0.90	1.05	0.27		0.40	7.88	0.42	0.53	0.81	1.15		0.28	0.73	0.53	0.29
30	Uranoscopidae			0.02			0.54											

4.3.3.1 Spatio-temporal Variation in Growth Stages of Four Fish Larvae Families

In one year period, four regularly present families (Blenniidae, Carangidae, Engraulidae and Gobiidae) were observed to have the highest abundance of preflexion larvae (Table 4.4).

Table 4.4: Abundance of fish larvae of four families (%) according to the growth stage.

Growth stage	Abundance (%)			
	Blenniidae	**Carangidae**	**Engraulidae**	**Gobiidae**
Preflexion	98.42	75.64	86.34	65.30
Flexion	1.27	10.03	11.45	27.24
Postflexion	0.32	14.33	2.21	7.46

At each station (Figure 4.6a), preflexion larvae density of Blenniidae were dominant with the highest density at Station 4 (73.46 individuals/100 m^3), while flexion larvae density were observed at Station 2, Station 3 and Station 4 with the highest density at Station 3 (0.91 individuals/100 m^3). Meanwhile, postflexion larvae density was observed only at Station 3 with larval density of 0.45 individuals/100 m^3. Based on One way ANOVA, there is no significant difference in fish larvae density among stations ($p>0.05$) for all growth stages.

According to monthly variation of Blenniidae larvae total density (Figure 4.6b), two peaks were observed in January 2013 and June 2013 with the highest density in June 2013 (56.38 individuals/100 m^3). According to fish larvae growth stages (Figure 4.6c), it was observed that preflexion larvae density was present every month with two peaks occurred in January 2013 and June 2013. The highest density of preflexion larvae was observed in June 2013 with 56.03 individuals/100 m^3 but it is not significantly different ($p>0.05$). Flexion larvae density was observed from May 2013 to August 2013 with the highest density occurred in August 2013 (0.91 individuals/100 m^3) while postflexion larvae density was observed only in June 2013 with 0.45 individuals/100 m^3. Density of both growth stages (flexion and postflexion) also did not show significant difference among months ($p>0.05$).

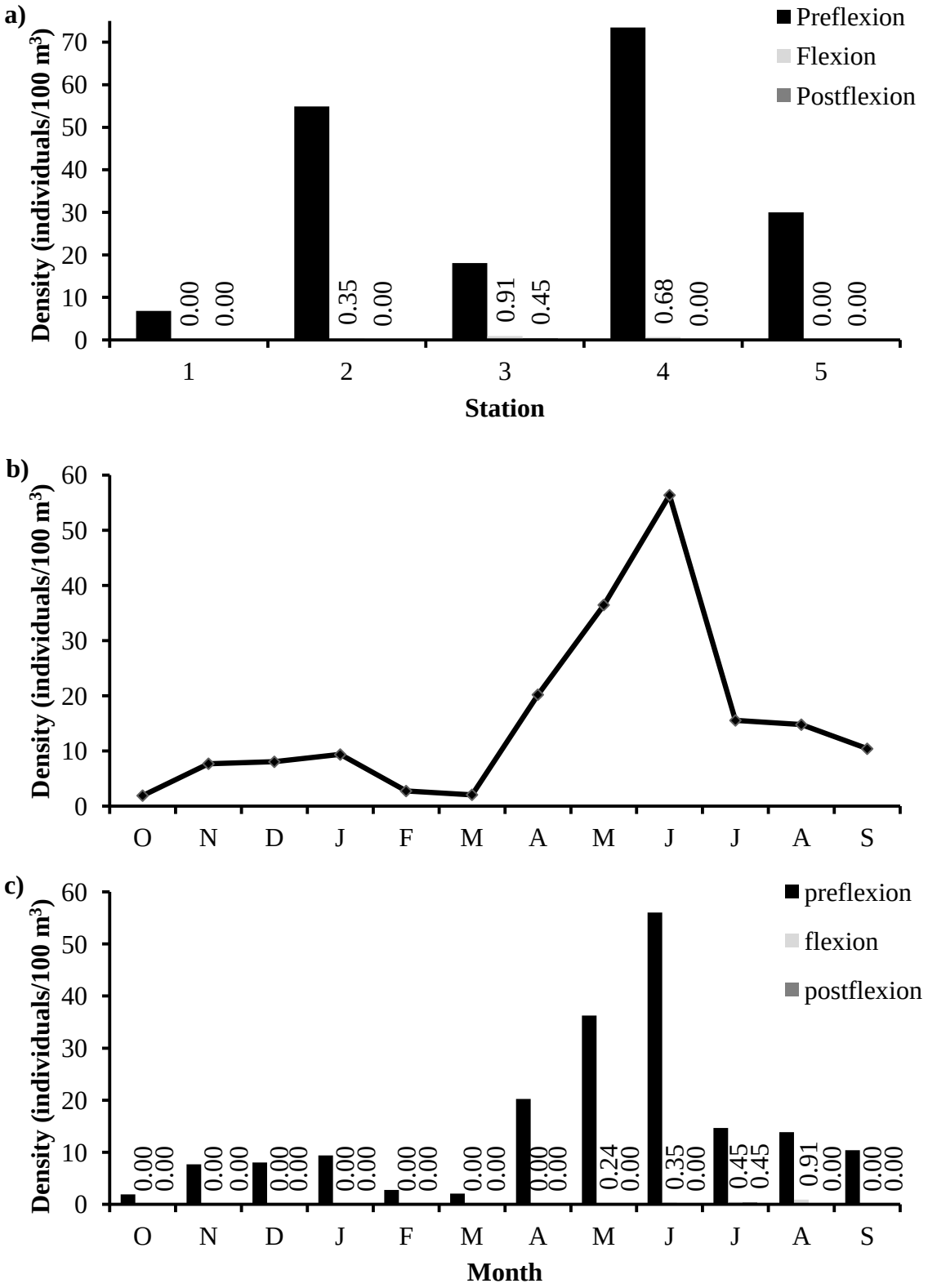


Figure 4.6: Density of Family Blenniidae larvae. (a) Density of fish larvae by growth stages according to station; (b) Total density of fish larvae obtained for each month; and (c) Density of fish larvae by growth stages according to month.

At each station (Figure 4.7a), preflexion larvae density of Carangidae were dominant with the highest density at Station 4 (41.30 individuals/100 m^3), while flexion larvae density were also observed at all stations but the highest density was observed at Station 5 (3.43 individuals/100 m^3). Meanwhile, postflexion larvae density was observed at Station 2, Station 3, Station 4 and Station 5 with the highest density at Station 4 (7.84 individuals/100 m^3). Based on One way ANOVA, there is no significant difference in fish larvae density among stations ($p>0.05$) for all growth stages.

According to monthly variation of Carangidae larvae total density (Figure 4.7b), two peaks were observed in December 2012 and March 2013 with the highest density in March 2013 (23.24 individuals/100 m^3). According to fish larvae growth stages (Figure 4.7c), it was observed that preflexion larvae density was present every month except February 2013 with two peaks occurred in December 2012 and March 2013. The highest density of preflexion larvae was observed in March 2013 with 19.54 individuals/100 m^3 but it is not significantly different ($p>0.05$). Flexion larvae density was present every month except October 2012, December 2012 and September 2013 with the highest density occurred in May 2013 (3.46 individuals/100 m^3). Based on One way ANOVA, there is significant difference in flexion fish larvae density among months ($p<0.05$) where May 2013 showed significantly higher density than other months. Meanwhile postflexion larvae density was observed only in March 2013, May 2013 and September 2013 with the highest density in March 2013 (11.90 individuals/100 m^3. Based on One way ANOVA, there is significant difference in postflexion fish larvae density among months ($p<0.05$) where March 2013 showed significantly higher density than other months.

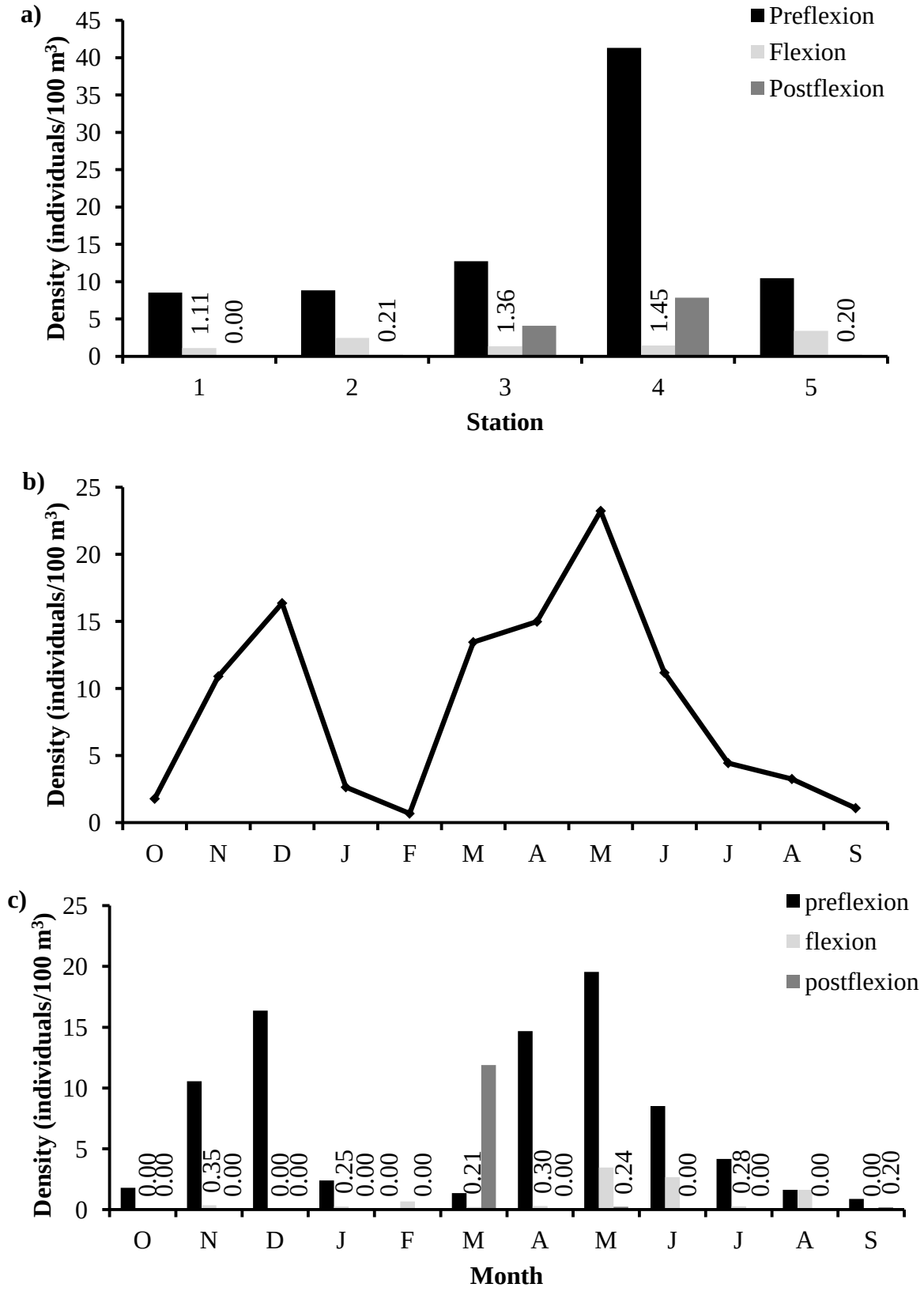


Figure 4.7: Density of Family Carangidae larvae. (a) Density of fish larvae by growth stages according to station; (b) Total density of fish larvae obtained for each month; and (c) Density of fish larvae by growth stages according to month.

At each station (Figure 4.8a), preflexion larvae density of Engraulidae were dominant with the highest density at Station 1 (184.12 individuals/100 m^3), while flexion larvae density were observed at Station 1, Station 3, Station 4 and Station 5 with the highest density at Station 5 (24.47 individuals/100 m^3). Meanwhile, postflexion larvae density was observed at Station 1, Station 4 and Station 5 with the highest density at Station 5 (3.76 individuals/100 m^3). Based on One way ANOVA, there is no significant difference in fish larvae density among stations ($p>0.05$) for all growth stages.

According to monthly variation of Engraulidae larvae total density (Figure 4.8b), four peaks were observed in January 2013, April 2013, July 2013 and September 2013 with the highest density in April 2013 (202.52 individuals/100 m^3). According to fish larvae growth stages (Figure 4.8c), it was observed that preflexion larvae density was present every month with three peaks occurred in January 2013, April 2013 and July 2013. The highest density of preflexion larvae was observed in April 2013 with 200.05 individuals/100 m^3 but it is not significantly different ($p>0.05$). Flexion larvae density was observed in all months except October 2012 and April 2013 with the highest density occurred in September 2013 (12.55 individuals/100 m^3) while postflexion larvae density was observed in January 2013, April 2013 and September 2013 with the highest density occurred in September 2013 (3.76 individuals/100 m^3. Both growth stages (flexion and postflexion) also did not show significant difference among months ($p>0.05$).

