CHAPTER 1

GENERAL INTRODUCTION

1.1 Fish Communities of Mangrove Estuary

Mangrove forests are among the world's most productive ecosystems. They are largely restricted to latitudes between 30ºN and 30ºS with some extensions of this limit occurring up to North Island, New Zealand and Kyushu Island, in southern Japan (Kathiresan & Bingham, 2001). Mangrove ecosystems are highly productive intertidal forests distributed along the tropical coast and they stabilize the coastal zone from erosion and act as a buffer zone between land and sea by their large and extensive aerial root systems and standing crop. They enrich coastal waters, yield commercial forest products, protect coastlines, support coastal fisheries and carbon sequestration (Huxham et al., 2007; Nagelkerken et al., 2008; Walters et al., 2008; Kristensen et al., 2008). However, they exist in an environment subject to extreme and fluctuating conditions e.g. variations in salinity, extreme tides, strong winds, high temperature, anoxic sediments and low nutrient availability (Krauss et al., 2008). In general, its environment is considered to result from a combination of climatic, hydrological, geophysical, geomorphic and biological factors (Varadachari & Kesava Das, 1984).

The mangrove estuaries represent one of the most exploited ecosystems in the world (Blaber, 2000). This is attributed to their rich and diverse assemblages of coastal and pelagic fishes, including many commercially valuable species. Extensive studies on fish community have been made in many mangrove estuaries around the world; e.g. Alligator Creek, northern Queensland, Australia (Robertson & Duke, 1990a); Leanyer Swamp of the Northern Territory and in the Dampier region of Western Australia (Robertson & Blaber, 1992); Matang mangroves, Malaysia, (Sasekumar et al., 1994a;

Chong et al., 2012); western coast of Taiwan (Kuo et al., 1999); East-African mangrove creek (Little et al., 1988); Guadiana estuary, Portugal (Faria et. al., 2006); northern Brazil (Barletta et al., 2002a; Krumme et al., 2004) and Ecuador (Shervette et al., 2007).

Mangroves, along with other shallow water habitats have been regarded as areas that provided food and shelter for juvenile fish and crustaceans and as well as source of recruits for nearby coral reefs. The utilization of estuarine mangroves as nursery areas is an important phase of the life history for many marine organisms, including the commercially valuable shrimps and fishes (Staples, 1980; Haedrich, 1983; Mumby et al., 2004; Verweij, 2006). This recognition that estuarine mangroves act as important nursery areas for certain teleosts by providing a rich food source and protection from predation has already been documented in many mangrove estuaries worldwide (Blaber et al., 1985; Robertson & Duke, 1987; Tzeng & Wang 1992; Whitfield, 1999; Blaber, 2000; Chong, 2007). Most of the fishes collected from the Lagos Lagoon (Nwadukwe, 1995) and the mangrove waters of Martinique Island (Loius et al., 1995) were small and sexually immature, proving that it is an important nursery ground for most of the fishes. However, estuaries are notably poorer in number of species than the surrounding marine and freshwater areas but higher in number of individuals (Kennish, 1990). The densities of juvenile fish in mangrove habitats are often higher than in adjacent habitats (Robertson & Blaber, 1992).

Two main hypotheses have been proposed to explain the attractiveness of mangroves to fish, as observed by many mangrove fisheries scientists (Robertson & Blaber, 1992; Laegdsgaard & Johnson, 2001; Faunce & Serafy, 2006; Chong, 2006):

1) The turbid waters in the mangrove estuary reduce the effectiveness of large visual fish predators. The predator refuge hypothesis states the need to avoid

potential predators draws fish into mangrove vegetation during inundation. The shallow waters also exclude larger fish. The structural complexity of habitat such as seagrass and mangrove restrict predator's vision and their movement.

2) The feeding hypothesis suggests higher diversity and quantity of food available in the mangrove estuaries is attributed to high productivity and mangrove-associated fauna.

In Peninsular Malaysia, mangrove swamps are a common feature of the west coast, where it covers an estimated area of 100,000 ha (Gan, 1995). The marine fish community in the Matang mangrove estuary was first described by Khoo (1990) when a total of 44 fish species were captured during a one-year study. Sasekumar et al. (1994a) identified 117 fish species in a 3½-year of study comparing mangrove channels and adjacent mudflat areas with nearshore waters. The seven most abundant fish families in mangrove channels in order of importance were Ambassidae, Sciaenidae, Clupeidae, Engraulidae, Scatophagidae, Ariidae and Leiognathidae. However, the fish density decreased in the offshore direction. In a two-year study of Matang estuaries, Hayase and Muhammad Fadzil (1999) recorded a total of 142 fish species, an addition of 25 species to the list of Sasekumar et al. (1994a). Chong (2005) gave an updated account of 138 fish species from Matang waterways and mudflats after taking into account the synonyms of taxa used. More recently, Then (2008) identified 94 fish species from 37 families that were sampled by otter trawl in six Matang mangrove estuaries. The Sciaenidae, Engraulidae, Scatophagidae and Ariidae apparently utilize the mangrove channels and adjacent mudflats as breeding and/or nursery grounds, while other fishes utilize the two habitats as nursery grounds (Sasekumar et al., 1994a).

1.2 Fish larva

The term ‘fish larva’ designates the stage in the life history from hatching to attainment of complete fin ray counts and beginning of squamation, at which stage the fish becomes a juvenile (Kendall et al., 1984). The development stages of the ichthyoplankton were categorized according to Ahlstrom & Ball (1954). The larval stage is classified on the basis of the flexion of the notochord that accompanies the hypochordal development of the homocercal caudal fin, into three stages: preflexion, flexion and postflexion. In the transformation stage, metamorphosis from larva to juvenile occurs. Therefore, in this study, the terminology for developmental stages used were preflexion larva, flexion larva, postflexion larva, juvenile and adult (see Figure 1.1)

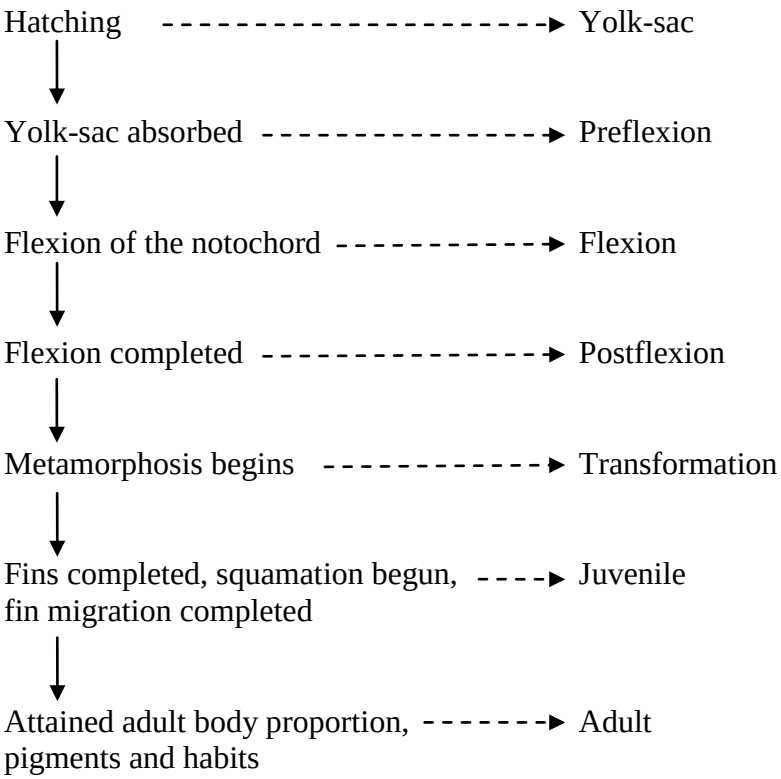

Figure 1.1. Ontogenetic stages of fish larva (modified from Kendall et al., 1984).

1.3 Recruitment of Fish Larvae into Estuary

With a wide array of advantages and attractiveness provided in the mangrove estuaries, recruitment and retention in estuaries are important parts of the early life history of many fish species. Many studies on larval fishes elucidate the way in which marine species are transported into estuaries (Tzeng, 1985; Boehlert & Mundy, 1988; Kingsford & Suthers, 1994). Fish larvae in estuaries can either be the result of spawning within the estuary or early life history stages entering the estuary from the nearshore marine and freshwater environments (Claridge et. al., 1986; de Lafontaine, 1990). Marine species that utilize estuaries as nurseries are recruited at a vulnerable life history stage, particularly at postflexion stage (Tzeng & Wang, 1992; Neira & Potter, 1994; Harris & Cyrus, 1995). Fish larvae do not drift aimlessly and many eventually reach suitable nursery areas and start a new phase of their life history. The main recruitment problem is how they could take advantage of oceanic transport processes to get to their destination (advection) and having done that, how they could maintain their position within it (retention) in estuaries and near shore areas. For resident species and some migrant species which spawned within the estuaries, their larvae face similar but an export problem. Therefore, different strategies of estuarine use are apparent among different taxa. Among them is the spawning strategy employed by the parent stock (Sherman et al., 1984). Other factors include the length of time that eggs and larvae remain in the plankton, egg and larval vertical distributions, and advective processes (Cushing, 1972; Sherman et al, 1984). For example, several resident species avoid the export of early life history stages by producing large, demersal eggs (Hempel, 1979) and having brief larval stages in the estuaries.

Boehlert and Mundy (1988) considers recruitment into estuaries by species spawned offshore as a two-stage process. The first stage is the accumulation of larvae in

the nearshore or coastal zone, either by, or a combination of surface drift, Ekman transport, flood tidal streams, eddies, gyres and surface slicks. Onshore advection is modulated by larval behavior (e.g. vertical migration) to maximize shoreward movement. The ability of larvae to remain at a given depth depends not only on their swimming capability but also their motivation to stay at that depth. Neilson and Perry (1990) concluded that the changes in depth at which the fish larvae reside are probably regulated by endogenous mechanisms. It also appeared to be triggered by environmental factors such as light levels, prey and predator density, hydrographic conditions and turbulence. The second stage is the process of accumulation of larvae or post larvae around the vicinities of the river mouths and subsequent penetration upstream. The ingressing larvae could make use of flood tidal currents to penetrate into the estuary. Hence, endogenous activity rhythms (daily, tidal and lunar periodicity) are also important for the recruitment of fishes into the estuaries which serves as nursery areas. Some organisms have evolved elaborate behavioral patterns that increase the chances of entering estuaries. Within a species, endogenous rhythms may change during ontogeny. Nevertheless, there are certain field studies which suggested mechanisms of estuarine recruitment that are entirely passive and require no behavioral response on the part of the larvae (Rijnsdorp et al., 1985).

Harden Jones (1968) describes the circuit of migration in the life history of temperate fishes as a triangle. Larvae passively migrate with the current from the spawning ground at A for the nursery ground at B while the juvenile and young actively migrate and recruit to the stock at C, the feeding ground. Mature and ripening adults leave the feeding ground against the current and return to the spawning ground to spawn. After spawning, the spent adults migrate with the current and return to the

feeding ground (Figure 1.2). Spawning migration may takemany timesforiteroparous species.

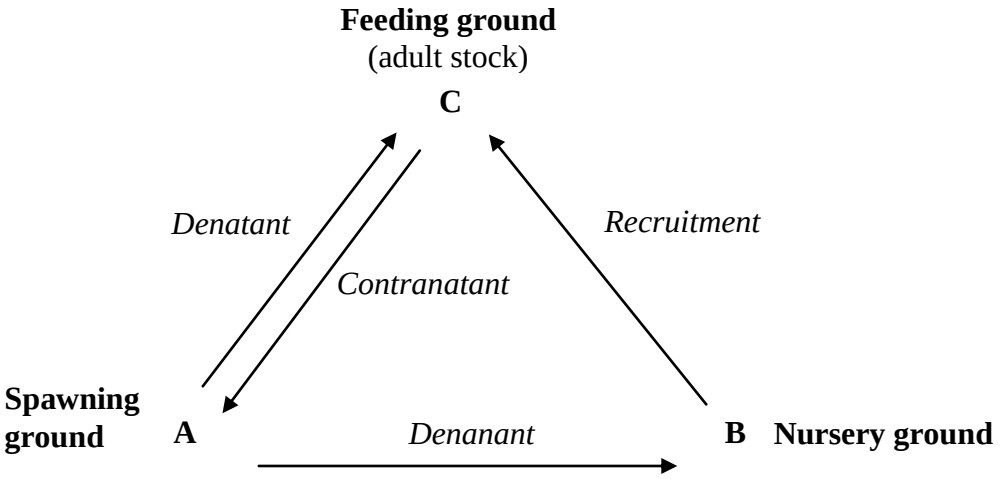

Figure 1.2. The migration circuit of temperate fish species (adapted fromHarden Jones, 1968).

In the tropical environment, the migration circuit is not well-defined (Figure 1.3). The time of spawning is less precise compared to the temperate environment (Cushing, 1975). For example, inshore migration period for some tropical anguillid eels might extend throughout the year due to year-round spawning and stable larval transport (Arai et al., 1999; Aoyama et al., 2003). In a tropical mangrove estuary, fish may shift habitats for feeding, reproduction and life stage-specific habitat use (Nagelkerken et al., 2002; Sheaves, 2005).

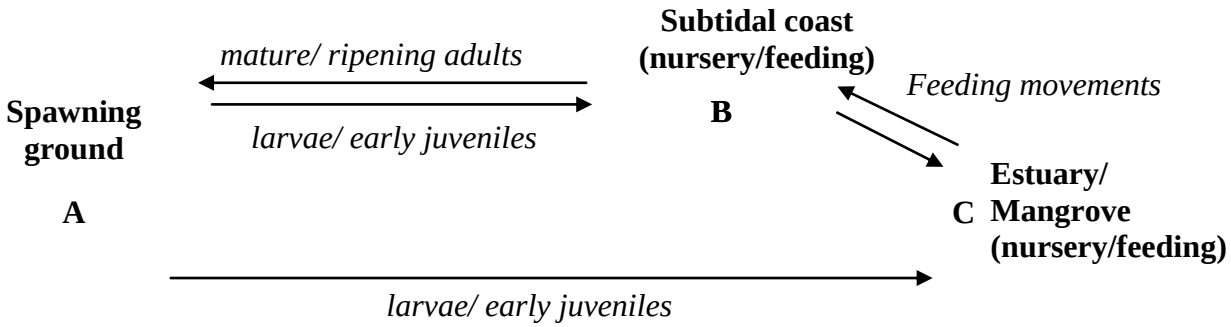

Figure 1.3. Example of amigration circuit of tropical fish species based on data from Selangor (Chong et al., 1990) and Matang, Perak (Sasekumar et al., 1994a) in Malaysia.

Figure 1.3 shows the ontogenetic migrations in habitat use of certain tropical fish species in Selangor and Matang, Perak in Malaysia. Fish larvae from spawning ground migrate to nursery ground in either coastal subtidal area or estuary where they also feed. Fish may migrate from the coastal subtidal area into the coastal mudflat or estuary to feed during high tide and return during low tide. Coastal subtidal areas may be vegetated areas such as seagrass bed or fringing coral reef, while mangrove forests may line the entire estuary. Certain tropical species may spawn in B and C. The distances between A and C or B are short (not exceeding 30 km) while between C and B is much shorter (<5 km).