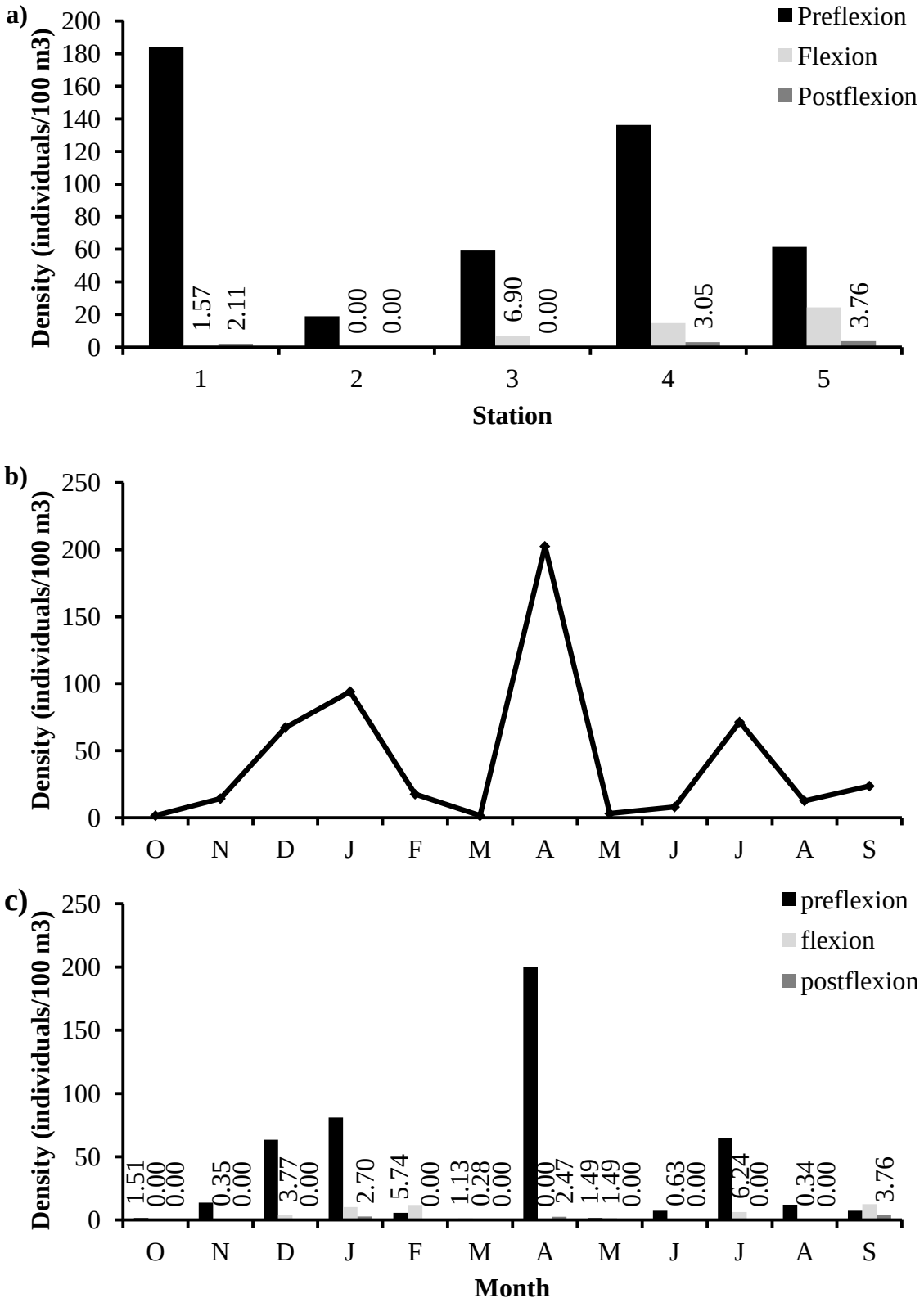


Figure 4.8: Density of Family Engraulidae larvae. (a) Density of fish larvae by growth stages according to station; (b) Total density of fish larvae obtained for each month; and (c) Density of fish larvae by growth stages according to month.

At each station (Figure 4.9a), preflexion larvae density of Gobiidae were dominant with the highest density at Station 4 (1,055.60 individuals/100 m^3). Meanwhile, flexion and postflexion larvae densities were also observed at all stations with both showed the highest density at Station 5 (451.68 individuals/100 m^3 and 204.37 individuals/100 m^3, respectively). Based on One way ANOVA, there is no significant difference in fish larvae density among stations ($p>0.05$) for all growth stages.

According to monthly variation of Gobiidae larvae total density (Figure 4.9b), five peaks were observed in November 2012, January 2013, April 2013, July 2013 and September 2013 with the highest density in July 2013 (1,065.37 individuals/100 m^3). According to fish larvae growth stages (Figure 4.9c), it was observed that all growth stages were present every month. Preflexion larvae density showed four peaks occurred in November 2012, January 2013, April 2013 and July 2013 with the highest density in July 2013 (806.87 individuals/100 m^3). Based on One way ANOVA, there is significant difference in preflexion fish larvae density among month ($p<0.05$) where July 2013 showed significantly higher than other stations. Flexion larvae density showed five peaks occurred in November 2012, January 2013, April 2013, July 2013 and September 2013 with the highest density in January 2013 (392.03 individuals/100 m^3) while postflexion larvae density showed four peaks occurred in January 2013, April 2013, July 2013 and September 2013 with the highest density in January 2013 (157.28 individuals/100 m^3). Both growth stages (flexion and postflexion) did not show significant difference among months ($p>0.05$).

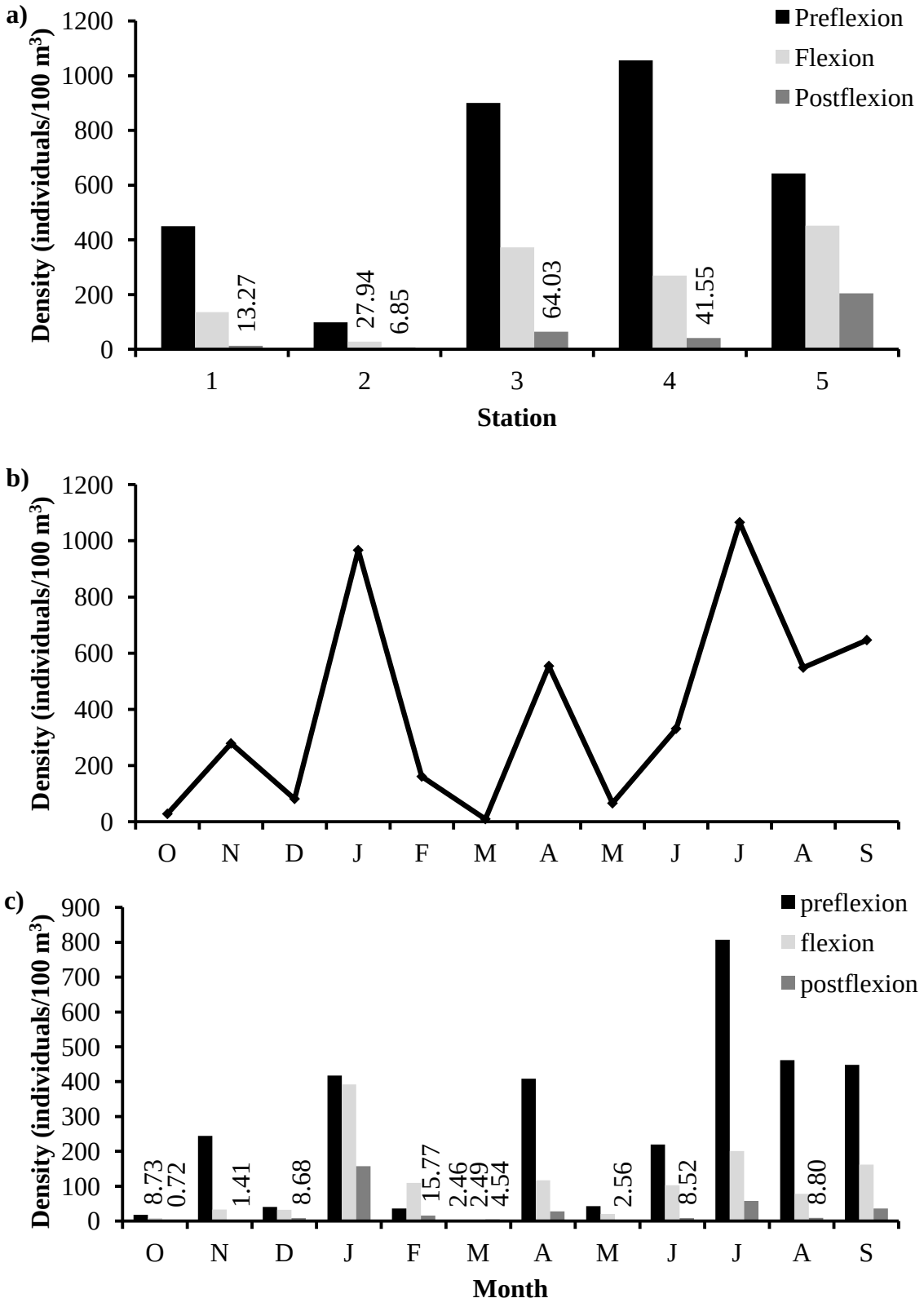


Figure 4.9: Density of Family Gobiidae larvae. (a) Density of fish larvae by growth stages according to station; (b) Total density of fish larvae obtained for each month; and (c) Density of fish larvae by growth stages according to month.

4.3.4 Physico-chemical Water Parameters of Sungai Sibu Laut-Sungai Salak

4.3.4.1 Dissolved Oxygen

Mean values of dissolved oxygen (DO) that were recorded throughout the one year period (Table 4.5) ranged from 3.13 mg/L (Station 1, November 2012) to 6.60 mg/L (Station 4, June 2013). Based on Two way ANOVA, there is significant difference in mean DO among stations and among months ($p<0.05$). It is found that mean DO at Station 4 was significantly higher than other stations throughout the year. Meanwhile, mean DO in January 2013 was significantly higher than other months at Station 1, Station 2 and Station 5 while at Station 3 and Station 4, the mean DO was significantly higher in June 2013 than other months.

Table 4.5: Temporal variation of mean dissolved oxygen (± SD) recorded at each station throughout the sampling period. The same superscript showed no significant different at 5% significant level. Superscript: Arabic numbers = among stations; Alphabet = among months.

Month	Station				
	1	2	3	4	5
Oct 12	$4.01 \pm 0.02^{c,2}$	$3.87 \pm 0.03^{b,1}$	$4.91 \pm 0.02^{c,4}$	$5.92 \pm 0.02^{f,5}$	$4.30 \pm 0.01^{b,c,3}$
Nov 12	$3.13 \pm 0.01^{a,1}$	$3.59 \pm 0.02^{a,2}$	$4.07 \pm 0.02^{a,3}$	$5.23 \pm 0.01^{c,5}$	$4.30 \pm 0.00^{b,c,4}$
Dec 12	$3.47 \pm 0.02^{b,2}$	$3.40 \pm 0.02^{a,1}$	$4.43 \pm 0.01^{b,4}$	$4.98 \pm 0.03^{b,5}$	$3.99 \pm 0.02^{a,b,3}$
Jan 13	$6.17 \pm 0.02^{h,2}$	$5.14 \pm 0.10^{f,1}$	$5.88 \pm 0.27^{f,2}$	$6.17 \pm 0.01^{g,2}$	$5.85 \pm 0.03^{f,2}$
Feb 13	$3.53 \pm 0.03^{b,1}$	$4.10 \pm 0.03^{b,c,3}$	$4.29 \pm 0.03^{a,b,4}$	$4.51 \pm 0.02^{a,5}$	$3.90 \pm 0.04^{a,2}$
Mar 13	$4.29 \pm 0.01^{d,1}$	$4.62 \pm 0.08^{d,2}$	$5.54 \pm 0.05^{e,3}$	$6.15 \pm 0.03^{g,4}$	$4.50 \pm 0.14^{c,d,2}$
Apr 13	$4.11 \pm 0.05^{c,d,1}$	$4.29 \pm 0.03^{c,2}$	$5.11 \pm 0.02^{c,d,4}$	$5.61 \pm 0.02^{e,5}$	$4.38 \pm 0.02^{c,3}$
May 13	$4.04 \pm 0.01^{c,2}$	$4.11 \pm 0.01^{c,3}$	$5.29 \pm 0.02^{d,e,4}$	$6.56 \pm 0.02^{i,5}$	$3.96 \pm 0.01^{a,b,1}$
Jun 13	$4.94 \pm 0.00^{f,2}$	$5.06 \pm 0.02^{e,f,3}$	$6.07 \pm 0.01^{f,4}$	$6.60 \pm 0.01^{i,5}$	$4.79 \pm 0.01^{d,1}$
Jul 13	$5.39 \pm 0.21^{g,3}$	$4.31 \pm 0.03^{c,1}$	$4.84 \pm 0.02^{c,2}$	$5.86 \pm 0.03^{f,4}$	$5.49 \pm 0.01^{e,3}$
Aug 13	$4.69 \pm 0.03^{e,1}$	$4.84 \pm 0.03^{d,e,2}$	$5.02 \pm 0.01^{c,d,3}$	$6.31 \pm 0.02^{h,5}$	$5.22 \pm 0.05^{e,4}$
Sep 13	$4.14 \pm 0.13^{c,d,1}$	$4.22 \pm 0.24^{c,1,2}$	$4.81 \pm 0.26^{c,2,3}$	$5.47 \pm 0.14^{d,3}$	$5.30 \pm 0.38^{e,3}$

4.3.4.2 Temperature

Mean values of temperature that were recorded throughout the one year period (Table 4.6) ranged from 26.60 °C (Station 1, January 2013) to 32.10 °C (Station 4, March 2013). Based on Two way ANOVA, there is significant difference in mean temperature among stations and among months ($p<0.05$). It is found that mean temperature at Station 5 was significantly higher than other stations throughout the year. Meanwhile, mean temperature in March 2013 was significantly higher than other months at Station 2, Station 3 and Station 4 while at Station 1, the mean temperature was significantly higher in June 2013 than other months.

Table 4.6: Temporal variation of mean temperature (± SD) recorded at each station throughout the sampling period. The same superscript showed no significant different at 5% significant level. Superscript: Arabic numbers = among stations; Alphabet = among months.

Month	Station				
	1	2	3	4	5
Oct 12	29.10 ± 0.00^{c}	$30.10 \pm 0.00^{f,g}$	$29.60 \pm 0.00^{b,c}$	30.10 ± 0.00^{b}	31.10 ± 0.00
Nov 12	29.10 ± 0.00^{c}	$29.30 \pm 0.00^{b,c}$	29.70 ± 0.00^{c}	30.20 ± 0.00^{c}	30.80 ± 0.00
Dec 12	$29.17 \pm 0.06^{c,1}$	$29.43 \pm 0.06^{b,c,d,2}$	$30.60 \pm 0.00^{f,4}$	$30.40 \pm 0.00^{d,3}$	31.10 ± 0.00^{5}
Jan 13	26.60 ± 0.00^{a}	27.50 ± 0.00^{a}	28.20 ± 0.00^{a}	28.20 ± 0.00^{a}	27.70 ± 0.00
Feb 13	$27.73 \pm 0.40^{b,1}$	$29.17 \pm 0.40^{b,2}$	$29.50 \pm 0.17^{b,2}$	$30.77 \pm 0.06^{g,3}$	30.50 ± 0.00^{3}
Mar 13	$30.70 \pm 0.00^{f,g}$	30.90 ± 0.00^{i}	32.00 ± 0.00^{i}	32.10 ± 0.00^{i}	28.00 ± 0.00
Apr 13	$30.50 \pm 0.00^{f,g}$	30.50 ± 0.00^{h}	30.50 ± 0.00^{f}	30.20 ± 0.00^{c}	30.70 ± 0.00
May 13	30.40 ± 0.00^{f}	$30.40 \pm 0.00^{g,h}$	30.90 ± 0.00^{g}	30.70 ± 0.00^{f}	30.60 ± 0.00
Jun 13	30.80 ± 0.00^{g}	31.10 ± 0.00^{i}	31.40 ± 0.00^{h}	31.10 ± 0.00^{h}	31.00 ± 0.00
Jul 13	$29.90 \pm 0.00^{d,e}$	$29.70 \pm 0.00^{d,e}$	29.90 ± 0.00^{d}	30.10 ± 0.00^{b}	30.10 ± 0.00
Aug 13	29.60 ± 0.00^{d}	$29.60 \pm 0.00^{c,d,e}$	30.10 ± 0.00^{e}	30.70 ± 0.00^{f}	29.50 ± 0.00
Sep 13	30.00 ± 0.00^{e}	$29.90 \pm 0.00^{e,f}$	30.20 ± 0.00^{e}	30.60 ± 0.00^{e}	30.20 ± 0.00

4.3.4.3 Turbidity

Mean values of turbidity that were recorded throughout the one year period (Table 4.7) ranged from 0.99 NTU (Station 1, January 2013) to 86.97 NTU (Station 2, June 2013). Based on Two way ANOVA, there is significant difference in mean turbidity among stations and among months ($p<0.05$). It is found that mean turbidity among stations was significantly higher at several stations within a year. Meanwhile, mean turbidity in January 2013 was significantly higher than other months at all stations.