1.4 Factors Affecting Dynamics of Fish larvae in Mangrove Estuary

The horizontal distribution of fish larvae in the sea is a function of the distance between the spawning and nursery grounds, the water parameters, the hydrography, the climate and the biology of the larvae (Sinclair & Tremblay, 1984; Owen et al., 1989). Climate also plays a major role by directly affecting fish abundance and distribution, and indirectly via the precursors of the food chain (i.e. nutrients, phytoplankton and zooplankton). There have been many studies on the role of local environmental conditions in determining the vertical and horizontal distribution of fish larvae (Olivar, 1990; Palomera, 1991; Gelwick et al., 2001; Griffiths, 2001). Among the main factors

are environmental conditions (Ramos et al., 2006; Sarpedonti & Chong, 2008), predation (Chew et al., 2007; Then, 2008) and food availability (Blaxter & Hunter, 1982; Blaber, 2000; Chew et al., 2007). It is also hypothesized that fish larvae recruitment are influenced by the abiotic factors (Boehlert & Mundy, 1988). Physical factors which exist near the entrance to estuaries may elicit behavior response appropriate for recruitment.

1.4.1 Behaviour

Generally, larvae of species with pelagic eggs are distributed some distance away from the adult habitat, further than those with demersal eggs (Kingsford & Choat, 1989; Brogan, 1994). Traditionally, it has been assumed that fish larvae have poor swimming abilities and drift passively with the currents (Roberts, 1997). However, recent studies have demonstrated that behavioural capabilities (swimming, orientation and sensory abilities) can influence, if not control dispersal trajectories (Leis, 2007). Thus, larval behavior and other biological factors such as planktonic larval duration and the spawning mode of adults could interact with physical factors which subsequently affect dispersal in nearshore environments (Sponaugle & Cowen, 1997). Changes in the fish fauna according to the lunar periodicity and the spring/neap alternation have been observed in some mangrove areas (Blaber et al., 1995, Wilson & Sheaves, 2001).

1.4.2 Biogeochemical, Hydrogeochemical and Hydrological Processes

Estuaries are characterized by a wide variation in physical parameters. The movement and distribution of fishes in tropical estuaries and coastal waters are mainly affected by physical factors. Physical structures of the environment such as the bottom substratum and mangrove root structure also influence the composition and distribution of estuarine fishes (Blaber, 1997).

Rainfall which contributes to alteration in river flow, salinity and turbidity exerts a great influence on the dynamics of estuarine fishes namely, the breeding cycle, recruitment and maintenance. Freshwater inflow into the estuary changes the flow rates and influences the salinity and turbidity. Currents is a dominant feature of estuarine tidal flux but only used by fishes that are able to orientate at the surface (Hoar, 1958 in Boehlert & Mundy, 1988).

Temperature is also one of the physical orientation factors for larvae because fish exhibit both temperature tolerance and preference (Brett, 1970). The majority of studies on the relationship between temperature and migration however, describe temperature-initiated migration out of an area. The effects of temperature on larval abundance and distribution are more obvious in temperate countries experiencing marked seasonal variations of temperature than in tropical countries.

The earliest developmental stages for fish after hatching represent a critical phase for the survival of a species especially in estuaries where the salinity varies widely. Hence, the variations in salinity can affect larval distribution (Ré, 1987) but only to a lesser extent compared to the effect of turbidity (Cyrus & Blaber, 1987).

Turbidity attenuates light penetration in the water and thus, affects larval distribution. Depending on the nature of the suspended particles, some wavelengths are absorbed which consequently affect the colour and the transparency of prey and predator (Boehlert & Morgan, 1985). Turbidity is positively correlated to the water current and surface wind speed and could reduce larval mortality by predation (Blaber, 1980; Robertson & Duke, 1990a). High turbidity increases zooplankton density in surface waters which in turn, promotes an increase in the number of filter-feeding fish

in turbid areas (Blaber & Blaber, 1980). Changes in the estuarine turbidity gradient associated with the monsoons have been proposed as a cue for postlarvae and juveniles to locate their nursery grounds (Blaber & Blaber, 1980).

The pH also affects the survival of fish larvae. For example, an increase in pH from 6.5 to 7.5 greatly improves the survival of American shad larvae, but had little effect on their growth rate (Leach & Houde, 1999). On the other hand, a sudden drop of pH from 7.0 to 6.0 can be lethal to these larvae.

The positive correlation between the abundance of primary producers, secondary producers and larval abundance has been reported in many studies (e.g. Walsh et al., 1980 on the Peruvian anchovy; Agate et al., 1991 on fish larvae in Thailand). Phytoplankton and zooplankton abundance and diversity have been positively related to rainfall, and subsequent river flow which carries a relatively high amount of nutrients from run-off (Trott & Alongi, 1999). Therefore, in tropical countries which experience little annual temperature fluctuations, the onset of two monsoon seasons with higher rainfall, appears as favorable period for larval survival and has been linked to the main breeding season for marine fishes (e.g. Sarpedonti, 2000 on *Stolephorus* species in Malaysia).

Nutrients play an important role in plant productivity and water quality of marine and estuarine environments because of their role in the functioning of biological systems. The term nutrient refers to anything beside water and carbon dioxide (CO_2) that is vital for plants in the synthesis of organic matter of skeletal material (Stowe, 1987). Major nutrients are nitrogen and phosphorus which are in the form of dissolved inorganic or organic compounds. Dissolved inorganic nitrogen comprises mainly of

dissolved nitrogen gas (N_2), ammonia (NH_4), nitrate ($N0_3$-N) and nitrite (NO_2-N), while dissolved inorganic phosphorus comprises of PO_4 ions. Organic compounds include those bound in plankton or biodetritus (Haris, 1986).

1.4.3 Predation

In tropical coastal waters, intense predation favours spawnings at suitable times and specific locations, so that eggs and larvae are dispersed to offshore areas where there is less predation (Johannes, 1978). Predation of fish larvae is also a major factor affecting the survival of larvae in mangrove habitats. Fish are important predators, consuming zooplankton, shrimp, gastropods, algae and other fish (Rooker, 1995, Chew et al., 2007, Then, 2008). Reduced visibility in the turbid mangrove waters may reduce predation by large fish. The structural complexity of mangroves provides excellent shelter and protection for the juveniles (Kathiresan & Bingham, 2001).

1.4.4 Food

Diverse communities of zooplankton exist in mangrove estuaries and their abundance can be extremely high (Kathiresan & Bingham, 2001; Chew & Chong, 2011). A few studies have shown that the mangrove estuaries generate an enormous amount of food especially the zooplankton, supplying sufficient food sources for juvenile fishes (Robertson & Duke, 1987; Chong et al., 1990; Blaber, 2000; Chew et al., 2007). Hence, zooplankton is of great importance as food for developing larvae. Copepod-dominated zooplankton is more common in mangrove estuaries than in adjacent coastal waters (Robertson & Blaber, 1992; Chew & Chong, 2011). Nevertheless, zooplankton abundance is usually dictated by the wet and dry season. In Gazi, Kenya, zooplankton abundance peaked around May when heavy monsoon rains increased nutrient input (Osore, 1992). Hence, spawning of fish usually occurs prior to this when environmental

conditions are most favourable for larval survival (Robertson & Duke, 1990b; Barletta-Bergan et al., 2002 a,b).

The horizontal gradient of food abundance may play a major role in the accumulation of young fish in coastal waters. Tanaka (1985) suggested that the gradient of copepod abundance that increased from offshore to inshore waters led immigrating red sea bream *Pagrus major* into the inshore areas in Shijiki Bay, southwestern Japan where their preferred prey, gammarid amphipods, were present. Although the larval Atlantic herring *Clupea harengus harengus* may show vertical distribution within estuaries that are adaptive for population maintenance, Fortier & Leggett (1983) suggested that these movements are simply a behavioral response to vertical movements of their prey organisms.

1.5 Ichthyoplankton of Mangrove Estuaries

Despite the large number of fish studies on mangrove estuaries due to their role as nursery and feeding areas (Faunce & Serafy, 2006), there are only a few studies that pertain to mangrove ichthyoplankton. These include those from Thailand (Janekarn & Boonruang, 1986), Malaysia (Blaber et al., 1997), India (Krishnamurthy & Jeyaseelan, 1981; Jeyaseelan, 1998), East Africa (Little et al., 1988), Brazil (Barletta-Bergan et al., 2002; Bonecker et al., 2009) and Puerto Rico (Austin, 1971). However, non-mangrove ichthyoplankton studies are many, including those from temperate waters (e.g. Moser et al., 1984; Neira et al., 1998; Aceves-Medina et al., 2004; Lo et al., 2010; Campfield & Houde, 2011) and tropical waters (e.g. Franco-Gordo et al., 2002; Katsuragawa et al., 2011).

Nonetheless, ichthyoplankton studies in southeast Asian waters are few and include those in the coastal waters of Vietnam (Nguyen, 1999), the Philippines (Chiu et al., 1992), Indonesia (Soewito & Schalk, 1990; Suharti & Sugeha, 2008) and shelf waters of the Andaman Sea (Munk et al., 2004). In South-Asian waters, larvae of more than 100 families of fish have been found in Thai waters with each family probably containing tens or hundreds of species (Janekarn & Kiørboe, 1991) and Liew (1992) identified 61 taxa (mainly family) from five Malaysian locations in the Straits of Malacca and South-China Sea. In the Australasian region, larval fish studies have been carried out mainly in coral reefs (e.g. Leis, 1993; Kingsford, 2001; McIlwain, 2003).

Many well developed methods are used for sampling larval fish populations in the open waters in neritic and oceanic environment. However, these open water ichthyoplankton collection methods are poorly suited to shallow waters especially in the mangrove estuaries where it might damage the sampling gear. High detritus derived from the mangroves often clog plankton nets. This problem will generate bias in estimating the abundance of ichthyoplankton. One of the major biases for estimating fish larval abundance is escape through the mesh of nets by eggs and early larvae, and the evasion of the approaching net by older larvae. The major source of imprecision is the tendency of larvae of all sizes to be aggregated, or patchy in distribution (Lasker, 1981). Oblique sampling is important to integrate larval abundance at the surface and bottom waters due to possible vertical stratification.

Tropical larval fish identification keys are few, except those by Delsman (1931), Leis & Rennis (1983), Leis & Trnski (1989) and Chayakul (1996). This taxonomic problem is compounded by the tremendous diversity of fish species in tropical waters. Larval identification keys are often specific to particular habitats, and are not useful if a

large portion of the ichthyoplankton of a region is unknown. The lack of ichthyoplankton studies are mainly due to the demands of sufficient sampling (to counter the problem of patchiness), the time-consuming examination of plankton samples, but most of all, the problem of identification due to the lack of larval fish identification keys. In most cases, fish larvae are at best identified to the familial level.

Typically, only a few species of so-called permanent residents, such as gobiids, spawn within estuarine ecosystems (Blaber, 2000). Many fish species found in mangrove estuaries are however, commonly known to be euryhaline and represent one phase of their life history patterns (Blaber & Milton, 1990; Chong, 2005). A few studies have so far suggested that most euryhaline fishes enter estuaries as juveniles or postlarvae after spending their larval stage in offshore waters where adults normally spawn (Bell et al., 1984; Little et al., 1988; Sarpedonti & Chong, 2008). The basic assumption is that the ichthyoplankton found in the estuaries are mainly derived from species that spawn within the estuary rather that at sea (Claridge et. al., 1986; de Lafontaine, 1990). However, studies have also shown that marine tropical fish may spawn in the estuary, for example, certain species of ariids (Singh, 2003), sciaenids (Yap, 1995), grey mullets (Chong, 1977), clupeids (Blaber et al., 1997), ambassids (Allen & Burgess, 1990) and centropomids (Moore, 1982). Most observations, however, are based on the presence of gravid females and are not substantiated conclusively by the presence of spawned eggs or the early larval stages.

Investigations on the larval stages of fish recruiting into the estuary would clarify the general function of estuaries as nursery sites. If post larvae and juveniles are captured throughout the year, spawning is likely to occur in adjacent coastal waters. Yolk-sac or flexion larvae however, indicate that the spawning takes place within the

estuary. Neither eggs nor larvae have been described, and nothing is known about the distribution or behavior of larvae in Matang mangroves estuaries.

1.6 Significance of Present Study

The Matang mangrove estuaries of Malaysia is one good example of a specific single location where numerous studies have been carried out to elucidate its nursery-ground function for coastal fishes and invertebrates (Sasekumar et al., 1994a; Chong et al., 2001; Ahmad Adnan et al., 2002; Kiso et al., 2003; Chong, 2005; Chong, 2007; Chew & Chong, 2011), yet no studies pertain to fish larvae. This is unfortunate because a complete understanding of the ecology of fish and their dependence on mangrove estuaries is not possible without a complete knowledge of their early life history. The latter includes the most fragile stages that are strongly influenced by the highly variable milieu of the estuary and ocean (Robertson & Blaber, 1992). Larval recruitment and survival in the mangrove estuaries will thus have a strong bearing on the structure and abundance of the juvenile fish community.

As the Straits of Malacca is one of the busiest waterways in the world, it is increasingly being polluted by land-based pollutants and hydrocarbons at sea (Chua & Ross, 1997). Although the MMFR is a reserved production forest, the estuary is however not spared from pollution, eutrophication and anthropogenic impacts. Depletion of dissolved oxygen due to land-derived nutrients and high organic decomposition from mangrove silviculture operations has affected density of larval fish directly via reduced food resources (e.g. zooplankton) (Kennish, 2002). Fish larvae are sensitive and in their most fragile stage of their life history. Their survival and numbers are dependent on the natural oceanographic conditions. These factors (and

anthropogenic effects, e.g. pollution) thus play an important role in determining subsequent production and recruitment into the fishery.

The spatial and temporal variation in estuarine assemblages particularly for tropical mangrove systems is still poorly understood and little is known about the mechanism by which larval fishes are recruited to, and concentrated in estuaries. The study of fish larvae and their ecology is crucial in defining the location of spawning grounds in space and time, determination of habitats used by fish during their larval phase, feeding habitats of larvae, condition of larvae, recruitment fluctuations and fishery-independent estimates of stock size and spawning boundaries. Such information serves as important guidelines for the implementation of more effective management plan and conservation efforts to protect both fish and habitat from drastic changes. For example in the USA, under the Magnuson-Stevens Fishery Conservation and Management Act as a result of the Sustainable Fisheries Act (1996), each fishery management plan must describe and identify Essential Fish Habitat (EFH). This is to minimize the adverse effects of fishing on EFH and identify other actions which could encourage the conservation and enhancement of such habitats (see Duval et al., 2004; Chong, 2006). Therefore, fishery management in Malaysia will need to consider protection of essential fish habitats including larval aggregation and nursery areas, and maintaining the health of these areas.

As most fish stocks are being overfished in Southeast Asia (McManus, 1997), aquaculture is viewed as a viable means to increase fish production (Chong, 2002). Therefore, there is a need to steer fish larval studies towards solving problems related to fisheries management and aquaculture. Research on fish larval development and

production will greatly benefit commercial aquaculture and governmental efforts in coastal fish stock enhancement.