Table 4.7: Temporal variation of mean turbidity (± SD) recorded at each station throughout the sampling period. The same superscript showed no significant different at 5% significant level. Superscript: Arabic numbers = among stations; Alphabet = among months.

Month	Station				
	1	2	3	4	5
Oct 12	$2.65 \pm 0.20^{a,b,1}$	$2.95 \pm 0.25^{a,b,1}$	$3.02 \pm 0.19^{a,b,1}$	$5.87 \pm 0.47^{b,c,3}$	$4.73 \pm 0.21^{b,c,2}$
Nov 12	$4.47 \pm 0.31^{b,c,2}$	$3.98 \pm 0.16^{b,2}$	$2.64 \pm 0.24^{a,b,1}$	$4.50 \pm 0.85^{a,b,2}$	$3.58 \pm 0.23^{a,b,1,2}$
Dec 12	$2.51 \pm 0.32^{a,b,1}$	$2.63 \pm 0.25^{a,b,1}$	$2.73 \pm 0.29^{a,b,1}$	$8.47 \pm 0.15^{c,d,2}$	$3.06 \pm 0.11^{a,1}$
Jan 13	$86.97 \pm 1.61^{f,4}$	$39.63 \pm 1.16^{d,3}$	$20.04 \pm 2.76^{d,1}$	$25.93 \pm 2.80^{g,2}$	$42.60 \pm 1.44^{g,3}$
Feb 13	$10.05 \pm 0.16^{d,2}$	$8.85 \pm 0.33^{c,1}$	$15.71 \pm 0.31^{c,5}$	$13.44 \pm 0.22^{e,4}$	$11.27 \pm 0.73^{f,3}$
Mar 13	$5.17 \pm 0.89^{c,2}$	$3.22 \pm 0.05^{a,b,1}$	$5.18 \pm 0.18^{b,2}$	$5.97 \pm 0.52^{b,c,2}$	$5.40 \pm 0.28^{c,d,2}$
Apr 13	$2.67 \pm 0.26^{a,b,1}$	$2.07 \pm 0.12^{a,b,1}$	$2.49 \pm 0.07^{a,b,1}$	$2.33 \pm 0.02^{a,1}$	$4.02 \pm 0.58^{a,b,c,2}$
May 13	$2.79 \pm 0.63^{a,b,2}$	$1.64 \pm 0.04^{a,1,2}$	$1.17 \pm 0.26^{a,1}$	$4.54 \pm 0.58^{a,b,3}$	$5.36 \pm 0.35^{c,d,3}$
Jun 13	$1.61 \pm 0.13^{a,1}$	$0.99 \pm 0.13^{a,1}$	$1.21 \pm 0.07^{a,1}$	$2.72 \pm 0.60^{a,2}$	$3.10 \pm 0.08^{a,2}$
Jul 13	$17.05 \pm 0.72^{e,2}$	$7.85 \pm 1.03^{c,1}$	$17.41 \pm 2.42^{c,d,2}$	$16.55 \pm 0.30^{f,2}$	$10.47 \pm 0.13^{f,1}$
Aug 13	$2.70 \pm 0.13^{a,b,1}$	$2.53 \pm 0.15^{a,b,1}$	$3.12 \pm 0.11^{a,b,1}$	$4.63 \pm 0.61^{a,b,2}$	$6.94 \pm 0.23^{d,e,3}$
Sep 13	$5.42 \pm 0.89^{c,1}$	$7.48 \pm 2.05^{c,1,2}$	$5.49 \pm 1.58^{b,1}$	$9.11 \pm 0.71^{d,2}$	$8.47 \pm 0.51^{e,1,2}$

4.3.4.4 Salinity

Mean values of salinity that were recorded throughout the one year period (Table 4.8) ranged from 11.00 PSU (Station 1 and Station 4, January 2013) to 34.67 PSU (Station 3, June 2013). Based on Two way ANOVA, there is significant difference in mean salinity among stations and among months ($p<0.05$). It is found that mean salinity was significantly higher at either Station 3 or Station 4 within a year. Meanwhile, mean salinity was significantly higher in June 2013 and July 2013 than other months at almost all stations.

Table 4.8: Temporal variation of mean salinity (± SD) recorded at each station throughout the sampling period. The same superscript showed no significant different at 5% significant level. Superscript: Arabic numbers = among stations; Alphabet = among months.

Month	Station				
	1	2	3	4	5
Oct 12	$28.00 \pm 0.00^{e,f,2}$	$22.00 \pm 0.00^{b,c,1}$	$27.33 \pm 0.58^{d,2}$	$29.00 \pm 0.00^{d,e,3}$	$22.00 \pm 0.00^{b,1}$
Nov 12	$26.00 \pm 0.00^{c,1}$	$27.00 \pm 0.00^{d,1}$	$29.33 \pm 0.58^{e,2}$	$33.67 \pm 0.58^{h,3}$	$30.33 \pm 1.15^{g,2}$
Dec 12	$26.67 \pm 0.58^{c,d,1}$	$27.33 \pm 0.58^{d,1,2}$	$31.00 \pm 0.00^{f,3}$	$28.33 \pm 0.58^{c,d,2}$	$28.67 \pm 0.58^{f,2}$
Jan 13	$11.00 \pm 0.00^{a,1}$	$13.00 \pm 0.00^{a,2}$	$16.33 \pm 0.58^{a,3}$	$11.00 \pm 0.00^{a,1}$	$13.00 \pm 0.00^{a,2}$
Feb 13	$21.00 \pm 0.00^{b,2}$	$21.33 \pm 0.58^{b,2,3}$	$22.00 \pm 0.00^{b,3}$	$20.00 \pm 0.00^{b,1}$	$21.33 \pm 0.58^{b,2,3}$
Mar 13	$29.00 \pm 0.00^{f,g,4}$	$23.00 \pm 0.00^{c,1}$	$26.00 \pm 0.00^{c,3}$	$30.33 \pm 0.58^{f,5}$	$24.00 \pm 0.00^{c,2}$
Apr 13	$27.67 \pm 0.58^{d,e,1}$	$27.67 \pm 0.58^{d,1}$	$29.67 \pm 0.58^{e,2}$	$28.00 \pm 0.00^{c,d,1}$	$28.00 \pm 0.00^{e,f,1}$
May 13	$27.33 \pm 0.58^{d,e,1,2}$	$26.67 \pm 0.58^{d,1}$	$28.00 \pm 0.00^{d,2}$	$27.67 \pm 0.58^{c,1,2}$	$28.00 \pm 0.00^{e,f,2}$
Jun 13	$32.33 \pm 0.58^{h,1,2}$	$32.67 \pm 0.58^{f,2}$	$34.67 \pm 0.58^{g,3}$	$33.33 \pm 0.58^{h,2,3}$	$31.00 \pm 0.00^{g,1}$
Jul 13	$32.33 \pm 0.58^{h,1}$	$33.67 \pm 0.58^{f,2}$	$32.00 \pm 0.00^{f,1}$	$32.00 \pm 0.00^{g,1}$	$32.33 \pm 0.58^{h,1}$
Aug 13	$30.00 \pm 0.00^{g,2}$	$30.33 \pm 0.58^{e,2,3}$	$31.00 \pm 0.00^{f,3}$	$31.00 \pm 0.00^{f,g,3}$	$27.00 \pm 0.00^{d,e,1}$
Sep 13	$28.00 \pm 0.00^{e,f,2}$	$27.33 \pm 0.58^{d,2}$	$28.00 \pm 0.00^{d,2}$	$30.00 \pm 0.00^{e,f,3}$	$26.00 \pm 0.00^{d,1}$

4.3.4.5 pH

Mean values of pH that were recorded throughout the one year period (Table 4.9) ranged from 5.74 (Station 5, January 2013) to 8.73 (Station 2, May 2013). Based on Two way ANOVA, there is significant difference in mean pH among stations and among months ($p<0.05$). It is found that mean pH was mostly significantly higher at Station 4 than other stations throughout the year. Meanwhile, mean pH was significantly higher in May 2013 at Station 1, Station 2 and Station 3 than other months while at Station 4 and Station 5, the mean pH was significantly higher in July 2013 than other months.

Table 4.9: Temporal mean with standard deviation of pH (± SD) recorded at each station throughout the sampling period. The same superscript showed no significant different at 5% significant level. Superscript: Arabic numbers = among stations; Alphabet = among months.

Month	Station				
	1	2	3	4	5
Oct 12	$7.50 \pm 0.02^{d,3}$	$7.40 \pm 0.01^{c,2}$	$7.53 \pm 0.01^{d,3}$	$7.31 \pm 0.02^{c,1}$	$7.32 \pm 0.02^{c,1}$
Nov 12	$6.44 \pm 0.09^{a,1}$	$6.65 \pm 0.16^{b,1}$	$7.11 \pm 0.01^{c,2}$	$7.64 \pm 0.20^{d,3}$	$7.30 \pm 0.02^{c,2}$
Dec 12	$7.17 \pm 0.03^{c,1}$	$7.38 \pm 0.01^{c,2}$	$7.78 \pm 0.02^{e,4}$	$7.96 \pm 0.00^{e,5}$	$7.66 \pm 0.02^{d,3}$
Jan 13	$6.40 \pm 0.04^{a,4}$	$5.98 \pm 0.01^{a,3}$	$5.91 \pm 0.02^{a,2}$	$5.94 \pm 0.03^{a,2,3}$	$5.74 \pm 0.02^{a,1}$
Feb 13	$6.57 \pm 0.07^{b,1}$	$6.90 \pm 0.02^{b,2}$	$6.84 \pm 0.05^{b,2}$	$7.09 \pm 0.01^{b,3}$	$6.75 \pm 0.09^{b,2}$
Mar 13	$7.77 \pm 0.04^{e,1}$	$7.93 \pm 0.04^{f,2}$	$7.90 \pm 0.03^{e,f,2}$	$7.96 \pm 0.01^{e,2}$	$7.90 \pm 0.03^{f,g,2}$
Apr 13	$7.54 \pm 0.01^{d,2}$	$7.75 \pm 0.04^{d,e,f,4}$	$7.45 \pm 0.01^{d,1}$	$7.64 \pm 0.02^{d,3}$	$7.75 \pm 0.03^{d,e,4}$
May 13	$8.35 \pm 0.05^{g,2}$	$8.73 \pm 0.32^{g,2}$	$8.56 \pm 0.13^{h,2}$	$7.89 \pm 0.03^{e,1}$	$7.84 \pm 0.03^{e,f,1}$
Jun 13	$7.75 \pm 0.01^{e,1}$	$7.78 \pm 0.01^{d,e,f,2}$	$7.83 \pm 0.02^{e,f,3}$	$7.92 \pm 0.01^{e,5}$	$7.86 \pm 0.02^{f,4}$
Jul 13	$8.13 \pm 0.06^{f,2}$	$7.50 \pm 0.00^{c,d,1}$	$8.13 \pm 0.06^{g,2}$	$8.30 \pm 0.00^{f,3}$	$8.27 \pm 0.06^{h,3}$
Aug 13	7.86 ± 0.00^{e}	$7.87 \pm 0.00^{e,f}$	7.91 ± 0.00^{f}	8.00 ± 0.00^{e}	7.98 ± 0.00^{g}
Sep 13	$7.43 \pm 0.00^{d,1}$	$7.56 \pm 0.09^{c,d,e,2}$	$7.95 \pm 0.02^{f,3}$	$8.19 \pm 0.00^{f,4}$	$7.36 \pm 0.00^{c,1}$

4.3.5 Relationship between Fish Larvae Data (Density, Shannon-Wiener Diversity Index, Number of Family) with Physico-chemical Water Parameters

In this study, Pearson correlation analyses (Table 4.10) showed that density of fish larvae is significantly influenced by the dissolved oxygen (DO) and turbidity with both showed weak positive correlation (DO: r=0.384, p=0.002; turbidity: r=0.271, p=0.036). Shannon-Wiener Diversity index (H') is significantly influenced by all physico-chemical parameters involved (DO, temperature, turbidity, salinity and pH). However, most of physico-chemical parameters showed weak positive correlation with H' which are DO (r=0.295, p=0.022), salinity (r=0.287, p=0.026) and pH (r=0.266, p=0.040), while temperature showed moderate positive correlation with H' (r=0.414, p=0.001). On the other hand, turbidity showed weak negative correlation with H' (r=-0.239, p=0.023). Meanwhile, the number of family of fish larvae is significantly influenced by DO with strong positive correlation (r=0.627, p<0.001).

Table 4.10: Pearson correlation analyses (p=0.05) among all physico-chemical parameters (dissolved oxygen, temperature, turbidity, salinity and pH), density, diversity (H') and family of fish larvae recorded in this study.

		DO	Temperature	Turbidity	Salinity	pH
Density	r	0.384**	-0.094	0.271*	-0.013	-0.031
	p	0.002	0.475	0.036	0.922	0.814
H'	r	0.295*	0.414**	-0.239*	0.287*	0.266*
	p	0.022	0.001	0.023	0.026	0.04
Family	r	0.627**	0.225	0.022	0.212	0.186
	p	0.000	0.084	0.869	0.104	0.154

Notes: ** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

4.3.6 Spatial Variation of Fish Larvae in Relation with Depth

The highest mean depth was recorded at Station 4 (19.27 ± 4.18 m) while the lowest mean depth was recorded at Station 2 (8.16 ± 1.85 m) (Figure 4.10).

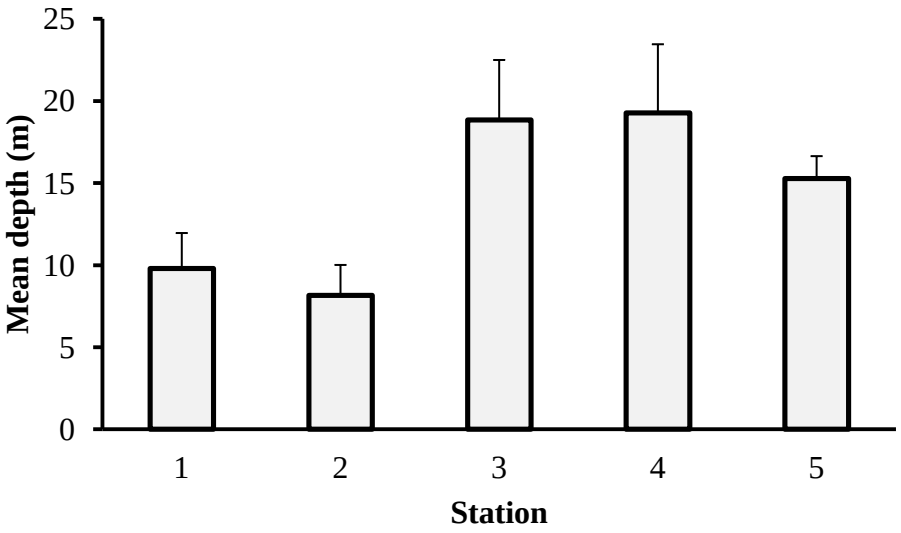


Figure 4.10: Mean depths of Sungai Sibu Laut-Sungai Salak estuaries at each station throughout the sampling period.