1.7 Research Questions

1. Do fish enter the mangrove estuary as larvae, given that most fish present in nursery area are juveniles?

2. How is spatial and temporal distribution of larvae influenced by the environmental factors?

3. What are the strategies adopted by larval fish in utilizing mangrove habitats?

4. Is peak abundance of larval fish timed to food abundance?

5. Is the match-mismatch hypothesis applicable to tropical waters?

1.8 Scope and Overall Objective of Study

The present study identifies and describes the fish larval assemblages to mainly the familial level, and to the specific level where possible. To provide an in-depth information on the recruitment and retention of fish larvae within the estuaries, this study elucidates the spatio-temporal distribution and abundance of fish larvae in the estuarine waters. As the rapid recruitment of fish larvae into the estuary could not be detected using the monthly sampling, intensive diel and weekly (lunar phase) samplings were carried out in the dry and wet period of the monsoon season to determine the distribution and abundance of fish larvae in the estuary. Interactions between larval fish and physical factors are analyzed using Canonical Correspondence Analysis.

The main objectives of this study are as follows:

1) To identify fish larvae and ontogenetic stages in the estuary and adjacent coastal waters.

2) To study the spatial and temporal distribution of fish larvae in the estuary and adjacent coastal waters and the influence of environmental factors.

3) To study the seasonal, lunar phase, tidal and diel fish larvae abundance in the estuary and the influence of environmental factors.

To achieve the above objectives, the following studies were carried out:

1) Description of fish larvae (Chaper 3)

2) Spatio-temporal abundance (Chapter 4)

3) Diel and lunar phase study (Chapter 5)

4) Relationship of larval fish abundance with environmental factors (Chapter 6)

The hypotheses tested in this study are as follows:

1) Spatial and temporal distribution of larvae is influenced by the physical factors and plankton abundance (phytoplankton and zooplankton) (proposed and tested in Chapter 6)

2.) The match-mismatch hypothesis (Cushing, 1975), which states that fish spawning (and thus larval abundance) which is matched to food abundance will result in recruitment success (tested in Chapter 6)

CHAPTER 2

STUDY AREA AND METHODOLOGY

2.1 Study Area

The study was carried out in the Matang Mangrove Forest Reserve (MMFR), Kuala Sepetang, Perak, Malaysia. The MMFR covers an estimated area of 41,711 ha and is well known for its well-managed and sustained silvicultured mangrove forest. The productive forest covers 32,746 ha (82%) while 7,405 ha (18%) comprises dry-land forest and newly accreted forest (Gan, 1995). The Matang Mangrove Forest Reserve forms a large crescent-shaped strip along the northern coast of Perak state, stretching 51.5 km from Kuala Gula (4º55'N 100°28'E) to the north and to Bagan Panchor (4º31'N 100°38'E) to the south measuring about 13 km wide. MMFR is built on deltaic islands (Pulau Gula, P. Kelumpang, P. Selinsing, P. Sangga Kecil, P. Sangga Besar, P. Terong and P. Pasir Hitam) criss-crossed by the major mangrove channels (of Sg. Terusan Gula, Selinsing River, Sg. Sangga Besar, Sg. Sangga Kecil, Sg. Jaha and Sg. Jarum Mas). Generally, 95% of the forest is inundated during tidal shifts (Gan, 1995). There are approximately 8,653 ha of mudflats adjoining the forest in the foreshore and between islands (Sasekumar et al., 1994a). While about 85% of the forests are productive forests, the numerous rivers and waterways have shown to be important nursery areas for commercially-valuable marine organisms like fish and prawns (Sasekumar et al., 1994a; Chong, 2006; 2007; Chew et al., 2007; Then, 2008). The coastal area (< 30 nautical miles from shore) is a major contributor to the total annual marine production (Annual Fisheries Statistics, 2009).

2.2 Sampling Design and Field Collection

2.2.1 Monthly Sampling (18 months)

Five sampling stations were established along the main water channels of the Sepetang (Station 1), Sangga Besar (Station 2) and Sangga Kecil (Stations 3, 4 and 5) rivers within the MMFR, and another two stations in the adjacent coastal waters (Stations 6 and 7) (see Figure 2.1 and Table 2.1). Upstream distances from the river mouth (Station 5) for Stations 1, 2, 3 and 4 were 10.6 km, 7.0 km, 3.5 km and 2.8 km, respectively. Offshore distances from the river mouth for Stations 6 and 7 were 8.0 and 16.0 km respectively. Mean depths at each station were as follows: Station 1 (3.81 ± 1.62 m), Station 2 (3.46 ± 0.71 m), Station 3 (7.25 ± 1.21 m), Station 4 (7.05 ± 1.98 m), Station 5 (5.75 ± 0.56 m), Station 6 (3.30 ± 0.74 m) and Station 7 (7.04 ± 0.86 m).

Zooplankton was regularly sampled by horizontally-towed bongo nets during neap tide each month from May 2002 to October 2003. The MARMAP bongo net system comprised of two 45-cm diameter net frames, fitted with pre-calibrated flow meters and twin nets of 363 μm and 180 μm mesh sizes. The nets sampled surface waters at approximately 0.5 m depth for 10-min durations. Oblique tow of the entire water column in the mangrove estuary was not done due to the shallow depths which were also variable along the tow path. The diel study using a 24”-mouth Clark-Bumpus at Station 5 however demonstrated no large discrepancy in larval fish catches, as well as zooplankton biomass, between top and bottom waters during daytime or nighttime (Ooi et al., 2005). Nevertheless, oblique tow was carried out in open offshore waters at Station 7.

Duplicate samples were taken at each station during day, one on the sea-bound journey and the other on the return. The collected zooplankton samples were immediately preserved in 10% buffered formaldehyde in 500-ml plastic bottles.

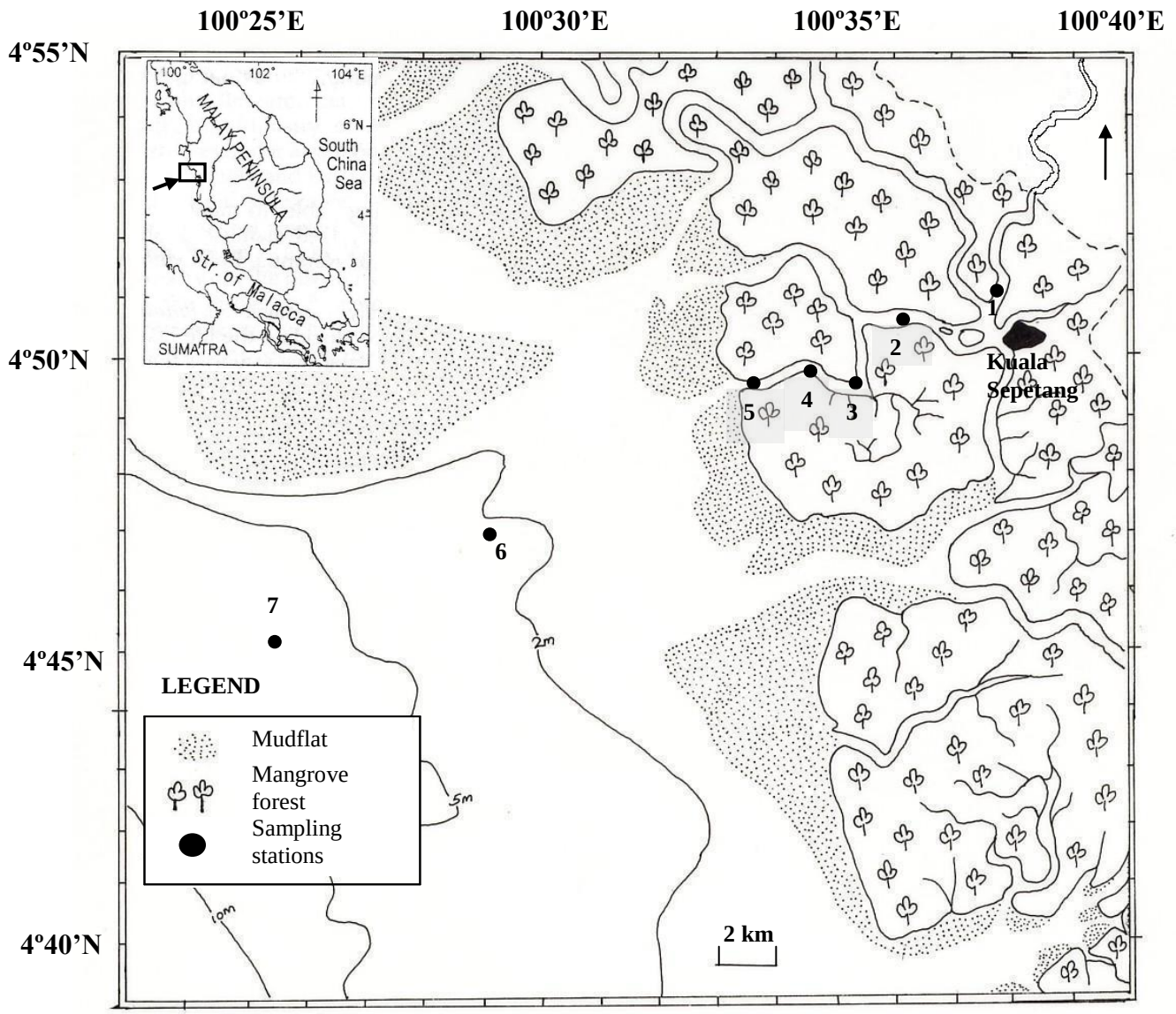

Figure 2.1. Sampling locations (numbered 1-7) in Sepetang, Sangga Besar, Sangga Kecil rivers and adjacent waters in Matang mangrove forest reserve (MMFR), Perak.

Table 2.1. Detailed information of location and sampling period.

Station	Location	Distance from river mouth (km)	Mean depth	Monthly Sampling	24-hr Sampling
1	4°50'N 100°37.5'	-10.6*	3.98	Nov 2002- Oct 2003	
2	4°50.5'N 100°36'	-7*	3.46	May 2002 - Oct 2003	
3	4°50'N 100°35'	-3.5*	7.25	May 2002 - Oct 2003	
4	4°50'N 100°34'	-2.8*	7.04	May 2002 - Oct 2003	
5	4°34'N 100°33'	0	5.75	May 2002 - Oct 2003	Jul 2003 and Nov 2003
6	4°47'N 100°29'	8	3.30	May 2002 - Oct 2003	
7	4°45'N 100°25'	16	7.04	May 2002 - Oct 2003	

*Indicates upstream distance

2.2.2 Diel Sampling

Eight 24-hour studies were carried out at the river mouth (station 5) of Sangga Kecil, to cover different lunar phases (over one month), in the dry and wet season. These 24-hr studies were carried out during the following dates, for dry season: 7-8 July (Neap tide, first quarter), 14-15 July (Spring tide, full moon), 21-22 July (Neap tide, third quarter) and 28-29 July (Spring tide, new moon) in 2003. Another similar set of 24-hr studies in the wet season, were carried out in 2-3 November 2003 (Neap tide, first quarter), 9-10 November (Spring tide, full moon), 17-18 November (Neap tide, third quarter) and 24-25 November (Spring tide, new moon). Samplings were carried out at two-hour intervals over 24 hours to cover two high and two low tides, during day and night. For each sampling, duplicate zooplankton samples were collected by a 24”-mouth diameter Clarke-Bumpus sampler which has a mouth closing mechanism at two depths, surface and near bottom using a160µm plankton net. Collected zooplankton samples were immediately preserved in buffered 10% formaldehyde.

2.3 Measurement of Environmental Parameters

2.3.1 Water Parameters

Water parameters were measured from all sampling stations during plankton tows. Five water parameters, viz. temperature, salinity, dissolved oxygen, turbidity and pH were measured at the surface of the water before the start of each tow. Water parameters were measured *in-situ* using a metered YSI 3800 multi-parameter sonde, and in later months by a Hydrolab 4a.

For diel studies, water parameters were measured at the two depths, surface and bottom. Water parameters were measured *in-situ* using a multi-parameter sonde, Hydrolab 4a in all sampling procedures.

2.3.2 Chlorophyll *a*

Monthly chlorophyll *a* analysis started in July 2002. Phytoplankton biomass at each station was assessed by measuring the amount of chlorophyll *a* in the top 1 meter layer of the water column. A Van Dorn sampler was used to collect 12 L of water which was collected three times and transferred into a clean pail. The water was mixed well and a pooled sample of 1L was transferred into a sterile plastic container kept in an icebox. It was immediately processed upon arrival to the laboratory after sampling.

2.3.3 Tides

Tidal condition at each sampling occasion was based on the Tide Tables of Peninsular Malaysia (2002 & 2003, HD). Slack water times at the sampling area Kuala Sepetang, 4º 50'N, 100º 35'E were interpolated based on the given tide table for Lumut (4º 14'N, 100º 37'E) (HD). The slack times at Kuala Sepetang were set back 1 hr 41 min before that in Lumut. The tidal levels at mean high water springs (MHWS), mean high water neaps (MHWN), mean low water neaps (MLWN) and mean low water springs (MLWS) at Lumut were reported at 2.7, 2.0, 1.2 and 0.5 m above chart datum.

At Kuala Sepetang, Matang, the water height differences at MHWS, MLWS, MLWN and MLWS were respectively 0.6, 0.5, 0.3 and 0.2 m lower than at Lumut. Based on this information, the mean spring and neap tidal amplitudes were respectively 1.8 m and 0.6 m at Kuala Sepetang.

2.3.4 Metereological Data

The standard precipitation index (SPI) developed by McKee et al. (1993) was used to define the annual precipitation pattern in the study area. Annual SPI over a 12-year time scale period (see Figure 2.2) was calculated based on the following equation:

$$SPI = \frac{X_i - \overline{X}}{SD}$$

Where X_i is the total rainfall of a particular month
$\overline{X}$ is the mean monthly total rainfall over a 12-year time scale
SD is the standard deviation of the total monthly rainfall over a 12-year timescale

The SPI values and precipitation categories are given in Table 2.2.

Table 2.2. Standard precipitation index (SPI) and precipitation categories.

SPI	Category
≥ 2.0	Extremely wet
1.5 to 1.99	Very wet
1 to 1.49	Moderately wet
-0.99 to 0.99	Nearly normal
-1 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
≤ -2	Extreme drought

Malaysia's rainfall pattern is strongly influenced by the region's monsoon regime, the South-west Monsoon (May – September) and the North-east Monsoon (November – March) which are interceded by two short periods (inter-monsoon) of variable winds (Figure 2.3). At the study site, the NE monsoon however brings the heaviest rainfall (above annual mean), whereas the SW monsoon is comparatively drier (below annual mean). A t-test result shows that the NE monsoon (Nov-Mac) is significantly higher than SW monsoon (May-Sept) ($P < 0.5$). Thus, in the diel and lunar study, July 2003 represented the drier SW monsoon and Nov 2003 as the wetter monsoon season. The rainfall data for the town of Taiping (4° 51' 0"N, 100° 44' 0"E), situated approximately 10 km east of Kuala Sepetang was taken as representative for the study site. Monthly rainfall data for 2002 and 2003 were obtained from the Malaysian Metereological Services (MMS).

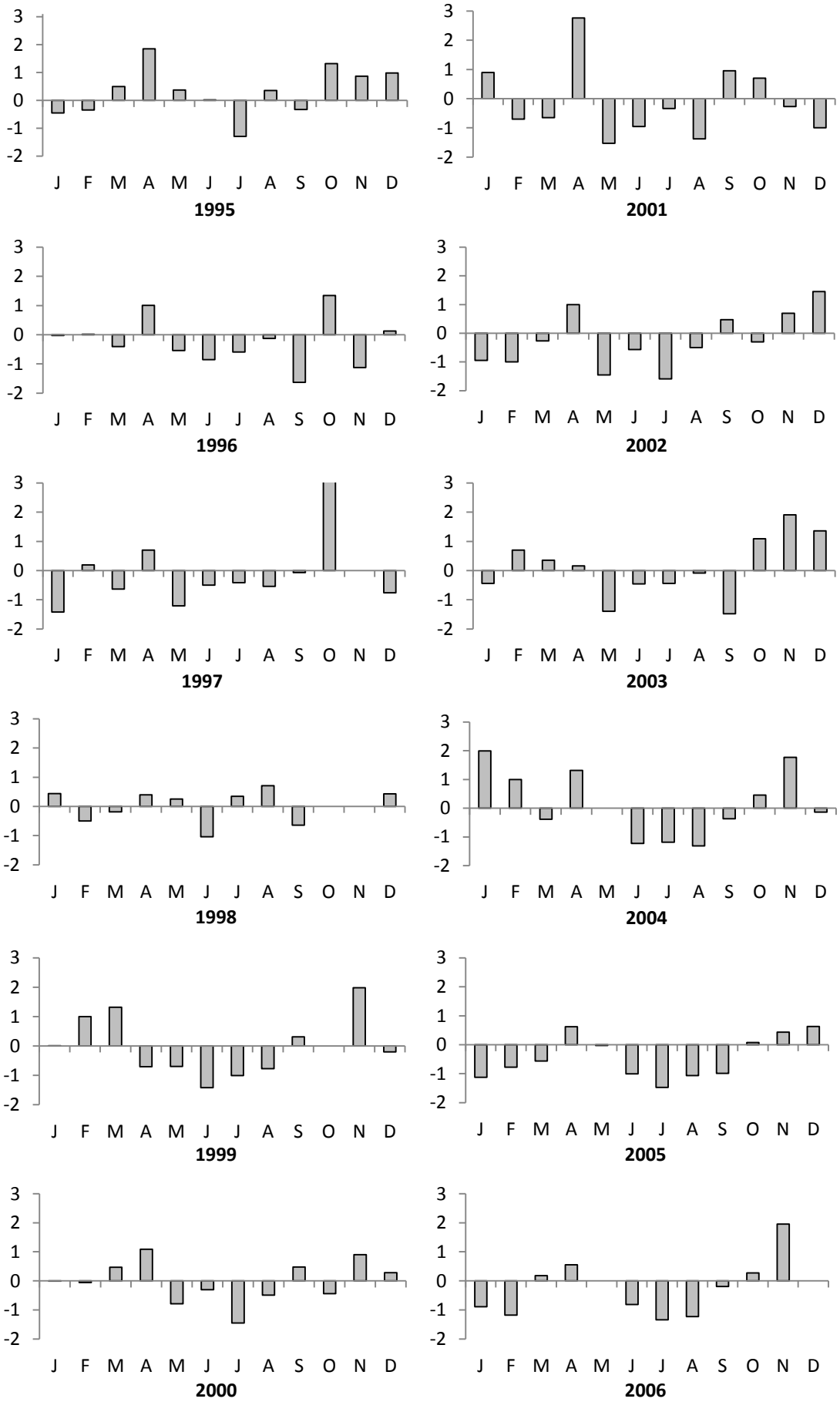

Figure 2.2. Annual standardized precipitation index (SPI) from 1995 to 2006 at Taiping (data provided by Malaysian Meteorological Department). May-Sept (SW monsoon), Nov-Mac (NE monsoon), Apr & Oct (Intermonsoons). See Table 2.2 for SPI descriptions.

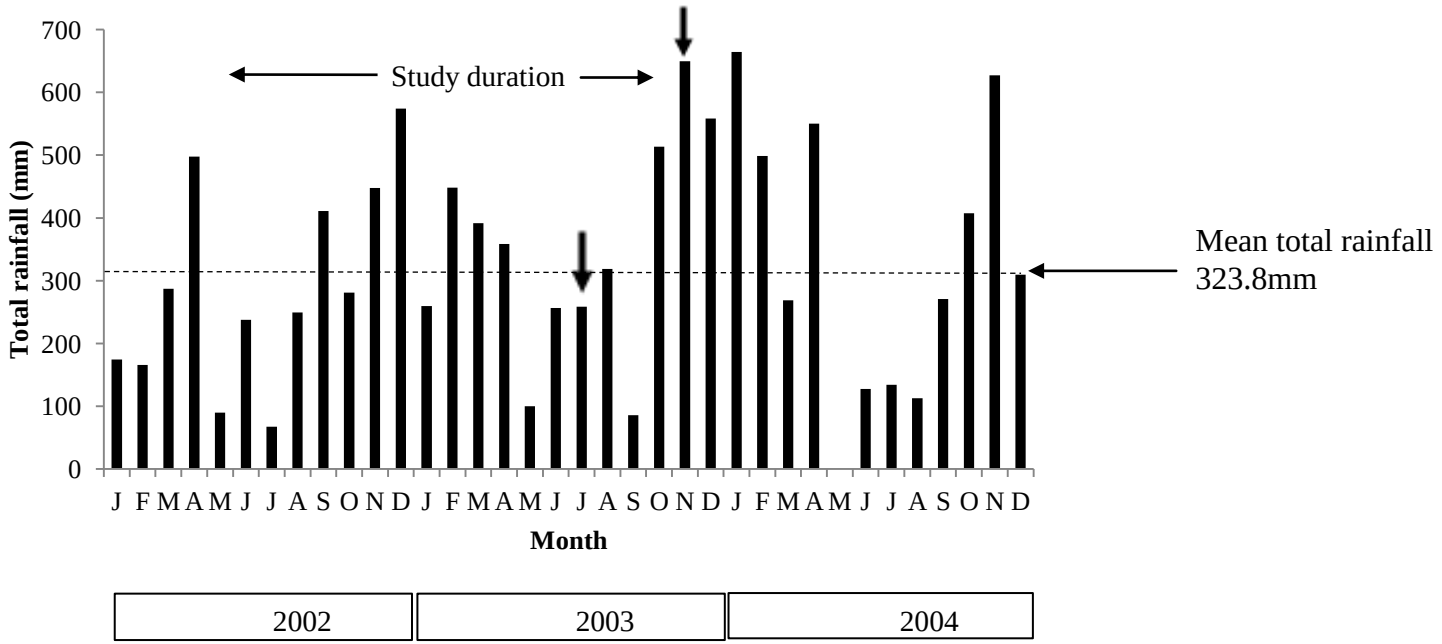

Figure 2.3. Total monthly rainfall of Taiping (Perak) area from January 2002 to December 2004. (Study duration for monthly sampling was from May 2002 to October 2003). Arrows show diel and lunar study in July and November 2003.

2.4 Laboratory Analysis

2.4.1 Zooplankton Biomass

In the laboratory, zooplankton samples collected by both 363 μm and 180 μm bongo nets were quickly washed and sieved through a stack of 500 μm, 250 μm and 125 μm Endecott sieves under running tap water. The sieved zooplankton fractions were transferred onto pre-weighed steel gauze and excess moisture was removed using blotting paper before the wet weight of each size fraction was determined by a fine balance (g, to 4 decimal places). The zooplankton fractions were immediately resuspended in 80% alcohol kept in separate 100-ml screw capped vials. The zooplankton biomass of each size-group was calculated from the volume of water filtered based on the flowmeter readings, and expressed in g 100 m^{-3}.

2.4.2 Sorting and Identification of Fish Larvae

All fish larvae were sorted out from the 250-500 μm and >500 μm size fractions collected by the 363 μm bongo net. The 125-250 μm size and <125 μm size fractions were ignored because preliminary examination of 100 samples of the former did not yield any fish larvae. All fish larvae were separated from the rest of the zooplankton using a dissecting microscope (magnification x 10 - 40). This was easily accomplished by using a custom-made plankton sorting cell (Figure 2.4). The fish larvae were immediately resuspended in 80% alcohol kept in separate 2 ml and 10 ml screw capped vials.

The taxonomic identification was mainly based on developmental series, working backwards from the known adults and juveniles captured in the same region by previous works (Sasekumar et al. 1994a; Chong, 2005) and utilizing characters common to successively earlier ontogenetic stages (Powles & Markle 1984). Fish larvae were

identified using available information from Okiyama (1988), Leis and Trnski (1989), Jeeyaseelan (1998), Termvidchakorn (undated) and Leis and Carson-Ewart (2000). Relative position of the dorsal and anal fins (in particular, engraulids), spine, fin ray and vertebrae counts and pigmentation patterns (in particular, Gobiidae) were used to identify fish larvae. Prior to sorting and identification, some samples were fractioned using a Folsom plankton splitter owing to the high abundance of eggs and larvae. The maximum number of splits was two.

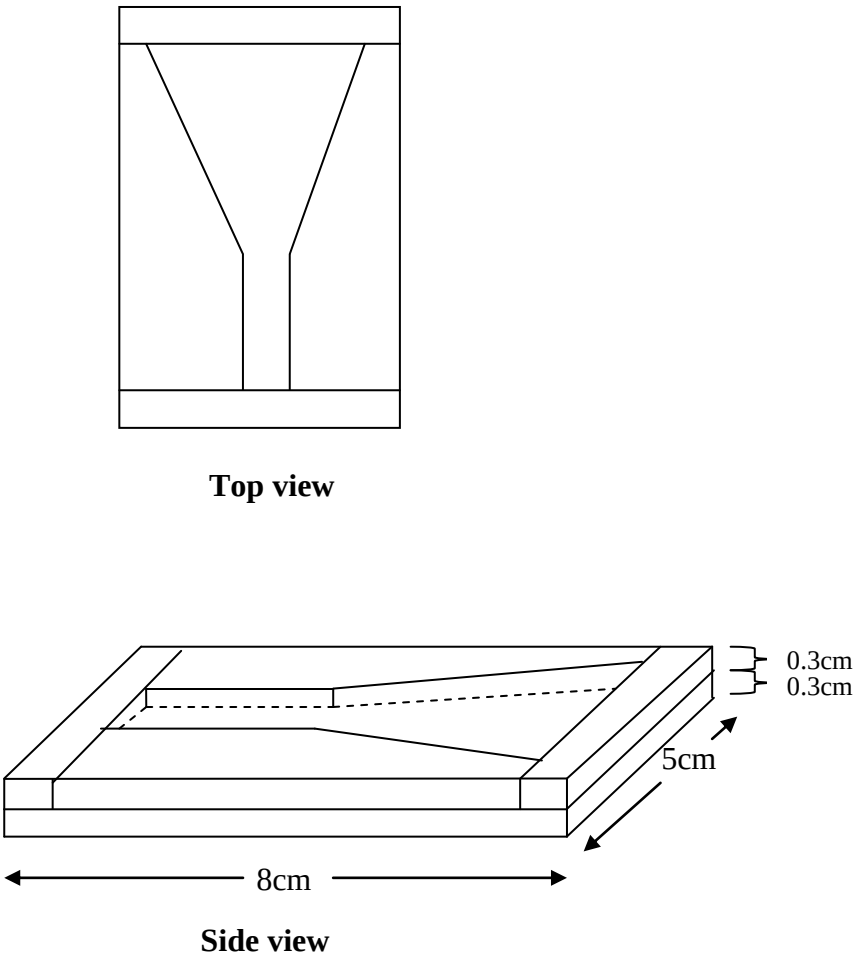

Figure 2.4. Plankton sorting cell (not to scale) (Chong, 1993)

2.4.3 Larval Fish Illustrations and Measurements

Illustration of fish larva is to represent precisely a three-dimensional, often transparent larva into a two-dimensional drawing. It emphasizes the characters that are most useful to identify the larva of the taxon illustrated (Sumida et al., 1984). In this study, although twenty-two fish larva families were identify to family level, only ten families were illustrated and described in the thesis. They were Gobiidae, Engraulidae, Clupeidae, Sciaenidae, Ambassidae, Blenniidae, Cynoglossidae, Scatophagidae, Mugilidae and Belonidae. These fish larva families were chosen as they were in their best condition to illustrate. The specimens selected were in the best available condition and representative of the particular developmental stage in both morphology and pigmentation pattern of the ten families. However, in a few cases when the only specimens required were twisted or bent, they were illustrated as they were. Illustrations of the larval fish in the present study were produced from a camera-lucida attached to a microscope.

Initial drawings were made in pencil and finished using a fine-tipped “Rotring” pen. The technique used was line-and-stipple. The internal pigmentation was represented using light stippling with a smaller sized pen-point. The specimen was checked constantly during this process. Illustrations are semi-diagrammatic in style, with body outline and major surface features shown with solid and dashed lines and pigment indicated by stippling or line. Incipient (forming) spines and soft rays were drawn as broken lines. Formed spines were drawn as solid, pointed structures. Formed soft rays of all fins were drawn combining a solid line for the leading (anterior) edge and a dotted line for the trailing (posterior) edge. The edges of gas bladder, gut and notochord tip were drawn as broken lines. The external melanophores were drawn with solid lines as branched or stellate. External dense pigments were drawn with dark stipping and internal melanophores and pigment, with light stippling. Examination of

fish larvae was aided by a phase contrast microscope or by staining the specimens with methylene blue.

2.4.4 Description of Fish Larva Family

Four methods of identifying fish larvae have been utilized: literature accounts, the series method, biochemical methods and rearing (Leis & Carson-Ewart, 2000). The present study used the literature and series method. Fish larva families were described in terms of morphology and pigmentation. All descriptions are based on examined specimens unless noted otherwise.

Morphology

Body size, head size, as well as gut size and morphology for the preflexion, flexion, postflexion and juvenile stages (if present) were described. These characters also provided the main distinguishing characters including teeth, type of head spines, presence of a gas bladder and its relative size. The gap between the anus and the origin of the anal fin was also included, if present. Other additional information relevant to distinguish developmental features included the size of the fins, transformation of soft rays into spines if these were present in the specimens examined.

Pigmentation

The external and internal pigmentation, and their changes during development of the larvae were described. The terms ‘heavily’ and ‘lightly’ pigmented is sometimes used to characterize a larva or a body region with densely or sparsely distributed melanophores.

2.4.5 Chlorophyll *a* Analysis

Water samples were collected into 500 ml bottles, kept in ice, before aliquots of 100 ml each were filtered through a 47 mm diameter GF/C Whatman microfiber filter paper. The filtered phytoplankton cells were buffered with a few drops of $MgCO_3$, then wrapped individually in aluminium foil and kept frozen in circular cream containers before analysis for 24 hours. The filter paper with its phytoplankton content was homogenized in a tissue grinder and put into a polypropylene test tube. 10 ml of 90% acetone was poured into the tube from the filter papers. The tube was screw-capped and stored without light at 4ºC in the refridgerator for 24 hours to facilitate complete pigment extraction of chlorophyll *a*.

After extraction, the homogenate was centrifuged at 3,000 rpm for 10 minutes. The concentration of chlorophyll *a* in the supernatant was measured by a Quantech Turner fluorometer Model FM109530-33, after spectrophotometric calibration based on extracted microalgal chlorophyll *a*. Blank (90% acetone) was measured and all readings were re-adjusted with blank reading.