Pearson correlation analyses showed that density, Shannon-Wiener Diversity Index (H') and number of family of fish larvae were significantly influenced ($p<0.05$) by the depth (Table 4.11). Density and H' of fish larvae showed weak positive correlation with depth (Density: $r=0.335$, $p=0.009$; H': 0.370, $p=0.004$), while the number of family of fish larvae showed moderate positive correlation with depth ($r=0.592$, $p<0.001$).

Table 4.11: Pearson correlation analyses (p=0.05) between depth of sampling site and fish larvae (density, H' and number of family).

		Density	H'	Family
Depth	r	0.335**	0.370**	0.592**
	p	0.009	0.004	0.000

Notes: ** Correlation is significant at the 0.01 level (2-tailed)

4.3.7 Fish Eggs Classification and Spatio-temporal Pattern

A total of 31,566 fish eggs were collected throughout the sampling period. Mean density of fish eggs was compared among stations and among months. According to the station (Figure 4.11a), the highest mean density was observed at Station 3 (252.41 ± 394.37 eggs/100 m^3), while the lowest mean density was observed at Station 2 (80.06 ± 182.13 eggs/100 m^3). However, One way ANOVA did not show any significant difference among the stations ($p>0.05$).

For the temporal variation (Figure 4.11b), mean density of fish eggs showed four peaks that occurred in October 2012, January 2013, April 2013 and August 2013 with the highest peak in April 2013 (965.32 ± 665.62 eggs/100 m^3). Based on One way ANOVA, there is significant difference in mean density among months ($p<0.05$) where mean density of fish eggs in April 2013 was significantly higher than other months.

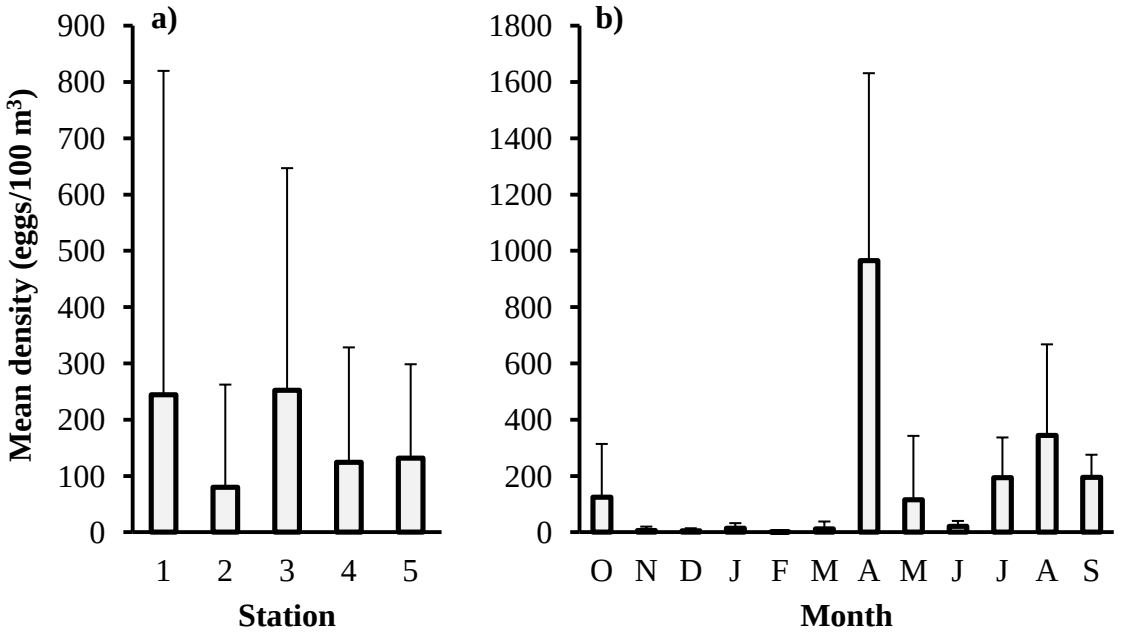


Figure 4.11: Mean density of fish eggs according to a) stations and b) months.

The temporal variation in fish eggs density at each station showed similar pattern (Figure 4.12). The highest density of fish eggs occurred in April 2013 at all stations except Station 5 which showed the second highest density during that month after August 2013. Throughout the study period, it is found that the highest fish eggs density was observed at Station 1 in April 2013 (2,018.11 eggs/100 m^3). Before April 2013, most stations recorded zero or low density of fish eggs except for Station 3 and Station 5 that showed relatively high density in October 2012. After April 2013, the fish eggs density decreased for all stations and started peaking up again in June 2013 until September 2013. All stations except Station 4 recorded no fish eggs in certain months. Station 1, Station 2 and Station 5 that are located at the upper part of the river showed more months without fish eggs compared to Station 3 which is near to the river mouth.

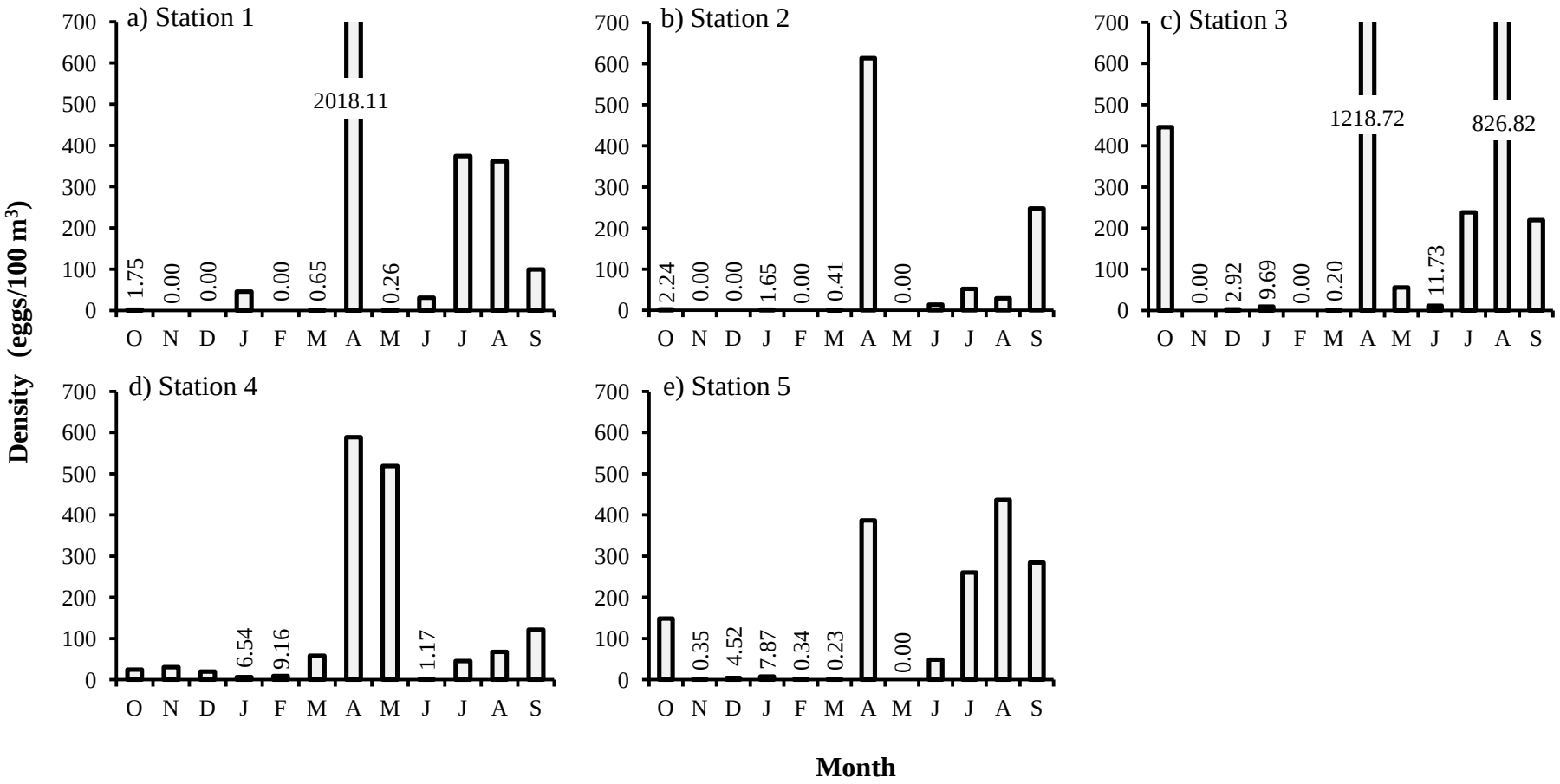


Figure 4.12: Temporal variation in density of fish eggs at each station throughout this study. Notes: all *y*-axis of the graphs are fixed to 700 egg/100 m^3 for comparison between stations. Values that exceed the fixed range are written on the bar.

Temporal occurrence of total number of fish eggs according to its shapes showed a continuous occurrence for both shapes throughout this study period (Figure 4.13). Temporal occurrence of spherical shaped eggs showed five peaks that occurred in October 2012, January 2013, May 2013, July 2013 and September 2013, with the highest peak recorded in May 2013 (2,425 eggs). On the other hand, temporal occurrence of elliptical shaped eggs showed three peaks that occurred in January 2013, April 2013 and August 2013, with the highest peak recorded in April 2013 (10,191 eggs). Least number of spherical shaped eggs was observed in December 2012 with only one egg, while least number of elliptical shaped eggs was observed in May 2013 with eight eggs. It was observed that the number of spherical shaped eggs was lower than the elliptical shaped eggs in most months except in October 2012, May 2013 and June 2013.

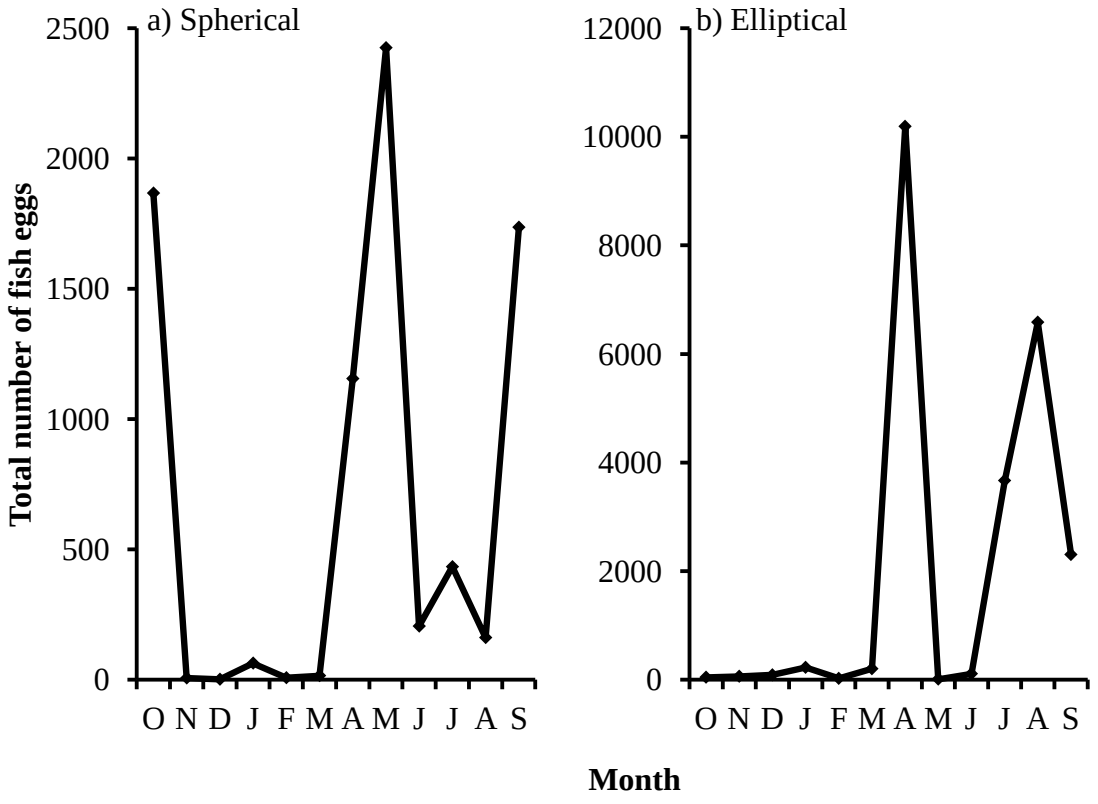


Figure 4.13: Temporal pattern in total number of fish eggs according to egg shapes.

Pearson correlation analyses showed that density of fish eggs was not significantly influenced ($p>0.05$) by all physico-chemical parameters of the water (Table 4.12).

Table 4.12: Pearson correlation analyses ($p=0.05$) between density of fish eggs and all physico-chemical parameters of water (dissolved oxygen, temperature, turbidity, salinity, pH and depth) recorded in this study.

		DO	Temperature	Turbidity	Salinity	pH	Depth
Density	r	0.049	0.120	-0.135	0.158	0.148	0.161
	p	0.712	0.361	0.305	0.228	0.259	0.220

4.3.8 Comparison between Fish Eggs and Fish Larvae

Mean density of fish eggs and fish larvae were compared among stations and among months (Figure 4.14). Based on stations, mean density of fish eggs were higher than the mean density of fish larvae at Station 1, Station 2, Station 3 and Station 5 but lower at Station 4. Based on months, mean density of fish eggs were higher than the mean density of fish larvae in these six months: October 2012, March 2013, April 2013, May 2013, August 2013 and September 2013. For the rest of other months, mean density of fish eggs were lower than mean density of fish larvae which was in November 2012, December 2012, January 2013, February 2013, June 2013 and July 2013.

Pearson correlation analyses showed that density of fish eggs is significantly influenced the density of fish larvae (Table 4.13) with a weak positive correlation ($r=0.303$, $p=0.019$).

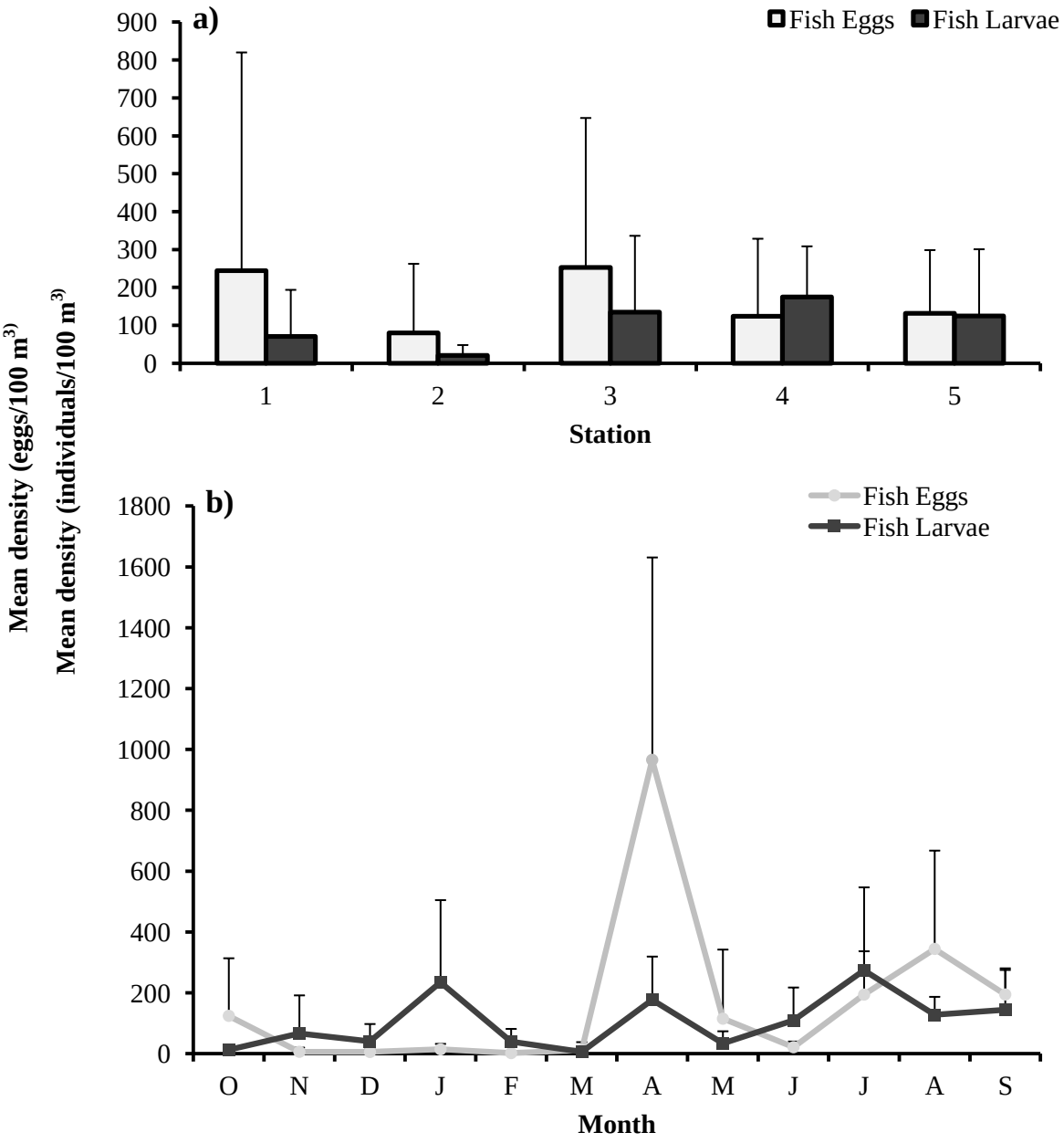


Figure 4.14: Comparison between mean density of fish eggs and fish larvae according to a) stations and b) months.

Table 4.13: Pearson correlation analyses (p=0.05) between density of fish eggs and density of fish larvae.

		Fish Larvae
Fish Eggs	r	0.303*
	p	0.019

Notes: * Correlation is significant at the 0.05 level (2-tailed)

4.4 Discussion

A total of 30 families were identified in this study which is higher than the previous study by Blaber *et al*. (1997) that recorded 24 families from 23 estuaries along Sabah and Sarawak. In addition, number of fish larvae family that was recorded from two estuaries in Johor (23 families) is lower than this study (Ara *et al*., 2011c; Arshad *et al*., 2012). A recent short survey in western part of Sarawak (Muhamad and Rahim, 2013) that was conducted at the same location with this study, recorded the lowest families (16 families) among those studies. Overall, a total of 21 families found in this study were also recorded in other studies that were mentioned above with eight families recorded in all studies (Table 4.14), namely Ambassidae, Blenniidae, Carangidae, Clupeidae, Engraulidae, Gobiidae, Hemiramphidae and Syngnathidae.

Family Gobiidae showed the highest abundance with 76.76% from the total fish larvae collected, followed by Engraulidae (7.23%) and Clupeidae (3.71%). Compared to other studies in Malaysian waters that were mentioned above, Blaber *et al*. (1997) recorded Gobiidae having the highest abundance in Sabah and Sarawak, while Clupeidae was reported as the most abundance larvae in western part of Sarawak (Muhamad and Rahim, 2013) and from two estuaries in Johor (Ara *et al*., 2011c; Arshad *et al*., 2012).

In comparison between this study and other studies in Malaysian estuaries, nine new records of fish larvae families were recorded, namely Acropomatidae, Centrolophidae, Haemulidae, Muraenidae, Paralichthyidae, Pristigasteridae, Scombridae, Scorpaenidae and Serranidae. For Sarawak waters, 12 families are new records, namely Acropomatidae, Centrolophidae, Haemulidae, Monacanthidae, Muraenidae, Paralichthyidae, Pristigasteridae, Scatophagidae, Scombridae, Scorpaenidae, Serranidae and Uranoscopidae.

Table 4.14: Fish larvae family recorded between this study and other local published articles.

	Family	This Study	Sarawak Survey	Sabah & Sarawak	Johor
1	Acropomatidae	+			
2	Ambassidae	+	+	+	+
3	Apogonidae	+		+	
4	Ariidae			+	
5	Atherinidae	+		+	
6	Belonidae		+		+
7	Blenniidae	+	+	+	+
8	Callionymidae	+	+		
9	Carangidae	+	+	+	+
10	Centrolophidae	+			
11	Clupeidae	+	+	+	+
12	Cynoglossidae	+		+	+
13	Eleotridae			+	
14	Elopidae		+		
15	Engraulidae	+	+	+	+
16	Gerreidae		+		
17	Gobiidae	+	+	+	+
18	Haemulidae	+			
19	Hemiramphidae	+	+	+	+
20	Leiognathidae	+	+		+
21	Lutjanidae			+	
22	Monacanthidae	+			+
23	Monodactylidae				+
24	Mugilidae	+		+	
25	Mullidae				+
26	Muraenidae	+			
27	Myctophidae		+		
28	Nemipteridae				+
29	Ostraciidae			+	
30	Pangasiidae			+	
31	Paralichthyidae	+			
32	Polynemidae			+	
33	Pristigasteridae	+			
34	Rachycentridae				+
35	Samaridae				+
36	Scatophagidae	+			+
37	Sciaenidae	+		+	
38	Scombridae	+			
39	Scorpaenidae	+			
40	Serranidae	+			
41	Siganidae			+	
42	Sillaginidae	+	+		+
43	Syngnathidae	+	+	+	+
44	Synodontidae	+		+	
45	Terapontidae				+
46	Tetraodontidae	+	+	+	
47	Toxotidae				+
48	Triacanthidae				+
49	Trichiuridae			+	
50	Triglidae			+	
51	Uranoscopidae	+			+
	Total	30	16	24	23
			Muhamad and Rahim (2013)	Blaber *et al.* (1997)	Ara *et al.* (2011c); Arshad *et al.* (2012)

Throughout this study, fish larvae showed variation in mean density among stations and among months. Low mean density of fish larvae were observed at the upstream of Sungai Sibu Laut (Station 1 and Station 2) and Sungai Salak (Station 5), compared to the downstream of Sungai Sibu Laut (Station 3) and towards the river mouth (Station 4). This situation could be related to the physico-chemical water parameters in the water column. In this study, it was observed that density of fish larvae showed weak positive correlation with dissolved oxygen (DO) and turbidity. According to stations, DO showed an increasing pattern towards the lower part of Sungai Sibu Laut indicating a high aeration process occurred at the lower part of the river. This is related to the increase of water movement due to the increase in river depth towards the river mouth and as a tidal influenced river, lower part of the river is exposed to strong ocean currents and tidal effects (Herbert and Ontario, 2008). As the DO concentrations increased towards downstream of Sungai Sibu Laut, the density of fish larvae also increased. This is because fish tend to avoid area with low DO concentrations and in case of larvae with a limited swimming ability and affected by the current, death is certain because it reduced the feeding rates of fish larvae (Breitburg, 1994).

Turbidity in the water column can be classified into two, namely inorganic turbidity which consist of sediment particles; and organic turbidity which consist of living planktonic organisms and plant materials, and both of them contribute to the turbidity in the water column. As observed with the positive correlation between fish larvae density and turbidity, turbidity in the water probably resulted from organic materials that served as nutrient source for the planktonic organisms to bloom and act as food for fish larvae. At the sampling site, there is a wastewater discharges from the nearby aquaculture (Soo *et al.*, 2014) and the residential area at Telaga Air Village which might contribute to the nutrient enrichment in the water column at lower part of the river where Station 3 and Station 4 are located.

Furthermore, river mouth is a place where freshwater and saltwater are mixed together and the nutrients from the upper part of the river will deposited at the river mouth (Herbert and Ontario, 2008) enhance the bloom of planktonic organisms.

According to monthly variation, mean density of fish larvae exhibits five peaks (November 2012, January 2013, April 2013, July 2013 and September 2013) which were \one or two months interval period from each other. However, according to each station, peak density of fish larvae at Station 1 and Station 2 showed one to three months interval period from each other, while the rest (Station 3, Station 4 and Station 5) showed similar pattern with mean density. These peaks indicate a breeding season of most fishes at Sungai Sibu Laut-Sungai Salak estuaries. A similar results were reported by both studies in Johor for the monthly density of fish larvae in both Sungai Pendas and Sungai Pulai estuaries, Johor (Ara *et al*, 2011c; Arshad *et al*., 2012).

The diversity of fish larvae is high at Station 4. However, the individuals of fish larvae were not distributed equitably within that station where one family (Gobiidae) consists of high number of individuals (65.66%). When looking at the temporal pattern, high diversity was observed in June 2013. However, due to the present of high number of individuals (56.43%) belonging to one family (Gobiidae), the individuals of fish larvae were not distributed equitably within the particular month. This temporal pattern of fish larvae diversity is quite similar with the data reported by Arshad *et al*. (2012) that conducted temporal study of fish larvae in estuary. The individual of fish larvae seems to be distributed more equitably in their study compared to this study. This is probably due to the differences is collection method and geographical area of the sampling sites.

In this study, 14 families were collected from all sampling stations, suggesting that these families have a wide larval dispersal area and can adapt to a wide range of habitat. On

the other hand, the other eight families showed narrow larval dispersal as they were found only in certain station throughout this study. However, three out of eight families (Sillaginidae, Synodontidae and Uranoscopidae) were also recorded in other studies. Sillaginidae was found to aggregate in small group in Johor estuaries (Ara *et al*., 2011c). Meanwhile, Synodontidae and Uranoscopidae larvae were recorded in small numbers from the studies in estuaries of Sabah and Sarawak (Blaber *et al*., 1997) and Sungai Pendas in Southwestern of Johor (Arshad *et al*., 2012), respectively. This suggests that these three families might be confined to only at certain location in a particular estuary habitat or they are not the resident of estuary but accidently enter the area with the flow of current.

As mentioned earlier, Gobiidae larvae were found to be a dominant family since it occupied more than 50% from the total fish larvae collected at each station. It shows that Gobiidae might be a resident family in Sungai Sibu Laut-Sungai Salak estuaries and aggregate in a large shoal. Fish that belong to Family Gobiidae are commonly known as Gobies and Mudskippers, and they are demersal type of fishes which can occupied various types of habitat such as estuaries, coral reefs (Department of Fisheries Malaysia, 2009; Muhamad-Norizam and Ali, 2009), sandy beaches (see Chapter 3) and off shore of estuary habitat (Ara *et al*., 2011a). Furthermore, Ryan (1991) mentioned a few factors that might contribute to the dominancy of Gobiidae which are euryhaline fish, small in size with excellent climbing ability, having various type of feeding habits (carnivore, omnivore and herbivore) because this study involved estuaries with mangrove habitat.

On the other hand, the other 13 families that were also found at all stations with low abundance are generally demersal and reef-associated type of fish which live in a small shoal probably due to the territorial behaviour of Gobiidae (Privileggi *et al*., 1997). Another reason

that leads to the low abundance of these 13 families is because they were not presence every month except for Blenniidae, Carangidae and Engraulidae.

Blenniidae, Carangidae, Engraulidae and Gobiidae that were collected every month with high abundance of preflexion larvae indicate a continuous reproduction of these families. However, the other two growth stages were not continuously recorded every month except for Gobiidae, suggesting that these larvae are not resident fish in this estuary and they probably migrate toward the ocean as they grow. This is because those three families are mostly reef-associated and pelagic type of fish (Department of Fisheries Malaysia, 2009).

Studies in Johor showed only Blenniidae (Arshad *et al*., 2012) and Clupeidae (Ara *et al*., 2011c) were collected every month. However, the monthly variation of Blenniidae larvae in Johor is different from this study, where high density of Blenniidae larvae were observed in February, April and August which happened to be low in this study. This could be related to the geographical factor of sampling site, where Johor is located at Malacca Strait where Andaman Sea and South China Sea met, while this study only faced South China Sea. In addition, different sampling approaches from both studies might also influence the results obtained.

In contrast with the families that were collected every month, nine families were observed only once throughout the sampling period, namely Centrolophidae, Haemulidae, Mugilidae, Muraenidae, Paralichthyidae, Scombridae, Sillaginidae, Synodontidae and Uranoscopidae with the number of individuals less than three. This suggests that adult fishes under these families might be a solitary fish, went to estuary for breeding, prefer to be a part of other shoaling fish called heterotypic grouping or can only be encountered at night (Hyndes *et al*., 1996; Santos and Castro, 2003; Pereira *et al*., 2011). Meanwhile, some families are benthic type of fish (Paralichthyidae, Synodontidae and Uranoscopidae) that inhabit the river

bed (Soares *et al*., 2002; Bray, 2011; Carpenter and Niem, 2011), which probably occurred during their larval stages thus lowering the probability to get caught in high abundance because the plankton net was not dragged close to the maximum depth in order to avoid net damage.

Fish eggs showed variation in mean density among stations and among months. There is no specific pattern in the mean density of fish eggs from stations at the upstream and downstream of the river. Furthermore, the correlation between fish eggs density and physico-chemical water parameters was not significant. This is because fish eggs are highly depend on water current to disperse in the water column (Ré and Meneses, 2009). However, water current was not measured in this study.

Density of fish eggs could determine fish recruitment pattern. Based on the monthly variation, high mean density of fish eggs was observed starting from April until October which coincides with dry season during southwestern monsoon (McGinley, 2011). According to the water parameters recorded during this study, temperature, salinity and alkalinity were higher, while turbidity was lower during dry season which increase the growth rate and shortened the incubation period of ichthyoplankton (Pearce and Hutchins, 2009; Petereit *et al.*, 2009; Rhody *et al.*, 2010; Ye *et al.*, 2010). On the other hand, low density of fish eggs was observed from November 2012 to March 2013 which is during rainy season and northeast monsoon. However, for fish larvae mean density, it showed high peak in both monsoon, while low mean density of fish larvae were observed only during inter monsoons which are in March and October suggesting a different influenced of monsoon seasons towards fish larvae. However, this is not a conclusive situation.