The standard curve of chlorophyll *a* was established based on a high but known concentration of chlorophyll extract. *Chlorella* algae were cultured in the laboratory to obtain a bloom, from which a chlorophyll sample of high concentration was extracted following the procedure described above. The concentration of the extracted chlorophyll solution was measured by Shimadzu UV-VIS Spectrophotometer in a 5 ml quartz cuvette. Three absorbance readings corresponding to three wavelengths (665, 645 and 630 nm) were obtained. The concentration of chlorophyll *a* in the solution was calculated using the following equation (Strickland & Parsons, 1968):

$C = 11.6 \times OD_{665} - 1.31 \times OD_{645} - 0.14 \times OD_{630}$

Where OD = the absorbance at different wavelengths

C = concentration of chlorophyll *a* in $(mg.mL^{-1})/10^3 = \mu g.mL^{-1}$

The concentration of chlorophyll *a* in $\mu g\ L^{-1}$ was calculated based on the following equation:

$$\text{Chlorophyll } a\ (\mu g\ L^{-1}) = \frac{C \times 10 \text{ ml of extracted sample}}{100 \text{ ml of filtered water sample} \times 1000}$$

The solution with known chlorophyll *a* concentration was then serially diluted to give five (known) different concentrations. The known chlorophyll *a* concentrations were used to set the standard curve in the fluorometer according to the Quantech Turner Fluorometer operation manual. New standard curves of chlorophyll a were prepared every 3 months.

2.4.6 Stable Isotope Analysis of Fish Larvae

This method traces the energy flow from producers to consumers and determines if the carbon source supporting the fish larvae is from mangrove, phytoplankton or benthic microflora (Rodelli et al., 1984; Newell et al., 1995). Isotopic ratios record materials that are actually assimilated by consumers andstored in their tissues. Typically, carbon provides information on the primary energy source, while nitrogen and clarifies trophic levels and relationships.

Only a few major fish larva families sampled from the mangrove estuary and offshore waters were use for this analysis namely, Gobiidae, Engraulidae, Blenniidae and Carangidae. Fresh specimens were immediately sorted out and processed. Whole

specimens were used and they were dried in the oven at 60ºC for 4 - 5 days. Dried samples were sealed in plastic bags and sent to Marine Biological Laboratory in Woods Hole, USA for stable carbon and nitrogen isotopes analyses.

2.5 Computational and Statistical Analysis

2.5.1 Rainfall and Water Parameters

Monthly averages of rainfall were calculated from the daily records. From the monthly rainfall averages, the onset of the Southwest and Northeast monsoons was determined. These were supported by the wind rose data, from the Malaysian Meteorological Department. The dry and wet seasons were determined based on the average rainfall volume.

For water parameters, the time series data for each variable were averaged for its arithmetic mean representative of the overall water characteristics, and plotted with mean monthly fluctuations (standard deviation). Results were presented for each month and sampling stations. All variables were tested for normality and homogeneity of variances prior to parametric analysis. Skewed data were either $\log_{10}$ (x) (environmental variable) or Kruskal-Wallis ANOVA test was conducted if the variable did not fulfill parametric assumptions even after data transformation. The water parameters were subjected to two-way analysis of variance (ANOVA). These ANOVA determined whether the water parameters were significant influenced by month (May 2002 to October 2003) and stations (Station 1 to 7) each of which was considered a fixed factor. Significant difference of more than two means was then tested by post-hoc Newman Keuls test (Zar, 1999).

For diel study, water parameters were tested for differences due to effects of lunar phase (1Q, FM, 3Q, NM), water column depth (S, B), tidal effects (E, F) and light (D, N). The levels of the 'Lunar phase' factor were first quarter (1Q), full moon (FM), third quarter (3Q) and new moon (NM). The levels of water depth were 'surface' (S) and 'bottom' (B) water. The levels of tidal effects were 'ebb' (E) and 'flood' (F) tides. The levels of light were 'day' (D) and 'night' (N). The STATISTICA software package version 9 was used for statistical analyses, unless otherwise stated.

2.5.2 Chlorophyll *a* and Zooplankton Biomass

The readings for chlorophyll *a* and zooplankton biomass of various fractions were averaged for its arithmetic mean and plotted for mean monthly distribution. Plankton biomass was based on plankton collected from the 180 µm bongo net. Results were presented for each month and sampling stations. All variables were tested and log-transformed for normality and homogeneity of variances prior to ANOVA analysis. The chlorophyll *a* measurement and zooplankton biomass in each replicate was subjected to two-way analysis of variance (ANOVA). These ANOVAs thus determined whether the chlorophyll *a* and zooplankton biomass were influenced significantly by months and stations, each of which was considered a fixed factor. Significant difference of more than two means was then tested by post-hoc Newman Keuls test (Zar, 1999). For monthly samples, differences in water parameters were also tested with regard to tides.

For diel study, chlorophyll *a* and zooplankton biomass were tested for differences due to effects of lunar phase, water depth, tidal effects and light. Significant difference among means was then tested by post-hoc Newman Keuls test (Zar, 1999). The STATISTICA software package version 9.0 was used for statistical analyses, unless otherwise stated.

2.5.3 Calculation of Larval Density

The density of individuals for each taxon captured was based on a standard water volume of 100 m^3. The calculation of the actual filtered water volume resulted from the following equation:

Filtered water volume in m^3 = Tow distance in meters (Difference between flowmeter reading before and after tow*F value)*Area of net mouth (Refer Appendix 2.1a & b; 2.2)

Where,

Distance of one revolution of the flow meter = F value (Refer Appendix 2.3 a & b)

Area of bongo net mouth with a diameter of 45cm = 3.142*(0.45/2)*(0.45/2) = 0.159 m^2

Hence, larval density (D), in terms of $N.100m^{-3}$, is

D = (N x 100)/ filtered water (in m^3)

The number of individuals per taxon was counted from the entire sample. Teleost eggs were enumerated but not identified. No attempt was made to separate all the fish larvae into species level.

2.5.4 Univariate Analysis

2.5.4.1 Monthly Sampling

For each fish larva family, descriptive statistics, such as frequency of occurrence, total abundance, mean abundance and standard deviations, were calculated for each months and stations. Developmental stages of the most abundant families, like Gobiidae, Engraulidae, Clupeidae, Sciaenidae, Ambassidae and Blenniidae, were also presented, based on month and station.

Analysis of variance (ANOVA) was used to test differences in total densities (N. $100m^{-3}$), and the densities of each of the fish larva family among months and stations. In marine sampling, the data under consideration often departs from normality and therefore, analysis of the raw data leads to considerable errors and incorrect conclusions (Barnes, 1952). In order to reduce the weight of the most abundant species, the data were log-transformed. The normality of data was tested with the Kolmogorov–Smirov test (Sokal & Rohlf, 1998). When the assumptions of parametric statistics could not be met, a non-parametric Kruskal-Wallis ANOVA test with a 5% level of significance was used (Zar, 1999). Where ANOVA showed significant interactions ($P \leq 0.05$), a posteriori Student-Newman-Keuls (SNK) test was used to determine whether the differences in the means were significant.

2.5.4.2 Diel Sampling

For each fish larva family, descriptive statistics, such as frequency of occurrence, total abundance, mean abundance and standard deviations, were calculated for each season, lunar phase, depth, tidal phase and light. Developmental stages of the most abundant families, like Gobiidae, Engraulidae, Clupeidae, Sciaenidae, Ambassidae and Blenniidae, were also presented, in relation to season, lunar phase and depth.

The mean densities of fish larvae ($N.100m^{-3}$) were subjected to log(x+1) transformation prior to parametric testings. A 4-way ANOVA was conducted to test the effects of the following factors: Lunar phase (first quarter moon, full moon, last quarter moon, new moon), Depth (surface, bottom), Tidal phase (ebb, flood), Light (day, night) and season on mean density of fish larva family. A post-hoc Student-Newman-Keuls (SNK) test was used to determine whether the differences among means were

significant. When the assumptions of parametric statistics could not be met, a non-parametric Kruskal-Wallis ANOVA test with a 5% level of significance was used (Zar, 1999). All statistical analyses were performed using Statistica Version 9.0 Software Package. The level of significance was tested at the 5% level.

2.5.4.3 Testing the Match-Mismatch Hypothesis

Results from monthly density of preflexion stage of Gobiidae and Engraulidae (most dominant families) larvae were treated as follows:

1) The mean monthly population densities of preflexion Gobiidae and Engraulidae in mangrove waters and adjacent coastal waters were log (x+1) transformed. The preflexion stage was used because their numbers is the result of survival from first feeding.

2) The 'annual' mean and standard deviation (i.e. for the 18 months of survey) of the monthly log-transformed densities were calculated.

3) The annual mean was then subtracted from the monthly means and the differences obtained were then divided by the annual standard deviation. The value thus obtained gives the deviations (from the annual mean) in terms of number of standard deviations. Hence, a negative value indicates a larval density lower than the annual mean stock density, whereas a positive value indicated a larval density above the annual mean.

4) As copepods are the most abundant and the main food for fish larvae and young juveniles (Chew & Chong, 2011), its abundance was used to represent the zooplankton abundance. Chlorophyll *a* was used to represent phytoplankton abundance. The data on copepod and chlorophyll *a* abundance were similarly treated as larval fish abundance, and their abundance were plotted together with larval fish abundance. The peak abundance of preflexion stage of Gobiidae and Engraulidae was compared with peak abundance of copepods and chlorophyll *a*. If the peaks of larval fish abundance and

plankton occur together, it would constitute a 'match'. A larger temporal lag period is expected to be observed between the peak larval fish abundance with chlorophyll *a* as compared to larval fish abundance with copepods (see Figure 2.5) since copepods are the primary consumers and constitute the main food for fish larvae.

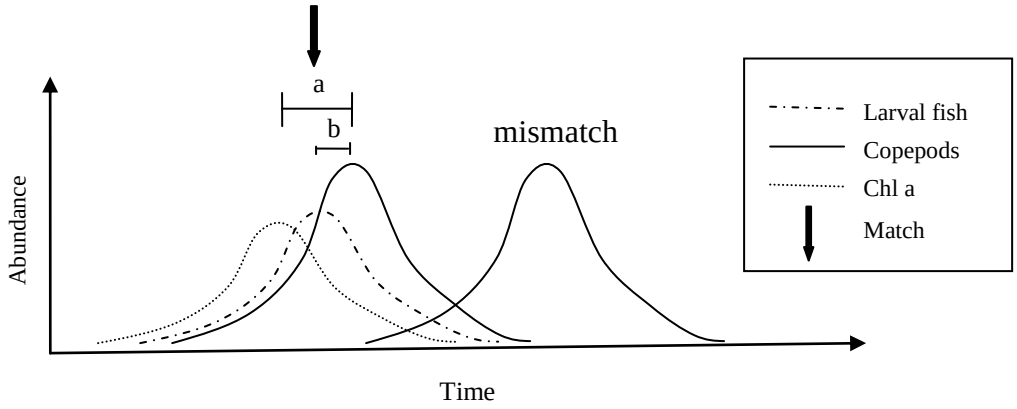

Figure 2.5. Example on how peak abundance of larval fish, copepods and chlorophyll *a* constitute a match. 'a' indicates lag period between peak of larval fish abundance and chlorophyll *a*. 'b' indicates lag period between peak of larval fish abundance and copepods (adapted from Cushing, 1990).

2.5.5 Multivariate Analysis

2.5.5.1 Monthly Sampling

Canonical Correspondence Analysis (CCA) was performed to determine the relationships between the abundance of total fish larvae and environmental variables. Developmental stages of the most abundant families, like Gobiidae, Engraulidae, Clupeidae, Sciaenidae, Ambassidae and Blenniidae, were also related to the environmental variables.

This was done using the CANOCO for Windows Version 4.5 software (ter Braak& Smilauer, 2002). One hundred and eighteen samples containing 19 major larval fish families were related to nine environmental parameters namely, salinity, pH, temperature, dissolved oxygen, turbidity, chlorophyll *a* concentration, and plankton

biomass of size fractions > 500µm, 250-500 µm and 125-250 µm. Plankton biomass was based on plankton collected by the 180 µm bongo net.

This CCA or non-linear eigenvector ordination technique enables the representation of multidimensional aggregated data in two or three dimensions, and thus the simultaneous analysis and comparison of two data matrices, one containing the species abundance data and the second one containing the environmental variables (Legendre & Legendre, 1998). This technique is particularly recommended for direct analysis of the relationships between multivariate ecological data sets (Rodriguez & Lewis, 1997). After several iterations of the data, the parameters of the final regression were given as canonical coefficients, which represent a measure of the association between fish larval abundance and environmental factors. The given eigenvalues give a measure of how much variation in the species data is explained by the axis and hence, by the environmental variables (ter Braak, 1995). The generated inter-set correlations give the correlation between the environmental variable and site scores derived from the species data.

The canonical coefficients define the ordination axes as linear combinations of the environmental variables, and the intraset correlations are the correlation coefficients between the environmental variables and these ordination axes (ter Braak, 1986). Both the canonical coefficients and intraset correlations can be used to infer the relative importance of each environmental factor for predicting larval abundance, but it has been shown that the former can be unstable when the environmental variables themselves covary (ter Braak, 1988). The intraset correlations do not suffer from this multicollinearity problem, and are thus used in this study to interpret the derived relationships between species and environmental factors in the given area. The intra-set

correlation corresponds to the inter-set correlation divided by the species-environment correlation of the axis or multiple correlation factor (ter Braak, 1995).

CHAPTER 3

DESCRIPTION OF EARLY LIFE STAGES OF FISH LARVAE

Summary of Important Findings

A total of 22 larval fish families were generally described in the present study. Gobiid larvae are usually identified through their prominent gas bladder which is located midway along the gut. Engraulidae consisted of two main species, *Stolephorus baganensis* and *Thryssa kammalensis*. *Stolephorus* are characterized by smaller anal ray counts while *Thryssa* is discriminated by longer anal fin rays. Scatophagidae was represented by a single species, *Scatophagus argus*. Based on the presence of the existing juveniles and adults, other species of larvae likely to occur in the present study are discussed.

3.1 INTRODUCTION

Adult and larval fish are often morphologically and ecologically distinct. They occupy different habitats, taking different food resources, and having different predators and different behaviour. During the larval phase, the fish develops from an egg to a larva which will have all fully functional organs. Many species have highly specialized larval morphologies, with various structures (e.g. strong spines on the head) that will be modified and lost upon transition towards adulthood (Leis & Carson-Ewart, 2000). Fish larvae differ so much from their adults that they are often difficult to identify. Nonetheless, they need to be identified to some level of confidence if larval ecological studies are to be meaningful, the positive identification of larvae is necessary. Unfortunately few ichthyoplankton studies have been carried out in Malaysia due to the problem of larval identification and taxonomy. The few studies included fish larvae sampledin coastal areas (e.g. Liew, 1992; Sarpedonti, 2000), offshore waters (Rosdi et

al., 2001) and over the coastal mudflat (e.g. Tsuhako et al., 2003). None pertains to the mangrove estuaries. Hence, the identity and description of the early life stages of mangrove fish larvae is important to enable more research on fish larvae in the mangrove ecosystem. Fish development (ontogeny) studies have increased understanding of the relationships between larval fish diversity and distribution with the environmental factors, and how fish larvae adapt to them. In particular, such studies will further elucidate the role played by mangroves as a nursery, feeding or spawning ground.