4.5 Conclusion

In this study, 30 families were recorded with Gobiidae as the dominant family throughout the sampling period. The density of fish larvae increased from upstream towards downstream of Sungai Sibu Laut-Sungai Salak estuaries. Temporal pattern of fish larvae density revealed that fish larvae occurred throughout the year with several peak densities. Low fish larvae diversity in the sample is due to the presence of high abundance of fish larvae in a single family (Gobiidae). Gobiidae is shown to be a resident family in this study site. Dissolved oxygen and turbidity are showed to affect the density of fish larvae. Temporal pattern of fish eggs density revealed a continuous production of fish eggs in study site. In short, this study revealed a continuous recruitment of ichthyoplankton in Sungai Sibu Laut-Sungai Salak estuaries. However, continuous research is needed because every year the issue of climate change is getting more serious and can affect fish supply to local people. Therefore, ichthyoplankton data need to be updated so that appropriate management can be made according to the current situation.

CHAPTER 5

GENERAL DISCUSSION AND CONCLUSIONS

5.1 General Discussion

Ichthyoplankton is an early life stage of fish that consist of fish eggs and fish larvae which is part of fish recruitment component. Information on fish recruitment is important in managing the fish resources and national food security. However, research on ichthyoplankton is quite limited in Malaysian waters especially in Sarawak since the last extensive study was conducted by Blaber *et al*. (1997) that cover most estuaries in Sabah and Sarawak. In addition, a recent short survey was done by Muhamad and Rahim (2012) at selected areas in western part of Sarawak.

In this present study, morphological characteristics of fish larvae at selected coastal waters of Sarawak were documented in Chapter 2; and the spatio-temporal assemblages and distribution of ichthyoplankton were discussed in Chapter 3 and Chapter 4, together with their relationship with physico-chemical parameters of water. Chapter 3 discussed about spatial study of fish larvae assemblages and distribution at selected intertidal areas of Sarawak coastal waters and one sampling site (Pulau Sampadi) was chosen to observe the differences of fish larvae assemblages between intertidal and subtidal zones. Meanwhile, spatio-temporal study on ichthyoplankton of Sungai Sibu Laut-Sungai Salak estuaries was investigated for one year and discussed in Chapter 4. Fish larvae are the main focused in this Chapter 4 while fish eggs were studied in detail.

Documentation on fish larvae in Chapter 2 recorded 38 families from both spatial study (Chapter 3) and spatio-temporal study (Chapter 4) in Sarawak coastal waters. Most of them are marine associated fishes that could be bathydemersal, bathypelagic, bentopelagic,

pelagic, reef-associated or demersal type of fishes (Department of Fisheries Malaysia, 2009). Their morphological characteristics were described according to the identification books and published articles, while the possible genera under those families were based on other studies of adult fish that were reported in Sarawak waters or from the nearby coastal areas. Commercially important fish family were identified and a few of them have been recorded at more than half of the sampling sites namely Clupeidae, Engraulidae and Gerreidae. Different habitat characteristics of the sampling sites could be the reasons for the variation in family composition of fish larvae. Basically, the selected sampling sites can be divided into two general habitats (marine and estuary) and different composition of fish larvae family were discovered in those habitats. Based on Table 5.1, it was observed that half of the fish larvae family found can inhabit both habitats.

Table 5.1: Classification of fish larvae families according to habitat types.

Habitat	**Family**				**Total**
Marine	Balistidae	Chanidae	Exocoetidae	Gerreidae	8
	Megalopidae	Myctophidae	Pterelectridae	Terapontidae	
Estuary	Acropomatidae	Centrolophidae	Haemulidae	Muraenidae	11
	Paralichthyidae	Pristigasteridae	Scombridae	Syngnathidae	
	Synodontidae	Tetraodontidae	Uranoscopidae		
Both	Ambassidae	Apogonidae	Atherinidae	Blenniidae	19
	Callionymidae	Carangidae	Clupeidae	Cynoglossidae	
	Engraulidae	Gobiidae	Hemiramphidae	Leiognathidae	
	Monacanthidae	Mugilidae	Scatophagidae	Sciaenidae	
	Scorpaenidae	Serranidae	Sillaginidae		

Spatial study (Chapter 3) recorded 27 families in which 18 families were found at intertidal zones, while 20 families were recorded at Pulau Sampadi alone (both intertidal and subtidal zones). It was found that more families were recorded at subtidal zone of Pulau Sampadi. Ambassidae was the dominant family in this study although it was not obtained from all sites. Meanwhile, Clupeidae and Gerreidae showed a wide larval distribution because they were collected from all sampling sites. Habitat heterogeneity between all intertidal sampling sites and between both zones at Pulau Sampadi could be the reason for the different family composition at each sampling site.

Comparison of fish larvae size obtained from intertidal and subtidal zones of Pulau Sampadi showed different habitats preference by fish larvae according to their growth stages. Intertidal zone of Pulau Sampadi recorded larger fish larvae which indicate that they are in the latter growth stage compared to subtidal zone that mostly have preflexion stage larvae. However, when compared with temporal sampling at Sungai Sibu Laut-Sungai Salak estuaries (Chapter 4), most families obtained consist of all growth stages (Table 5.2). This suggests that Sungai Sibu Laut-Sungai Salak estuaries played an important role as nursery ground for most fish in Sarawak waters.

Table 5.2: The size of fish larvae (mean total length or total length) and their growth stages according to family, obtained at three different types of habitat. Alphabets in superscript refer to: a = preflexion; b = flexion; and c = postflexion. '–' means no larvae were recorded from that habitat.

Family	Intertidal	Subtidal	Estuary
Ambassidae	7.66 ± 2.91^{c}	$2.86 \pm 1.04^{b,c}$	$6.37 \pm 1.31^{b,c}$
Apogonidae	-	$2.43 \pm 1.03^{a,c}$	2.11 ± 0.35^{a}
Atherinidae	5.77 ± 0.23^{c}	2.85 ± 0.42^{a}	$3.79 \pm 1.30^{a,b}$
Blenniidae	13.56 ± 3.85^{c}	2.34 ± 0.71^{a}	2.90 ± 0.64^{a}
Callionymidae	-	$2.49 \pm 0.89^{a,b,c}$	$3.61 \pm 1.44^{a,b,c}$
Carangidae	34.47 ± 4.99^{c}	-	$3.68 \pm 3.51^{a,b,c}$
Chanidae	11.67 ± 0.58^{c}	3.85 ± 1.50^{a}	-
Clupeidae	19.49 ± 2.50^{c}	3.21 ± 1.17^{a}	$6.85 \pm 5.32^{a,b,c}$
Cynoglossidae	-	3.00 ± 0.71^{a}	$3.77 \pm 1.50^{a,b}$
Engraulidae	22.60 ± 4.69^{c}	-	$8.14 \pm 5.60^{a,b,c}$
Gerreidae	10.26 ± 4.89^{c}	3.40 ± 1.17^{c}	-
Gobiidae	7.07 ± 0.81^{c}	$3.03 \pm 0.85^{a,b,c}$	$4.61 \pm 2.41^{a,b,c}$
Hemiramphidae	32.34^{c}	-	22.69 ± 13.12^{c}
Leiognathidae	47.00 ± 16.63^{c}	-	$2.61 \pm 1.10^{a,b}$
Monacanthidae	-	2.07 ± 0.06^{a}	2.75 ± 0.64^{a}
Mugilidae	12.98 ± 5.02^{c}	-	3.9 ± 1.13^{c}
Scatophagidae	13.32^{c}	-	$3.60 \pm 3.94^{a,c}$
Sciaenidae	7.00 ± 1.51^{b}	-	$6.10 \pm 3.70^{a,b,c}$
Scorpaenidae	-	$3.57 \pm 1.29^{a,b}$	$3.61 \pm 1.41^{a,b}$
Serranidae	-	$4.28 \pm 2.26^{a,c}$	1.96 ± 0.39^{a}
Sillaginidae	6.40 ± 4.79^{c}	-	14.00^{c}

The spatio-temporal study of ichthyoplankton in Kuching Wetland National Park estuaries (Chapter 4) recorded 30 families with Gobiidae as a dominant family collected in this study. Stations at the river upstream recorded low density and diversity of fish larvae compared to downstream of the river but for fish eggs density, it showed vice versa. Meanwhile, according to the temporal pattern of fish eggs density, data indicate that spawning season of fish occurred during southwest monsoon season due to the presence of high density of fish eggs. However, the monsoon seasons influenced differently on fish larvae, whereby high peak density of fish larvae were observed in both monsoons. In short, the recruitment of fish is continuous throughout the year in Kuching Wetland National Park estuaries. It was

reported that fishes in tropical water are known to have continuous recruitment throughout the year (Ault and Fox, 1988).

Physico-chemical parameters of water influenced the assemblages and distribution of ichthyoplankton in various ways. Even though there is no direct relationship between fish larvae family abundance and physico-chemical parameters of water in Chapter 3, certain family is able to tolerate to certain parameters. Meanwhile, density of fish larvae in Sungai Sibu Laut-Sungai Salak estuaries has a positive correlation with dissolved oxygen (DO) and turbidity. A positive correlation was also observed between fish larvae diversity (H') with all water parameters except for turbidity, while number of family only showed positive correlation with DO. On the other hand, density of fish eggs showed no correlation with all physico-chemical water parameters.

5.2 General Conclusions

In conclusion, this study had shed some important information regarding the spatial distribution and temporal pattern of ichthyoplankton at selected Sarawak coastal waters. The findings may be used as baseline data for fisheries in order to improve the fishery management in the future. In addition, there are several aspects that can be explored for future ichthyoplankton research as this study had provided some foundations about the early life stage of fish, their ecology and habitat.

5.3 Recommendations

There are several recommendations that could be useful for future ichthyoplankton research. Regarding the morphological study of fish larvae (Chapter 2), more detail features could be recorded such as myomeres count, type of gut and head spination for each specific larval stage because fish larvae do undergo some morphological changes as they grow. In this study, the above detail morphological descriptions were not documented due to time constraint to process samples containing high density larvae.

Findings on the ichthyoplankton assemblages and distribution for spatial study using one-time visit per site approach (Chapter 3) had managed to establish some foundation on composition of larval fish at selected intertidal and subtidal areas in Sarawak waters. But for further improvement in future work, several sampling trips which involve different monsoon seasons are needed in order to reflect the overall diversity of ichthyoplankton throughout the year at each study sites.

For the spatio-temporal study in the estuaries (Chapter 4), findings on assemblages and distribution of ichthyoplankton are confined to one replicate per station at daytime. Future research may consider including replicates at each sampling station and performing night time sampling for comparison between day and night ichthyoplankton assemblages. Detail study on other plankton community is also highly recommended because they were reported to influence the ichthyoplankton density and distribution. In addition, water current need to be measured because this parameter may has significant influence on ichthyoplankton. The above recommendations were unable to be done in this study due to limited funding, logistic and time constraint.

REFERENCES

Abu Talib, A. & Alias, M. (1997). Status of fisheries in Malaysia-an overview. In *Status and Management of Tropical Coastal Fisheries in Asia.* Philippines: *International Center of Living Aquatic Resource Management (ICLARM) Conference Proceedings*, 53:47-61.

Anand, P.E.V. & Pillai, N.G.K. (2005). Occurrence of juvenile fishes on the seagrass beds of Kavaratti Atoll, Lakshadweep, India. *Indian Journal of Fisheries*, 52(4):459-467.

Anderson, P.J. & Piatt, J.F. (1999). Community reorganizing in the Gulf of Alaska following ocean climate regime shift. *Marine Ecology Progress Series*, 189:117-123.

Ara, R., Arshad, A., Amin, S.M.N., Daud, S.K. & Mazlan, A.G. (2011a). Comparison of larval fish density between seagrass beds of the Southwestern Johor, Peninsular Malaysia. *Journal of Fisheries and Aquatic Science*, 6(7):795-801.

Ara, R., Arshad, A., Musa, L., Amin, S.M.N. & Kuppan, P. (2011b). Feeding habits of larval fishes of the Family Clupeidae (*Actinopterygii*: *Clupeiformes*) in the estuary of River Pendas, Johor, Malaysia. *Journal of Fisheries and Aquatic Science*, 6(7):816-821.

Ara, R., Arshad, A., Amin, S.M.N., Daud, S.K. & Ghaffar, M.A. (2011c). Environment and diversity of ichthyoplankton in the seagrass beds of Sungai Pulai Estuary, Johor, Peninsular Malaysia. *Journal of Food, Agriculture and Environment*, 9(3&4):733-738.

Ara, R., Arshad, A., Amin, S.M.N. & Ghaffar, M.A. (2016). Food and feeding habits of *Omobranchus* sp. (Blenniidae: Omobranchini) larvae in the seagrass-mangrove ecosystem of Johor Strait, Malaysia. *Journal of Environmental Biology*, 37:735-743.

Araújo, F.G. and Santos, A.C.A. (1999). Distribution and recruitment of Mojarras (Perciformes, Gerreidae) in the continental margin of Sepetiba Bay, Brazil. *Bulletin of Marine Science*, 65(2):431-439.

Arkhipov, A.G. (2009). Seasonal and interannual variation of ichthyoplankton off Mauritania. *Journal of Ichthyology*, 49(6):460-468.

Arshad, A., Ara, R., Amin, S.M.N., Daud, S.K. & Ghaffar M.A. (2012). Larval fish composition and spatio-temporal variation in the estuary of Pendas River, southwestern Johor, Peninsular Malaysia. *Coastal Marine Science*, 35(1):96-102.

Atack, K. (2006). *A field guide to the fishes of Kuching rivers, Sarawak, Malaysian Borneo*. Natural History Publications (Borneo) Sdn. Bhd. & DANIDA.

Ault, J.S. & Fox, W.W. (1988). The spawning and recruitment patterns of tropical marine fish stock. *Fisheries Stock Assesment Title XXI*.

Avsar, D. & Mavruk, S. (2011). Temporal changes in ichthyoplankton abundance and composition of Babadillimani Bight: Western Entrance of Mersin Bay (Northeastern Mediterranean). *Turkish Journal of Fisheries and Aquatic Science*, 11:121-130.

Bailey, K.M. (1981). Larval transport and recruitment of Pacific Hake *Merluccius productus*. *Marine Ecology Progress Series*, 6:1-9.

Baran, E. (2002). The importance of non-commercial fish. *Fisheries and aquaculture: towards sustainable aquatic living resources management. UNESCO Encyclopaedia of Life Support Systems*. EOLSS Publishers, Oxford, 2-11.

Beaugrand, G., Reid, P.C., Ibañez, F., Lindley, J.A. & Edwards, M. (2002). Reorganizing of North Atlantic marine copepod biodiversity and climate. *Science*, 296:1692-1694.

Blaber, S.J.M., Farmer, M.J., Milton, D.A., Pang, J., Boon-Teck, O. & Wong, P. (1997). The ichthyoplankton of selected estuaries in Sarawak and Sabah: composition, distribution and habitat affinities. *Estuarine,Coastal and Shelf Science*, 45(2):197-208.

Blaber, S.J. (1997). *Fish and Fisheries in Tropical Estuaries.*Springer Netherlands.

Blaxter, J.H. (Ed.). (2012). *The Early Life History of Fish: The Proceedings of an International Symposium Held at the Dunstaffnage Marine Research Laboratory of the Scottish Marine Biological Association at Oban, Scotland, from May 17–23, 1973*. Springer Science & Business Media.

Boeing, W.J. & Duffy-Anderson, J.T. (2008). Ichthyoplankton dynamics and biodiversity in the Gulf of Alaska: responses to environmental change. *Ecological Indicators*, 8:292-302.

Bray, D.J. (2011). Common Stargazer, *Kathetostoma laeve*, in Fishes of Australia. [Online] Available at: http://www.fishesofaustralia.net.au/home/species/756 [Accessed: 10 March 2016].

Brazner, J.C. (1997). Regional, habitat and human development influences on coastal wetland and beach fish assemblages in Green Bay, Lake Michigan. *Journal of Great Lakes Resource*, 23(1):36-51.

Breitburg, D.L. (1994). Behavioral response of fish larvae to low dissolved oxygen concentrations in a stratified water column. *Marine Biology*, 120(4):615-625.

Breitburg, D.L., Palmer, M.A. & Loher, T. (1995). Larval distributions and spatial patterns of settlement of an oyster reef fish: responses to flow and structure. *Marine Ecology Progress Series*, 125:45-60.

Brewer, G.D. & Kleppel, G.S. (1986). Diel vertical distribution of fish larvae and their prey in nearshore waters of southern California. *Marine Ecology Progress Series*, 27:217-226.

Brodeur, R.D. & Rugen, W.C. (1994). Diel vertical distribution of ichthyoplankton in the northern Gulf of Alaska. *Fishery Bulletin*, 92:223-235.

Brunel, T. & Boucher, J. (2007). Long-term trends in fish recruitment in the north-east Atlantic related to climate change. *Fisheries Oceanography*, 16(4):336-349.

Campbell, B.C. & Able, K.W. (1998). Life history characteristics of the Northern Pipefish, *Syngnathus fuscus*, in Southern New Jersey. *Estuaries*, 21(3):470-475.

Carpenter, K.E. & Niem, V.H. (2001). *FAO species identification guide for fishery purposes. The living resources of the Western Central Pacific*, Volume 3-5, FAO Library.

Castro, R.J., Nakatani, K., Bialetzki, A., Sanches, P.V. & Baumgartner, G. (2002). Temporal distribution and compotition of the ichthyoplankton from Leopoldo's Inlet on the Upper Paraná River floodplain (Brazil). *Journal of Zoology London*, 256(4):437-443.

Catalán, I.A., Rubín, J.P., Navarro, G. & Prieto, L. (2006). Larval fish distribution in two different hydrographic situations in the Gulf of Cádiz. *Deep-Sea Research II*, 53:1377-1390.

Chamchang, C. & Chayakul, R. (2000). Composition, abundance and distribution of ichthyoplankton in the South China Sea, Area III: Western Philippines. In *Proceedings of the Third Technical Seminar on Marine Fishery Resources Survey in the South China Sea, Area*, 3:148-163.

Coleman, R.M. (1991). Measuring parental investment in nonspherical eggs. *Copeia*, 4:1092-1098.

Conway, D.V.P., Coombs, S.H. & Smith, C. (1997). Vertical distribution of fish eggs and larvae in the Irish Sea and southern North Sea. *ICES Journal of Marine Science*, 54:136-147.

Cushing, D.H. (1975). *Marine ecology and fisheries*. Cambridge University Press Archive.

Deepananda, K.H.M.A. & Arsecularatne, H.S. (2013). Distribution and abundance of finfish larvae in coastal waters off the Rekawa, Sri Langka. *Journal of Environment*, 2(3):79-84.

Department of Fisheries Malaysia (2009). *Malaysia. Valid Local Name of Malaysian Marine Fishes*. pp. 180

Devi, C.B.L., Stephen, R., Aravindakshan, P.N. & Meenakshikunjamma, P.P. (1996). Ichthyoplankton from Andaman and Nicobar seas. *Proceeding of the Second Workshop on Scientific Results of FORV Sagar Sampada*, pp. 239-248.

Doyle, M.J., Mier, K.L., Busby, M.S. & Brodeur, R.D. (2002). Regional variation in springtime ichthyoplankton assemblages in the northeast Pacific Ocean. *Progress in Oceanography*, 53:247-281.

Ehrlich, M.D., Sánchez, R.P., Ciechomski, J.D., Machinandiarena, L. & Pájaro, M. (1999). Ichthyoplankton compotition, distrinbution and abundance on the southern Patagonian Shelf and adjacent waters. *INIDEP Documento Cientifico*, 5:37-65.

Encyclopaedia Britannica, (2012). South China Sea. *Encyclopædia Britannica Online Academic Edition*. Encyclopædia Britannica Inc. [Online] Available at: http://www.britannica.com/EBchecked/topic/556146/South-China-Sea [Accessed: 31 January 2012].

Espinosa-Fuentes, M.L., Flores-Coto, C., Sanvicente-Añorve, L. & Zavala-García, F. (2009). Vertical distribution of zooplankton biomass and ichthyoplankton density during an annual cycle on

the continental shelf of the southern Gulf of Mexico. *Revista de Biología Marina y Oceanografía*, 44(2):477-488.

Evseenko, S.A. (1982). Ichthyoplankton of slope and gulf stream waters off Nova Scotia in late autumn 1974. *Journal of Northwest Atlantic Fishery Science, 3:127-139.*

Ferreiro, M.J. & Labarta, U. (1988). Distribution and abundance of teleostean eggs and larvae on the NW coast of Spain. *Marine Ecology Progress Series*, 43:189-199.

Fleischer, A.J. (2007). The abundance, distribution and diversity of ichthyoplankton in the Puget Sound estuary and San Juan Islands during early spring. *Oceanography 444 Senior Thesis*, pp. 1-41.

Food and Agricultural Organization (Eds) (2005). The state of food and agriculture. *FAO Agriculture Series*, 36. FAO, Rome.

Franco-Gordo, C., Godínes-Domínguez, E., Suárez-Moralez, E. & Vásquez-Yeomans, L. (2003). Diversity of ichthyoplankton in the central Mexican Pacific: a seasonal survey. *Estuarine, Coastal and Shelf Science*, 57:111-121.

Freitas, D.M. & Muelbert, J.H. (2004). Ichthyoplankton distribution and abundance off Southeastern and Southern Brazil. *Brazilian Archives of Biology and Technology*, 47(4):601-612.

Galacatos, K., Barriga-Salazar, R. & Stewart, D.J. (2004). Seasonal and habitat influences on fish communities within the lower Yasuni River basin of the Ecuadorian Amazon. *Environmental Biology of Fishes*, 71:33-51.

Ghazali, N.H.M. (2006). Coastal erosion and reclamation in Malaysia. *Aquatic Ecosystem Health and Management*, 9(2):237-247.

Gibson, R.N. (1982). Recent studies on the biology of intertidal fishes. *Oceanography and Marine Biology Annual Review*, 20:363-414.

Greve, W., Prinage, S., Zidowitz, H., Nast, J. & Reiners, F. (2005). On the phenology of North Sea ichthyoplankton. *ICES Journal of Marine Science*, 62:1216-1223.

Gruber, D., Ahlstrom, E.H. & Mullin, M.M. (1982). Distribution of ichthyoplankton in the Southern California Bight. *CalCOFI Report*, 23:172-179.

Hermes-Silva, S., Reynalte-Tataje, D. & Zaniboni-Filho, E. (2009). Spatial and temporal distribution of ichthyoplankton in the Upper Uruguay River, Brazil. *Brazilian Archives of Biology and Technology*, 52(40):933-944.

Hernandez-Miranda, E., Palma, A.T. & Ojeda, F.P. (2003). Larval fish assemblages in nearshore coastal waters off central Chile: temporal and spatial patterns. *Estuarine, Coastal and Shelf Science*, 56:1075-1092.

Herbert, P. & Ontario, B. (2008). *Physical Properties of Rivers*. Retrieved from http://www.eoearth.org/view/article/155233 [Accessed: 18 November 2015].

Houde, E.D. (1989). Comparative growth, mortality and energetic of marine fish larvae: temperature and implied latitudinal effects. *Fishery Bulletin*, 87:471-495.

Huang, J.B. & Chiu, T.S. (1998). Seasonal and hydrographic variations of ichthyoplankton density and composition in the Kuroshio edge exchange area off Northeastern Taiwan. *Zoological Studies*, 37(1):63-73.

Hyndes, G.A., Potter, I.C. & Lenanton, R.C. (1996). Habitat partitioning by whiting species (Sillaginidae) in coastal waters. *Environmental Biology of Fishes*, 45(1):21-40.

International Pacific Research Center, 2005. South China Sea takes center stage. *IPRC Climate*, 4(2):2-6.

Islam, M.S. & Tanaka, M. (2009). Diet and prey selection in larval and juvenile Japanese anchovy *Engraulis japonicas* in Ariake Bay, Japan. *Aquatic Ecology*, 43(2):549-558.

Ismail, M.Z. (1992). *Background Paper on Marine and Freshwater Fisheries*. Malaysian National Conservation Strategy.

Jenkins, G.P. & May, H.M.A. (1994). Variation in settlement and larval duration of King George Whiting, *Sillaginodes punctata* (Sillaginidae), in Swan Bay, Victoria, Australia. *Bulletin of Marine Science*, 54(1):281-296.

Jeyaseelan, M.J.P. (1998). *Manual of fish eggs and larvae from Asian mangrove waters*. UNESCO Publishing, France.

Jonna, R. 2004. Gobiidae (On-line), *Animal Diversity Web*. Retrieved from http://animaldiversity.org/accounts/Gobiidae/ [Accessed: 2 March 2016]

Joseph, E.B. (1973). Analysis of a nursery ground. In: *Proceedings of a workshop on Egg, Larval and Juvenile Stages of Fish in Atlantic Coast Estuaries* (Pacheco, A. L., ed.) Middle Atlantic Coastal Fisheries Center Technical Publication, 1:11-22.

Kingsford, M.J., & Suthers, I.M. (1994). Dynamic estuarine plumes and fronts: importance to small fish and plankton in coastal waters of NSW, Australia. *Continental Shelf Research*, 14(6):655-672.

Knights, A.M., Crowe, T.P. & Burnell, G. (2006). Mechanisms of larval transport: vertical distribution of bivalve larvae varies with tidal conditions. *Marine Ecology Progress Series*, 326:167-174.

Konishi, Y., Chayakul, R., Chamchan, C. & Duangdee, T. (2012). *Early Stages of Marine Fishes in Southeast Asean Region*. Southeast Asian Fisheries Development Center.

Köster, F.W., Hinrichsen, H.H., St. John. M.A., Schnack, D., MacKenzie, B.R., Tomkiewicz, J & Plikshs, M. (2001). Developing Baltic cod recruitment models. II. Incorporation of environmental variability and species interaction. *Canadian Journal of Fisheries and Aquatic Science*, 58(8):1534-1556.

Koutrakis, E.T., Kallianiotis, A.A. & Tsikliras, A.C. (2004). Temporal patterns of larval fish distribution and abundance in a coastal area of northern Greece. *Scientia Marina*, 68(4):585-595.

Kuiter, R. & Debelius, H. (1994). *Southeast Asia tropical fish guide : Indonesia, Philippines, Malaysia, Singapore, Thailand, Andaman Sea. Over 1000 photographs of marine fishes taken in their natural habitat*. IKAN-Unterwasserarchiv, Frankfurt, Germany.

Lafontaine, Y., Sinclair, M., El-Sabh, M.I., Lassus, C. & Fournier, R (1984). Temporal occurrence of ichthyoplankton in relation to hydrographic and biological variables at a fixed station in the St. Lawrence Estuary. *Estuarine, Coastal and Shelf Science*, 18:177-190.

Lasiak, T.A. (1986). Juveniles, food and the surf zone habitat: implications for teleost nursery areas. *South African Journal of Zoology*, 21(1):51-56.

Lasker, R. & Smith, P.E. (1976). Estimation of the effects of environmental variations on the eggs and larvae of the northern anchovy. *CalCOFI Report*, XIX, pp. 128-137.

Laurenne, N., Tuominen, J., Saarenmaa, H. & Hyvönen, E. (2014). Making species checklist understandable to machines-a shift from relational databases to ontologies. *Journal of Biomedical Semantics*, 5:40.

Lee, T.S. (2010). Characterizing mid-summer ichthyoplankton assemblages in Gulf of Alaska: analyzing density and distribution gradients across continental shelf. *Aquatic Ecology*, pp. 1-31.

Leh, C.M.U. (2000). Inventory of freshwater fish. In Chai, P.P.K & Yaw, K.S. (2000). *Proceedings of ITTO Workshop 2000: Development of Lanjak Entimau Wildlife Sanctuary as a Totally Protected Area Phase II*. Session 1(Paper 3):150-167.

Leis, J.M. & Carson-Ewart, B.M. (2000). *The larvae of Indo-Pacific coastal fishes: an identification guide to marine fish larvae.* BRILL.

Longhurst, A.R. (1971). The clupeoid resources of tropical seas. *Oceanography and Marine Biology, An Annual Review*, 9:349-385.

Marchetti, M.P. & Moyle, P.B. (2000). Spatial and temporal ecology of native and introduced fish larvae in lower Putah Creek, California. *Environmental Biology of Fishes*, 58:75-87.

Marcolin, C.D.R., Conceição, B.L., Nogueira, M.M., Júnior, P.M. & Johnsson, R. (2010). Mesozooplankton and ichthyoplankton compotition in two tropical estuaries of Bahia, Brazil. *Check List*, 6(2):210-216.

Margalef, D.R. (1958). *Information theory in ecology*. Society for General System Research, 3:36-71.

Markowski, M. (2009). The international legal standard for sustainable EEZ fisheries management. *Towards Sustainable Fisheries Law*, 3. *A Comparative Analysis.* Germany: International Union for Conservation of Nature and Natural Resources.

Matić-Skoko, S., Tutman, P., Petrić, M., Skaramuca, D., Đikić, D., Lisičić, D & Skaramuca, B. (2011). Mediterranean moray eel *Muraena Helena* (Pisces: Muraenidae): biological indices for life history. *Aquatic Biology*, 13:275-284.

Matsunuma, M., Motomura, H., Matsuura, K., Shazili, N.A.M & Ambak, M.A. (2011). *Fishes of Terengganu-east coast of Malay Peninsula, Malaysia*. National Museum of Nature and Science, Universiti Malaysia Terengganu and Kagoshima University Museum.