The specific objective of this study was to identify and describe the fish larvae at least to the family level. Certain fish groups, for instance, the Gobiidae is very diverse which makes the identification even to the family level very difficult. Thus, only general descriptions of identified fish larvae to the lowest taxonomic level are reported here.

3.2 RESULTS

Results are presented according to fish larval families. Twenty two larval fish families are described in this chapter. Only ten larval fish families are described with illustrations. There are probably a few different species of fish larvae in a single family examined. Different morphology and pigmentation patterns could be observed from these fish larvae. However, they were only described in general. Terminology of the developmental stages of fishes used in this chapter (and overall study) is based on the widely used text by Ahlstrom and co-workers (Kendall et al., 1984), namely, preflexion larva, flexion larva, postflexion larva, juvenile and adult. Characters used in the descriptions of the larvae include as follows: body shape, myomere counts, gut shape,

gas bladder, head spination, eyes, fin formation, size, pigmentations and vertebral counts.

3.2.1 Family Gobiidae

The following descriptions are based on specimens ranging from 2.0 mm - 4.73 mm SL.

Morphology: Gobiid larvae are elongate to moderate in depth. There are slight changes in the depth from head to tail as the larva grows. They have a long caudal peduncle. Body is compressed and has 24-26 myomeres. The gut is moderate to long and it is usually straight or gently curved below the gas bladder. After flexion, the gut extends to approximately midbody (see Figure 3.1 D) and is never fully coiled and unfolded. Gobiids have prominent gas bladder which is located midway along the gut. Their head is small to moderate in size before flexion, and moderate thereafter. Head spination is absent in gobiids. The snout is small and pointed. The rounded eye is large. The oblique mouth reaches to beyond the anterior edge of the eye. The soft rays of the anal, dorsal, and pectoral fins begin to form near the start of flexion, but are not fully developed until postflexion stage (Figure 3.2 F). There are two separate dorsal fins; second dorsal fin usually overlaps or is in alignment with the anal fin. The pelvic fins are large. It is usually joined and forms a sucking disc at settlement. There is no gap between anus and origin of anal fin.

Pigmentation: Pigmentation usually forms on the dorsal surface of the gas bladder. Melanophores also appear over the hindgut, just anterior to the anus. Pigment is often found on the ventrum of the gut and at the isthmus and pelvic-fin base. There is one to many melanophores along the ventral midline of tail. Evenly-spaced melanophores are also found on the ventral midline of the tail. Continuous external melanophores are also found on the ventral midline of the tail (Figure 3.1 A-B). For some species, large stellate

melanophore appears on the ventral surface of tail (Figure 3.1 A). Pigment is usually found ventrally along the isthmus and cleithral symphysis (Figure 3.1 B - C).

Meristic Characters: Dorsal: VII +I, 7; Anal: 0, 10; Caudal: 16-17

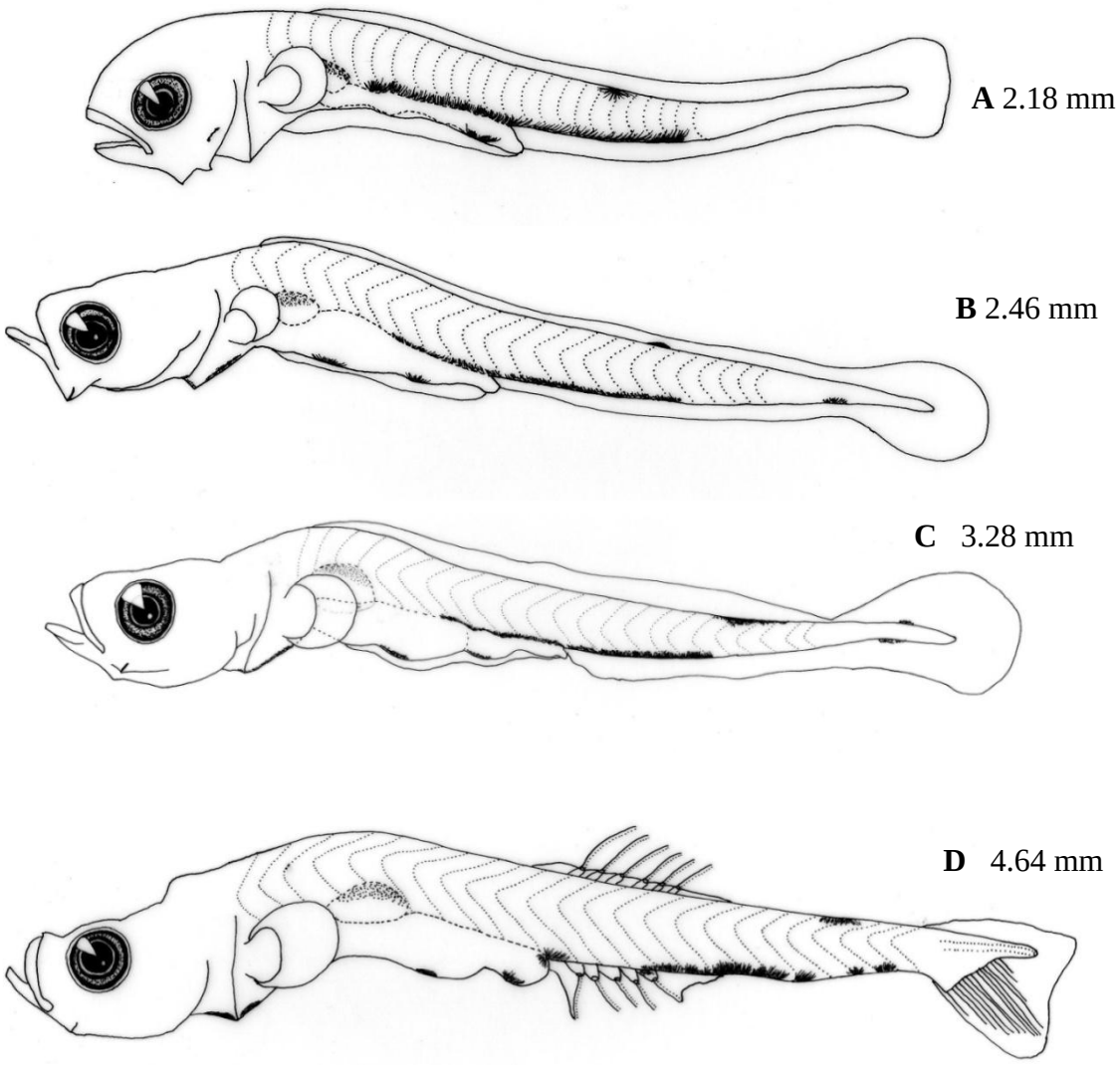

Figure 3.1. Gobiidae. Larvae series of morphospecies GOB1 (*Periophthalmus* sp.?) from Matang mangrove estuary and adjacent coastal waters. **A** - **C** Preflexion, **D** - Flexion.

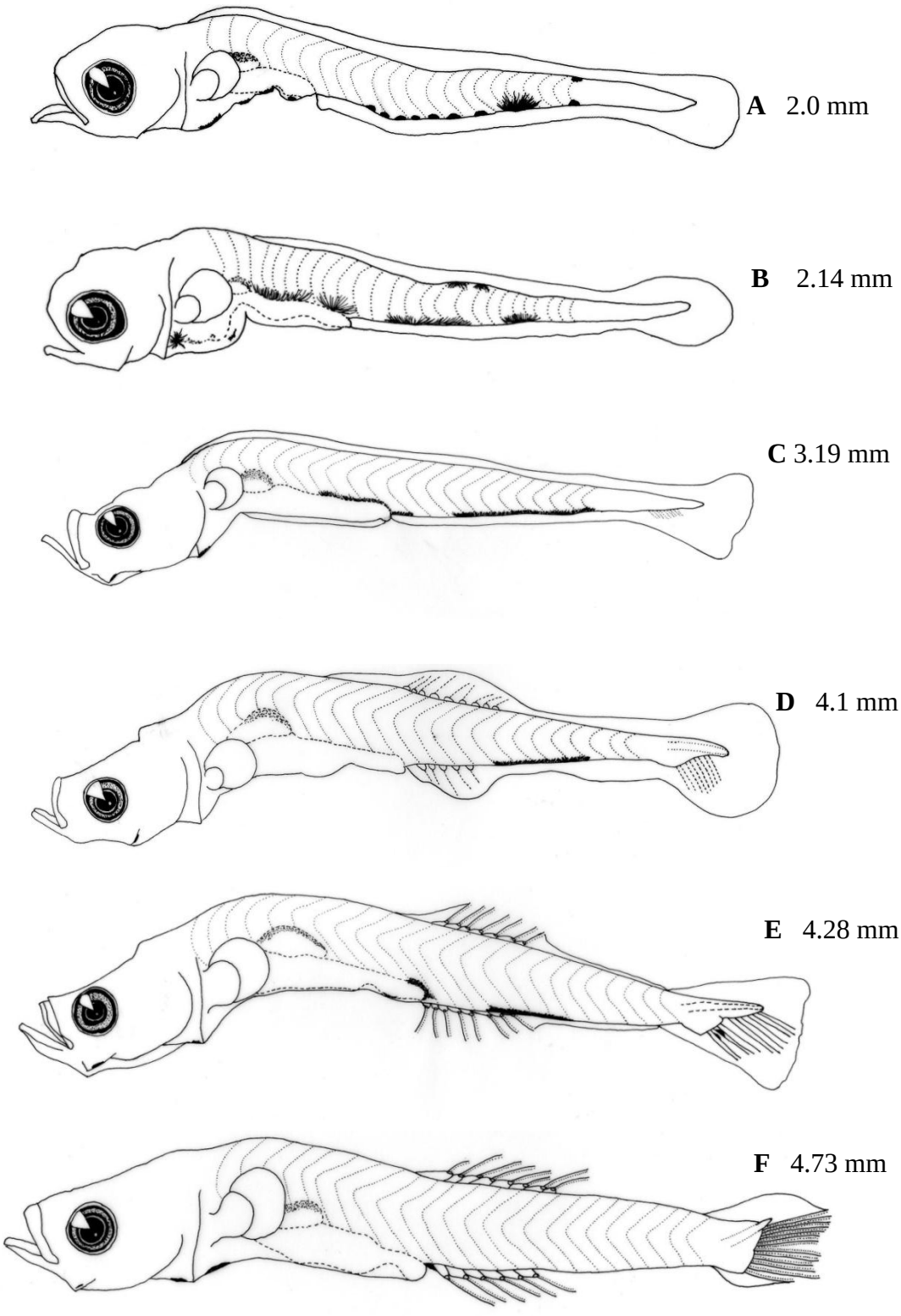

Figure 3.2. Gobiidae. Larvae of morphospecies GOB2 (A), morphospecies GOB3 (B), morphospecies GOB4 (C), morphospecies GOB5 (D), morphospecies GOB6 (E), morphospecies GOB7 (F) from Matang mangrove estuary and adjacent coastal waters. **A – C** Preflexion.**D – E** Flexion. **F -** Early postflexion.

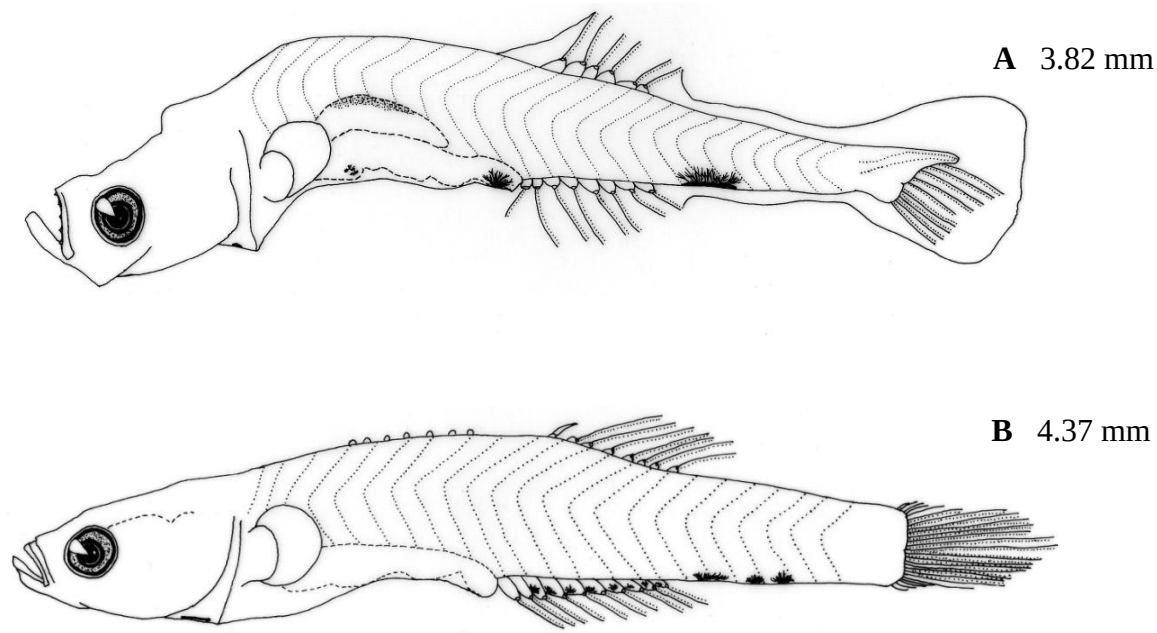

Figure 3.3. Gobiidae. Larvae of morphospecies GOB8 (A) and morphospecies GOB9 (B) from Matang mangrove estuary and adjacent coastal waters. **A -** Flexion. **B -** Early postflexion.

3.2.2 Family Engraulidae

The following descriptions are based on specimens ranging from 4.5 mm – 11.6 mm SL.

Morphology: Engraulid larvae are very elongate. At preflexion stage, they usually have a cylindrical body which becomes moderately compressed by the end of the flexion stage. The body deepens and becomes more compressed as transition approached. Muscle fibres in a cross-hatched pattern at the surface of the myomeres are apparent especially in preflexion and postflexion larvae. The anus migrates anteriorly thus, the ratio of preanal to postanal myomeres changes. This makes the tail particularly the caudal peduncle become relatively longer and the trunk shorter. The long, straight gut reaches to myomere 26-31 (Figure 3.4). The hindgut becomes strongly striated in early preflexion larvae by about 3.0 mm. The gas bladder is located near midbody with its origin at myomeres11-17, and does not move when the anus does. The anus could migrate anteriorly by up to 7 myomeres (Neira et al., 1998). The head is initially slightly depressed and, by the end of the preflexion stage, it is moderately to strongly depressed.

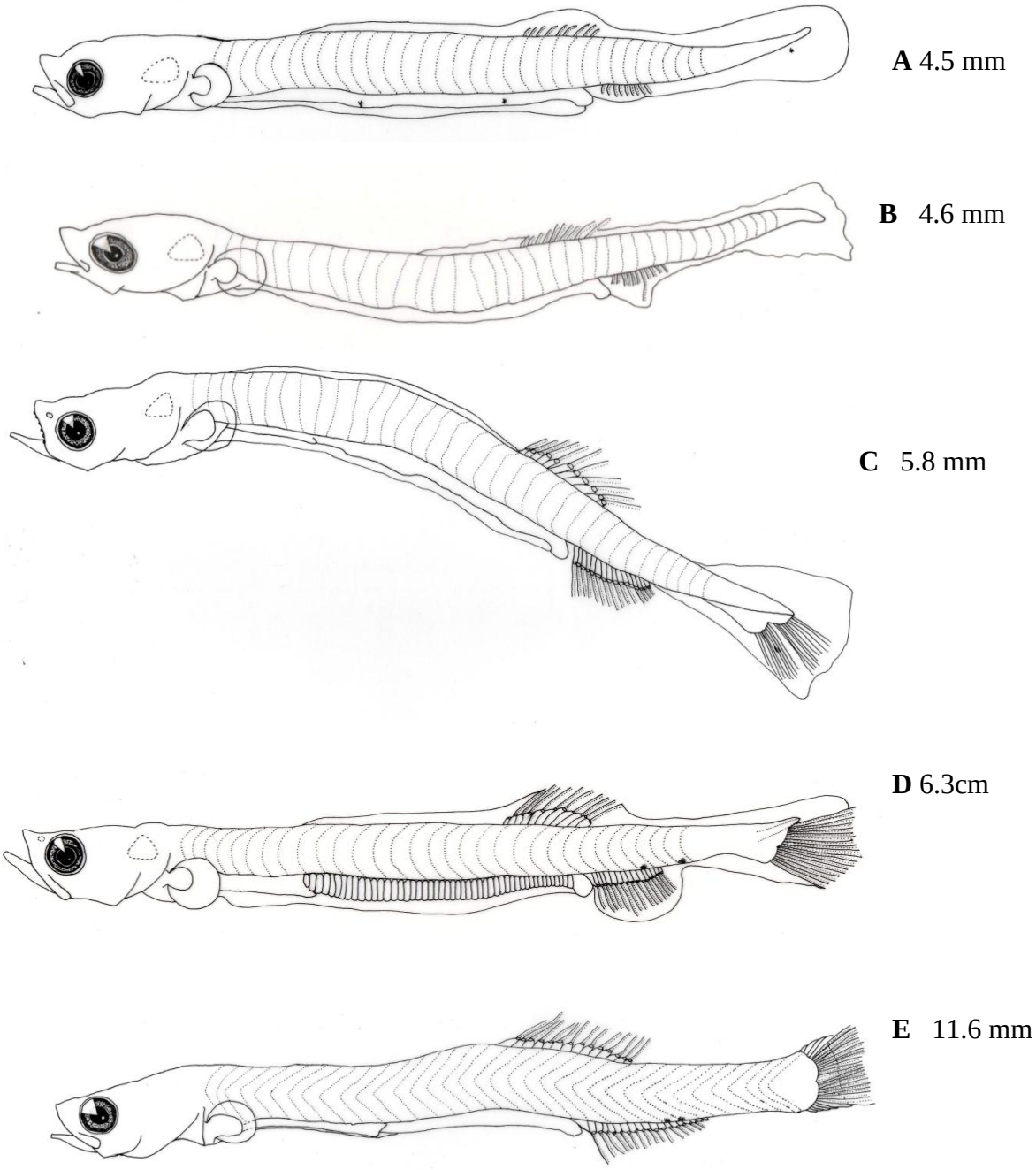

Figure 3.4. Engraulidae. Larvae series ENG1 (*Stolephorus baganensis*) from Matang mangrove estuary.**A** – **B**. Flexion. **C – D**. Postflexion. **E** – Juvenile.

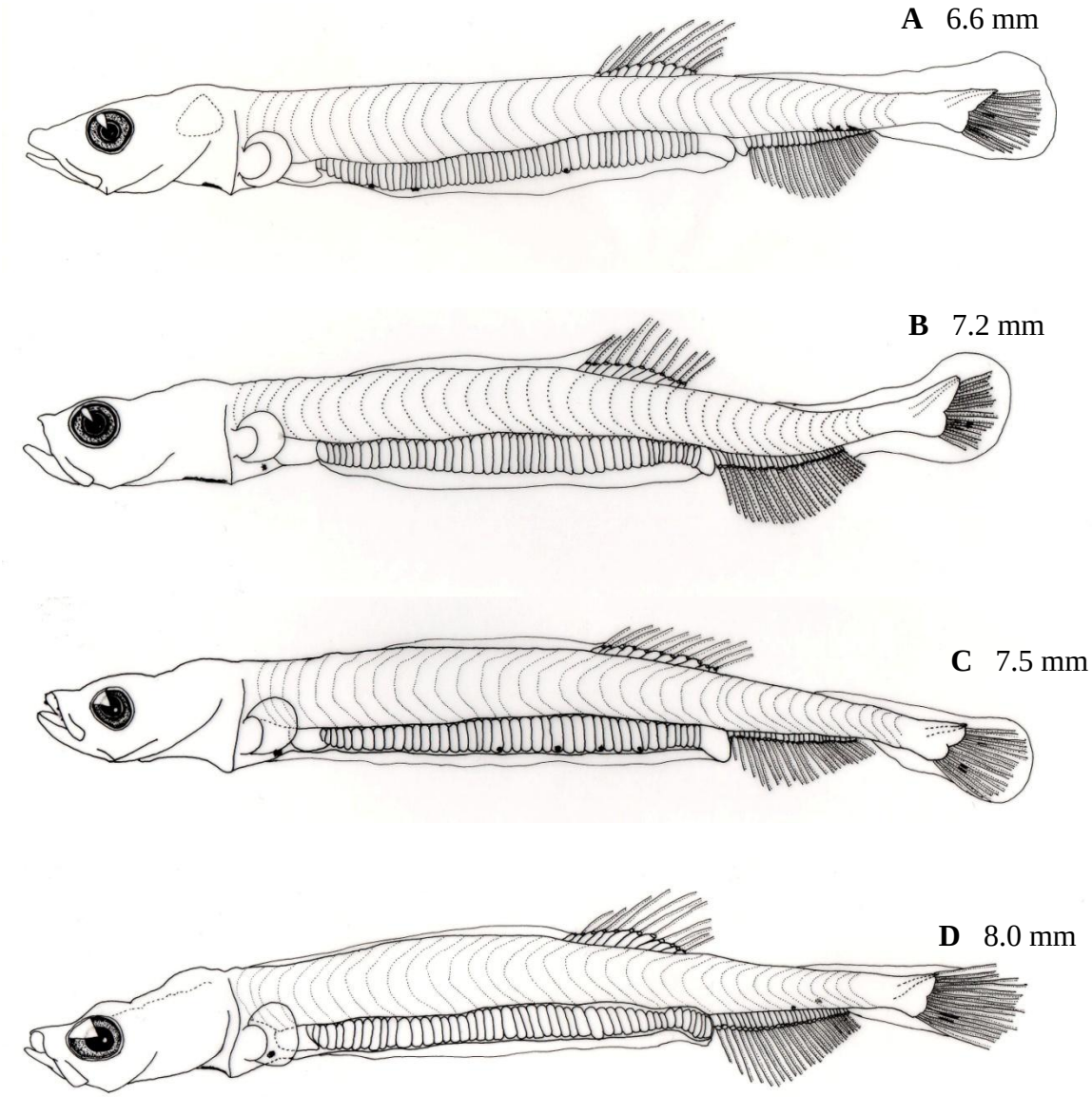

Figure 3.5. Engraulidae. Larvae series ENG2 (*Thryssa kammalensis*) from Matang mangrove estuary. **A- D**. Postflexion.

There is no head spination in engraulids. In preflexion larvae, the snout is short and slightly concave but becomes convex and more pointed from about 8-10mm. The mouth is initially small, and the maxilla reaches to the anterior half of the eye. Minute teeth are present in both jaws by the end of the preflexion stage. The eyes may be large in very small (< 3 mm) larvae. Otherwise, the eyes are small to moderate in larger larvae. The dorsal and anal fin anlagen located posteriorly appear in preflexion larvae between 3.9 and about 6.0 mm. The dorsal fin differentiates slightly earlier than the anal fin. The dorsal fin never has more fin rays than the anal fin. The posterior 2-7 bases of

dorsal fin lie posterior to the anus of *Stolephorus*. In *Thryssa*, the dorsal fin is entirely anterior to the anus (Figure 3.5). Pelvic-fin buds appear just anterior to the gas bladder (at myomere 12- 15) between 10 -12 mm.

Pigmentation: Engraulid larvae are lightly pigmented with apattern along surface of gut is species-specific. Two melanophores are dorsalaterally on the foregut. One melanophore is at the notochord tip (Figure 3.4 A). There are also a 2 stellate melanophores on the ventral midline of the tail at postflexion and juvenile stage (Figure 3.4 D - E).

3.2.3 Family Clupeidae

Morphology: Clupeid larvae initially have a very elongate, cylindrical body. The body starts to compress during flexion. There are 40 – 47 myomeres (29 - 40 + 6 - 13). The ratio of pre- to post-anal myomeres changes because the anus migrates anteriorly. The myomeres have a cross-hatched pattern of muscle fibres which are evident in preflexion and flexion larvae. The gut is straight and long to very long which initially reaches to myomere 33 - 40. At 12-18 mm, the anus begins to migrate anteriorly, by 3 – 6 myomeres. Moderately strong striations first appear on the hindgut in flexion larvae from about 6.9 mm (Figure 3.6 E). The small, elongate head is initially slightly depressed to cylindrical. It becomes relatively larger, deeper and more compressed by about 17 – 20 mm (Leis & Trnksi, 1989). There is no head spination in clupeids. The snout is initially short and concave, but it becomes increasingly elongate and pointed. Clupeid has small mouth which reaches to the anterior edge of the pupil. The dorsal fin develops prior to the anal fin. The base of the dorsal fin is always entirely anterior to the anal fin. Posterior end of dorsal fin and origin of anal fin is usually separated by 4 myomeres (Figure 3.6 F - G).

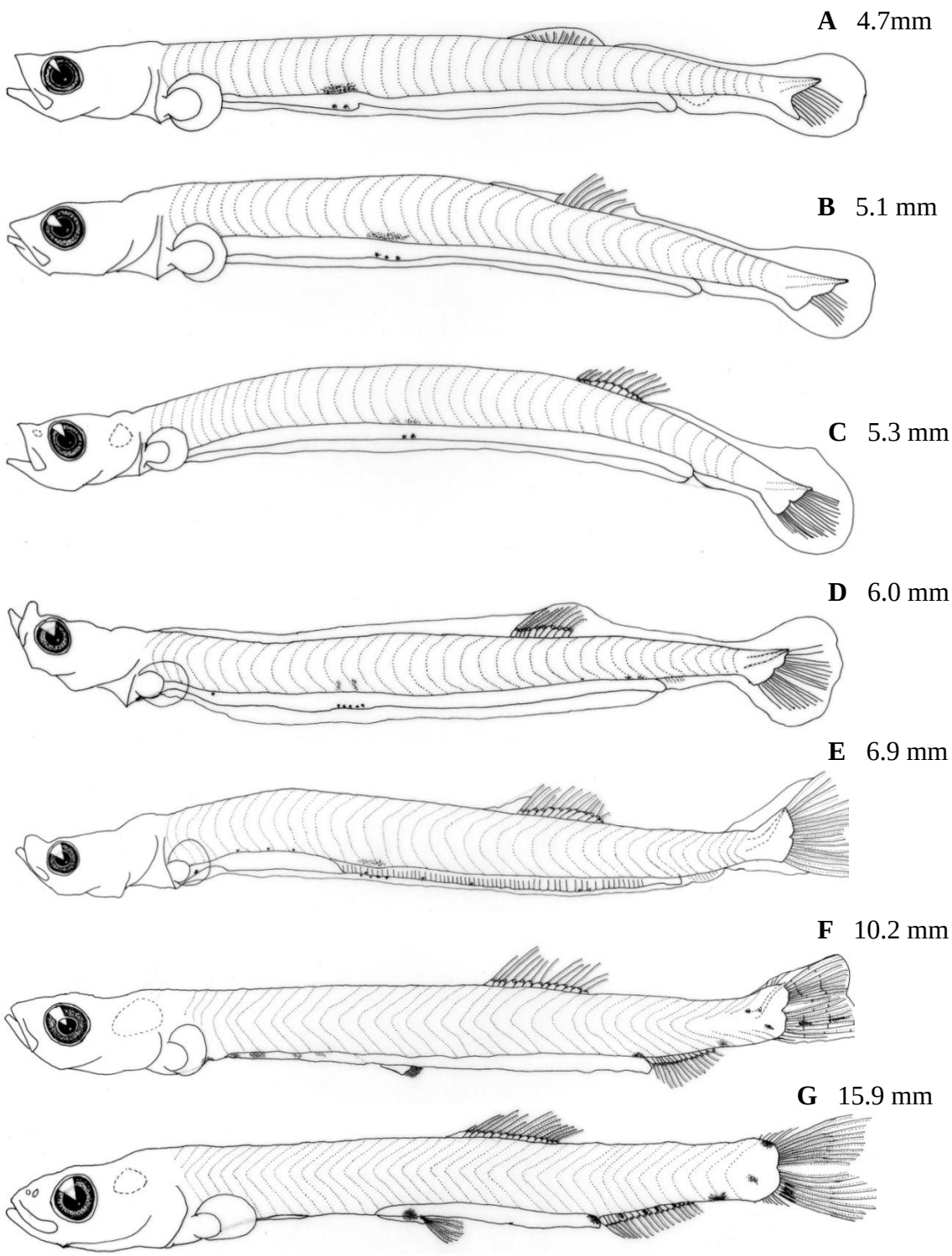

Figure 3.6. Clupeidae. Larvae series of morphospecies CLU1 (*Anodontostoma chacunda*?) from Matang mangrove estuary: **A – D**. Preflexion. **E – F**. Flexion. **G**. Postflexion.

Pigmentation: The body of the clupeid larva is lightly pigmented. They are characterized by melanophore(s) on or at the: foregut dorsolaterally and notochord tip,

caudal-fin base and caudal-fin rays (Figure 3.6 E - F). The larger larvae develop pigment midventrally along the base of the anal fin, hindgut near the anus, onto the peduncle ventrally, and on the pelvic-fin base (Figure 3.6 G)

3.2.4 Family Sciaenidae

Morphology: Sciaenid larvae are of moderate to deep and compressed. Their tail is slightly narrow. They have 25 myomeres. The gut is triangular, moderate to long, coiled and compact. It has a conspicuous gas bladder which is dorsal to the apex of the gut. The large gap between anus and origin of anal fin will reduce by late postflexion stage. Sciaenids have large round head. The short snout is initially concave to uneven shape and becomes rounded in postflexion larvae. The large, oblique mouth rarely reaches to the pupil in preflexion larvae. In postflexion larvae, the mouth becomes increasingly horizontal and may reach to the posterior margin of the eye. The moderate round eye initially becomes relatively small in postflexion larvae. Sciaenid larvae have short to moderate preopercular spines. Dorsal and anal-fin anlagen form in late preflexion larvae. In some taxa, moderate preopercular spines, supraocular, subopercular, interopercular and supracleithral spines, serrate infraorbital, pterotic, low supraoccipital and postemporal ridges are formed (Steffe & Neira, in Neira et al., 1998).