McGinley, M. (2011). *Climate of Malaysia*. Retrieved from http://www.eoearth.org/view/article/151260 [Accessed: 18 November 2015].

McGurk, M.D. (1986). Natural mortality of marine pelagic fish eggs and larvae: role of spatial patchiness. *Marine Ecology Progress Series*, 34:227-242.

Mohamad-Norizam, M. & Ali, A.B. (2009). Spatial-distribution pattern of fish larvae in the east coast off Pulau Payar Marine Park, Kedah, Malaysia. *Journal of Sustainability Science and Management*, 4(2):141-145.

Mohsin, A.K.M. & Ambak, M.A. (1996). *Marine fishes and fisheries of Malaysia and neighbouring countries.* Universiti Pertanian Malaysia Press, Serdang, Malaysia.

Mokhtar, M. & Ghani Aziz, S.A. (2003). Integrated coastal zone management using the ecosystems approach, some perspectives in Malaysia. *Ocean and Coastal Management*, 46:407-419.

Moser, H.G. & Boehlert, G.W. (1991). Ecology of pelagic larvae and juveniles of the genus *Sebastes*. *Environmental Biology of Fishes*, 30:203-224.

Moser, H.G. & Smith, P.E. (1993). Larval fish assemblages and oceanic boundaries. *Bulletin of Marine Science*, 53:283-289.

Muhamad, N. & Rahim, S.A.K.A. (2013). Preliminary survey of ichthyoplankton at Telaga Air and Satang coastal waters. *Aquatic Science Colloquium 2012: Experience Sharing in Aquatic Science Research II, Talang-Satang National Park to Santubong*. Monograph, Department of Aquatic Science, Universiti Malaysia Sarawak, Kota Samarahan, Sarawak, Malaysia, pp. 19-27.

Nakazono, A. & Kawase, H. (1993). Spawning and biparental egg-care in a temperate filefish, *Paramonacanthus japonicas* (Monacanthidae). *Environmental Biology of Fishes*, 37(3):245-256.

Neira, F.J. (1991). Larval development of the oral brooding cardinalfish *Apogon rueppellii* (Teleostei: Apogonidae) in Western Australia. *Records of the Western Australian Museum*, 15:573-584.

Nyanti, L., Ling, T.Y. & Jongkar, G. (2012a). Fish and crustacean communities and fish length-weight relationship of Lutong River, Miri, Sarawak, Malaysia. *World Journal of Fish and Marine Science*, 4(1):102-110.

Nyanti, L. Nur 'Asikin, R., Ling, T.Y. & Jongkar, G. (2012b). Fish diversity and water quality during flood mitigation works at Semariang Mangrove area, Kuching, Sarawak, Malaysia. *Science Malaysiana*, 41(12):1517-1525.

Nyanti, L., Jongkar, G., James, B., & Norhadi, I. (2014). Fish Fauna and Fisheries in the Coastal Waters of Similajau, Bintulu, Sarawak, Malaysia. *Kuroshio Science*, 8:53-57.

Nyanti, L. & Bolhen, H. (2015). Fish and crustacean fauna composition at Rambungan River and waters of Sampadi Island, Lundu, Sarawak. *Aquatic Science Colloquium 2014: Experience Sharing in Aquatic Science Research III, Pulau Sampadi – Marine Life Experience*. Monograph, Department of Aquatic Science, Universiti Malaysia Sarawak, Kota Samarahan, Sarawak, Malaysia, pp. 19-27.

Ocana-Luna, A. & Sanchez-Ramirez, M. (2003). Diversity of ichthyoplankton in Tampamachoco Lagoon, Veracruz, Mexico. *Serie Zoología*, 74(2):179-193.

Okiyama, M. (ed) 2014. *An Atlas of the Early Stage Fishes in Japan*. 2nd Edition. Tokyo: Tokai University Press, Japan.

Ong, J.E. (2001). Vulnerability of Malaysia to sea level change. In *Proceedings of the APN/SURVAS/LOICZ Joint Conference on Coastal Impacts of Climate Change and Adaptation in the Asia-Pacific Region*, Kobe, Japan, Asia Pacific Network for Global Change Research, pp 89-93.

Parenti, L.R. & Lim, K.K. (2005). Fishes of Rajang Basin, Sarawak, Malaysia. *Raffles Bulletin of Zoology*, 13:175-208.

Partridge, B.L. (1982). Structure and function of fish schools. *Scientific American*, 246(6):114-123.

Pearce, A.F. & Hutchins, J.B. (2009). Oceanic processes and the recruitment of tropical fish at Rottnest Island (Western Australia). *Journal of the Royal Society of Western Australia*, 92:179-195.

Pereira, P.H.C., Feitosa, J.L.L. & Ferreira, B. P. (2011). Mixed-species schooling behaviour and protective mimicrt involving coral reef fish from the genus *Haemulon* (Haemulidae). *Neotropical Ichthyology*, 9(4):741-746.

Petereit, C., Hinrichsen, H., Voss, R., Kraus, G., Freese, M. & Clemmesen, C. (2009). The influence of different salinity conditions on egg buoyancy and development and yolk sac larval survival and morphometric traits of Baltic Sea sprat (*Sprattus sprattus balticus*, Schneidae). *Scientia Marina*, 59-72.

Pielou, E.C. (1966). The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology*, 13:131-144.

Privileggi, N., Ota, D. & Ferrero, E.A. (1997). Embryonic and larval development of the grass goby *Zosterisessor ophiocephalus* (Teleostei, Gobiidae). *Italian Journal of Zoology*, 64:210-207.

Randall, J.E. & Lim, K.K.P. (eds)(2000). A checklist of the fishes of the South China Sea. *The Raffles Bulletin of Zoology*, 8:569-667.

Ré, P. & Meneses, I. (2009). Early stages of marine fishes occurring in the Iberian Peninsular. Instituto de Investigaçáo das Pescas e do Mar/ Instituto del Mar.

Rhody, N.R., Nassif, N.A. & Main, K.L. (2010). Effect of family on growth and survival of common snook *Centropomus undecimalis* (Bloch, 1972) larvae. *Aquaculture Research*, 41: 357-360.

Richards, F.P., Cook, C.J. & D'auteuil, R.R. (1985). The ichthyoplankton of the Scioto River near Omega, Ohio. *Ohio Journal of Science*, 85(4):164-174.

Rijnsdorp, A.D., Peck, M.A., Engelhard, G.H., Möllmann, C. & Pinnegar, J.K. (2009). Resolving the effect of climate change on fish populations. *ICES Journal of Marine Science*, 66:1570-1583.

Robichaud-LeBlanc, K.A., Courtenay, S.C. & Hanson, J.M. (1997). Ontogenetic diet shifts in age-0 striped bass, *Morone saxatilis*, from the Miramichi River estuary, Gulf of St. Lawrence. *Canadian Journal of Zoology*, 75:1300-1309.

Rothlisberg, P.C., Craig, P.D. & Andrewaartha, J.R. (1996). Modeling penaid prawn larval advection in Albatross Bay, Australia, defining the effective spawning stock. *Marine and Freshwater Research*, 47:157-168.

Ryan, P.A. (1991). The success of the Gobiidae in tropical Pacific insular streams. *New Zealand Journal of Zoology*, 18(1):25-30.

Sameoto, D.D. (1984). Environmental factors influencing diurnal distribution of zooplankton and ichthyoplankton. *Journal of Plankton Research*, 6(5):767-792.

Sampey, A., Meekan, M.G., Carleton, J.H., McKinnon, A.D. & McCormick, M.I. (2004). Temporal patterns in distributions of tropical fish larvae on the North-west Shelf of Australia. *Marine and Freshwater Research*, 55:473-487.

Santos, F. B., & Castro, R. (2003). Activity, habitat utilization, feeding behaviour, and diet of the sand moray Gymnothorax ocellatus (Anguilliformes, Muraenidae) in the South western Atlantic. *Biota Neotropica*, *3*(1):1-7.

Sanvicente-Añorve, L., Soto, L.A., Espinosa-Fuentes, M.L., & Flores-Coto, C. (2006). Relationship patterns between ichthyoplankton and zooplankton: a conceptual model. *Hydrobiologia*, 559:11-22.

Sarpedonti, V., Anunciação, E.M.S. & Nahum, V.J.I. (2008). Ichthyoplankton variations in two mangrove creeks of the Curucá Estuary, Pará, Brazil. *Ecotrópicos*, 21(1):1-12.

Sasekumar, A., Chong, V.C., Leh, M.U. & D'Cruz, R. (1992). Mangroves as a habitat for fish and prawns. *Hydrobiologia*, 247:195-207.

Shannon, C.E. & Weaver, W. (1963). The mathematical theory of communications. University of Illinois Press, Urbana.

Sherman, K., Lasker, R., Richards, W. & Kendall, A.W. (1983). Ichthyoplankton and fish recruitment studies in large marine ecosystems. *Marine Fisheries Review*, 45:1-25.

Smith, K.A. & Suthers, I.M. (1999). Displacement of diverse ichthyoplankton assemblages by the coastal upwelling event on the Sydney shelf. *Marine Ecology Progress Series*, 176:49-62.

Soares, M.S.C., Barreiros, J.P., Sousa, L. & Santos, R.S. (2002). Agonistic and predatory behaviour of the lizardfish *Synodus saurus* (Linaeus, 1758) (Actinopterygii: Synodontidae) from the Azores. *Journal of Ichthyology and Aquatic Biology*, 6(2):53-60.

Soo, C.L., Ling, T.Y. & Nyanti, L. (2014). Assessment of the characteristic of nutrients, total metals, and fecal coliform in Sibu Laut River, Sarawak, Malaysia. *Applied Water Science*, pp. 1-20.

Southeast Asian Fisheries Development Center (n.d.). *Notes of completion for the fishery statistical bulletin of Southeast Asia*. SEAFDEC.

Southward, A.J. (1980). The western English Channel-an inconsistent ecosystem. *Nature*, 285:361-366.

Spooner, G.M. (1931). Some observations on schooling in fish. *New Series*, 17(2):421-448.

Tamutis, V., Tamutė, B., & Ferenca, R. (2011). A catalogue of Lithuanian beetles (Insecta, Coleoptera). *ZooKeys*, (121), 1-494. Advance online publication. http://doi.org/10.3897/zookeys.121.732

Termvidchakorn, A. & Hortle, K.G. (2013). *A guide to larvae and juvenile of some common fish species from the Mekong River basin*. MRC Technical Paper No. 38. Mekong River Commission, Phnom Penh, 234 pp.

Vagelli, A. (1999). The reproductive biology and early ontogeny of the mouthbrooding Banggai cardinalfish, *Pterapogon kauderni* (Perciformes, Apogonidae). *Environmental Biology of Fishes*, 56:79-92.

Vidthayanon, C. (1998). Species composition and diversity of fishes in the South China Sea, Area II: Sarawak, Sabah and Brunei Darussalam waters. In *Proceedings of the second technical seminar on marine fishery resources survey in the South China Sea, Area II: Sarawak, Sabah and Brunei Darussalam Waters. SEAFDEC, Kuala Lumpur, Malaysia* (pp. 14-15).

Windle, J. & Cramb, R.A. (1997). Remoteness and rural development: economic impacts of rural roads on upland farmers in Sarawak, Malaysia. *Asia Pacific Viewpoint*, 38(1):37-53.

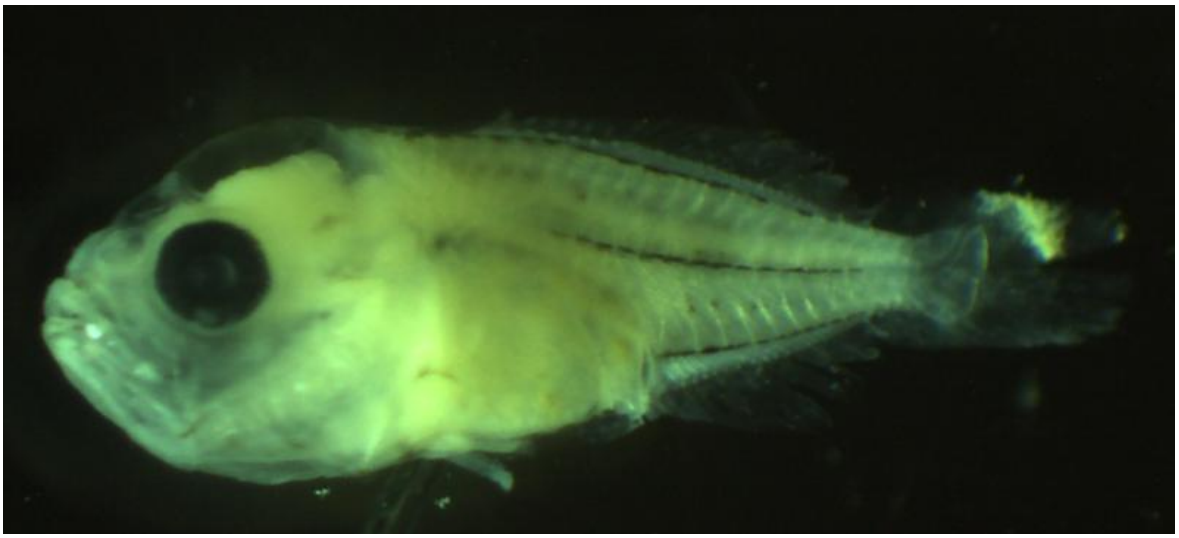
Ye, Q., Cheshire, K.J. & McNeil, D.G. (2010). *Influences of salinity, water quality and hydrology on early life stages of fishes in the lower River Murray, South Australian Research and Development Institute (Aquatic Science) Adelaide.* SARDI Publication.

Yu, H.J., Im, Y.J., Jo, H.S., Lee, S.J. & Kim, J.K. (2015). Morphological development of eggs, larvae and juvenile of *Sebastes koreanus* (Scorpaeniformes: Scorpaenidae) from the Yellow Sea. *Ichthyological Research*, 62:439-449.

Zhou, M., Lin, Y., Yang, S., Cao, W. & Zheng, L. (2011). Composition and ecological distribution of ichthyoplankton in eastern Beibu Gulf. *Acta Oceanologica Sinica.*, 30(1):94-105.

APPENDICES

Appendix 1: Other genera that were identified under Family Carangidae



Family name : Carangidae
Genus : Kaiwarinus
Growth stage : Flexion
Total length : 5.21 mm

Family name : Carangidae
Genus : Scomberoides
Growth stage : Preflexion
Total length : 3.47 mm

Appendix 2: Calculation formula for diversity indices

1) **Shannon-Wiener Diversity Index (H')** (Shannon and Weaver, 1963)**:**

$$H' = \Sigma\, pi \ln pi$$

where *p* is the proportion of each family, *i*

2) **Pielou's Evenness Index (J)** (Pielou, 1966)**:**

$$J = H' / H'max = H' / \log S$$

where S is the number of family at each station.

3) **Margalef's Richness Index (D)** (Margalef, 1958)**:**

$$D = (S - 1) / \log N$$

where N is the total number of fish larvae at each station.