Pigmentation: Pigmentation is highly variable in sciaenids. Melanophores are usually present on the gas bladder dorsally and the ventral midline over the anal-fin base. Pigments also occur at the ventral midline of the gut. One melanophore is at the angle of lower.

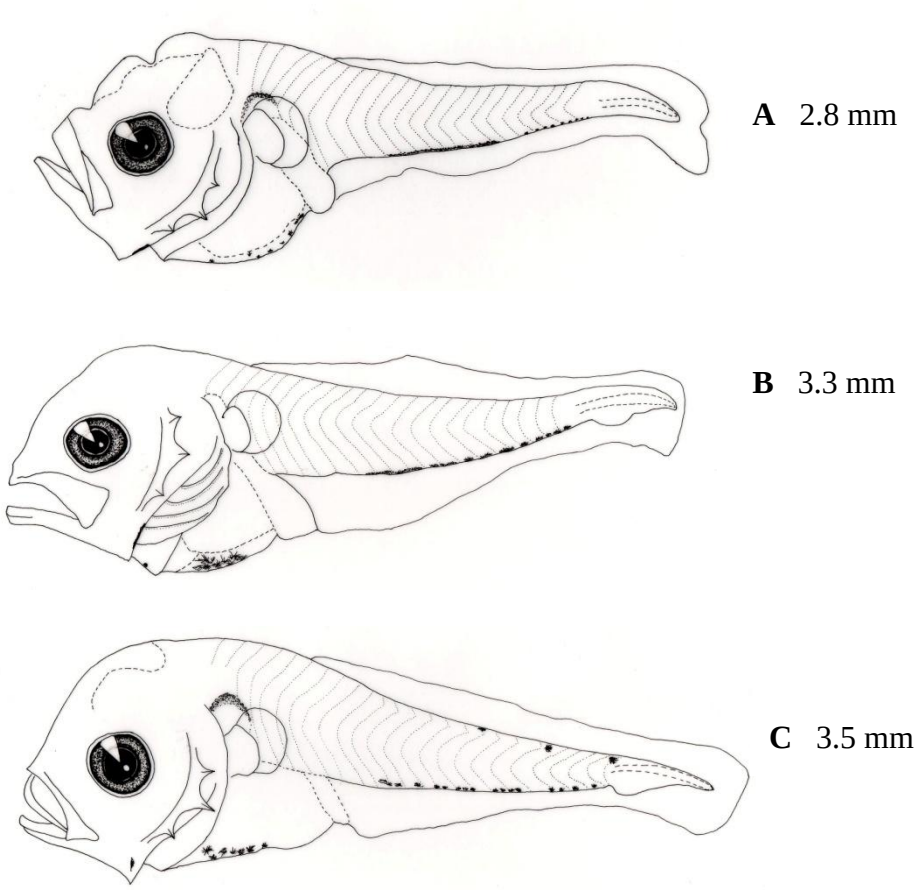

Figure 3.7. Sciaenidae. Larvae series of morphospecies SCI1 (*Johnius* spp.) from plankton tows in Matang mangrove estuary and adjacent coastal waters. **A**. Preflexion. **B - C**. Flexion.

3.2.5 Family Ambassidae

Morphology: Ambassid larvae have moderate depth and compressed. They have 24 myomeres. The small, triangular gut is coiled and very compact. The gas bladder increased in size with larval growth. The compressed head is initially round but becomes slightly elongate in postflexion larvae. The short, steep snout is slightly concave to irregularly rounded shape and later becomes less steep in conjunction with lengthening of the head. The small mouth is oblique, and does not reach the eye. Minute teeth are present in 4.1 mm SL specimen. The moderate to large eye is round. Very small preopercular spines are present by the flexion stage. From about 4.5 mm, the lower margin of the interopercle thickens and develops a sharp angle, and at 7.5 mm, a small spine is present. All anal-fin elements are present by 4.8 mm. The first ray

transforms into a spine by 7.5 mm. The dorsal fin is fully ossified by 6.5 mm. The pectoral-fin rays begin to ossify at 4.8 mm, and all are present by 7.5 mm.

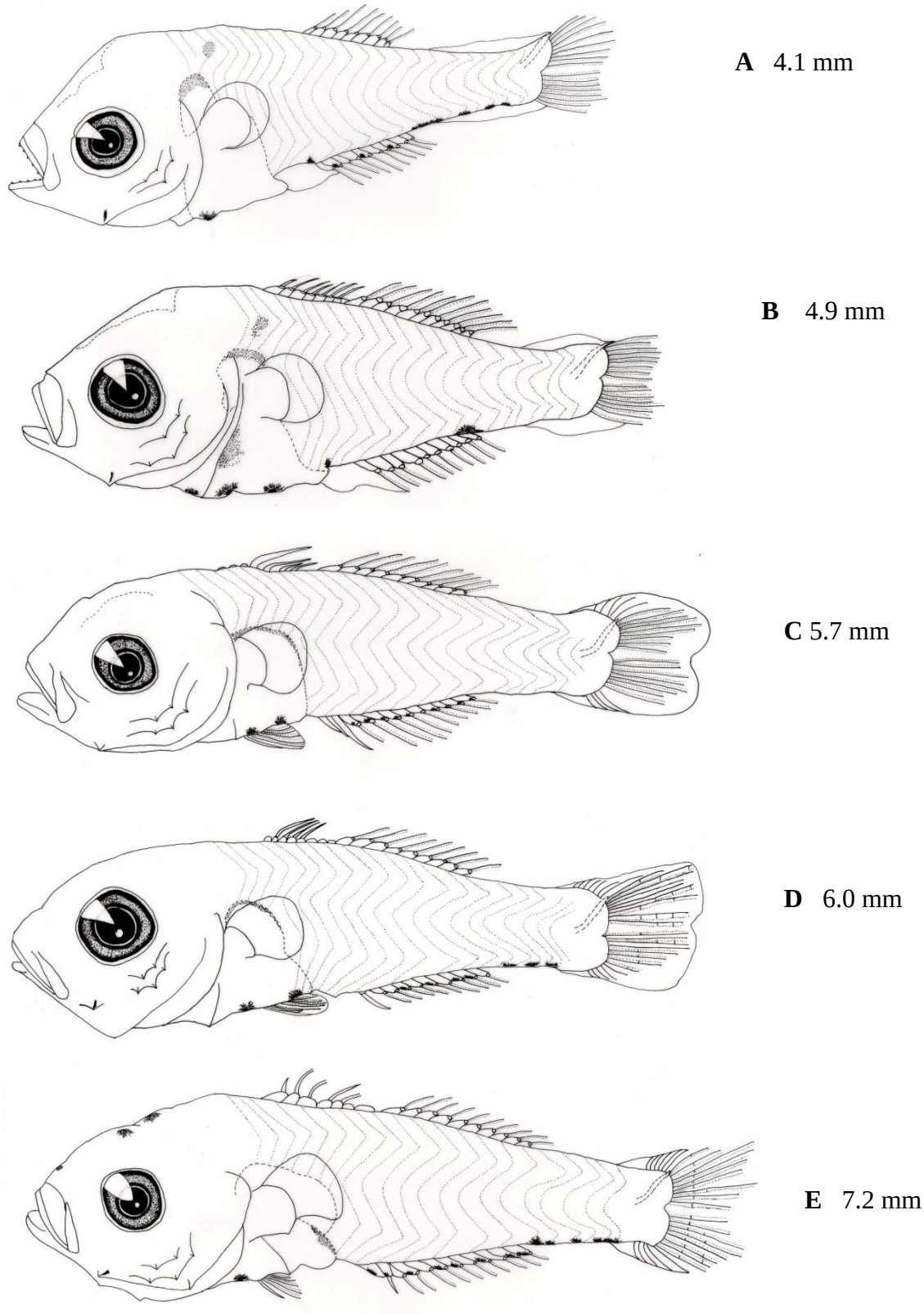

Figure 3.8. Ambassidae. Larvae of morphospecies AMB1 (*Ambassis gymnocephalus*) from Matang mangrove estuary: **A - E**. Postflexion.

Pigmentation: Ambassids are lightly pigmented. They have one prominent melanophores ventrally on the gut; one melanophore on the angle of the lower jaw and pigment dorsally on the gut and gas bladder. At specimen 7.2 mm SL, pigment develops dorsally on the brain.

3.2.6 Family Blenniidae

Morphology: Blenniid larvae identified in this study are probably from the Omobranchini tribe, *Omobranchus* sp. They are of moderate depth with a compressed trunk and tail. There have 35-40 myomeres. The short, wide coiled gut rarely reaches to midbody. The gas bladder is only visible in preflexion larvae. The rounded, broad head is of moderate size and has a short, rounded snout which elongates only slightly with larval growth. The mouth reaches just past the anterior border of the eye. Following flexion, the mouth becomes inferior. The eye is large and round. Larva of Omobranchini probably hatch without head spines (Leis & Carson-Ewart, 2000), but preopercular spines soon develop (1.6 – 2.5 mm). The spine at the angle of the outer border of the preopercle quickly becomes long and broad, and is ornamented with small spinules. Spinules also occur dorsally on the head and on the lower jaw. The preopercular spines attain maximum development in the late flexion or early postflexion stage when the spine at the angle may extend nearly to the level of the anus; they decline in length and in number thereafter. The upper pectoral-fin rays are first to form. The full complement of rays is present by the end of the flexion stage. Pectoral fin rays may become moderately long. The caudal anlagen develops next, later in the preflexion stage (3 – 4 mm). The dorsal and anal anlagen and pelvic buds appear early in flexion stage (4.2-4.5 mm). Principal caudal-fin rays begin to develop late in the preflexion stage or during notochord flexion, followed by dorsal and anal soft rays in the late flexion or early postflexion stage. Bases of the dorsal and anal fins have large blade-like extensions.

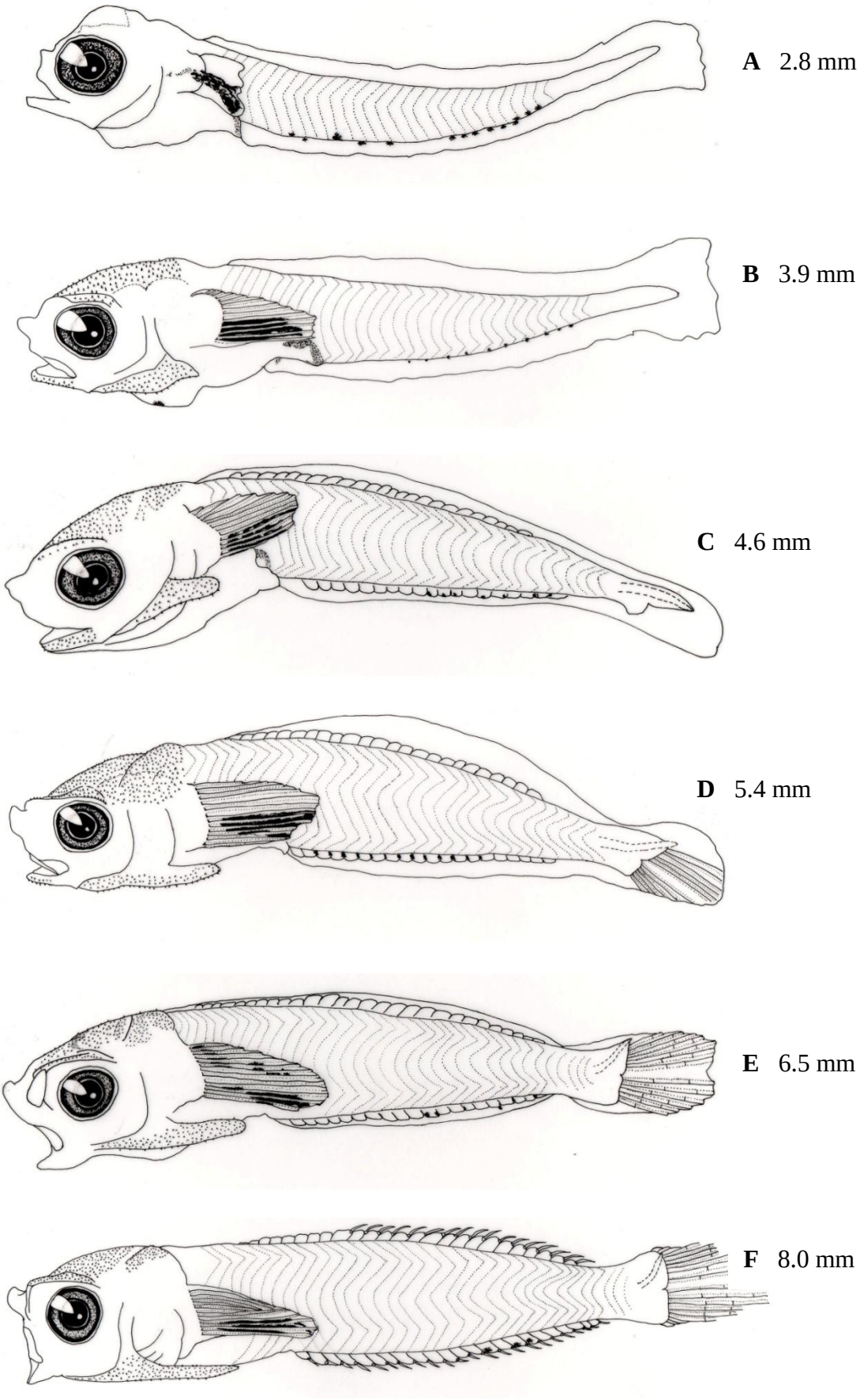

Figure 3.9. Blenniidae. Larvae series of BLE1 (*Omobranchus* sp.?) from Matang mangrove estuary: **A - B**. Preflexion. **C - D**. Flexion. **E - F**. Postflexion.

Pigmentation: Lateral melanophores may develop on the trunk, sometimes extending onto the anterior part of the tail. Heavy pigment develops on inner surface of pectoral-fin base which is commonly confined lower part of the fin. Series of melanophores also appear along ventral midline of tail (14) in preflexion which decreases as the larvae grow (Figure 3.9A).

3.2.7 Family Cynoglossidae

Morphology: Cynoglossid larvae are normally elongate to moderate in depth, compressed and bilaterally symmetrical. They develop to become very compressed and deeper after notochord flexion is complete. The head and trunk are initially much deeper than the tapering tail. As the larvae grow, the tail will gradually become deeper. Nevertheless, it remains less deep than the rest of the body. There are 43-59 myomeres. The gut is thick and coiled into a single, large loop. It protrudes markedly from the ventral body margin. The anus is usually trailing and in flexion and postflexion larvae, it projects to the right of and posterior to the origin of the anal fin. Gas bladder is located over the posterior portion of the gut and apparently disappears during transformation. The small to moderate head is initially deep and round. It has a short, rounded snout. The round eye is initially moderate to large, but is small to moderate in postflexion larvae. Head spines are absent. The caudal fin is the last medial fin to form. Two elongate rays are the first to form and become relatively smaller as transformation approaches, then degenerate and disappear during transformation. The non-elongate dorsal-fin rays and anal-fin rays develop concurrently. The dorsal and anal fins are confluent with the caudal fin once it forms and together form a continuous fin from snout to anus.

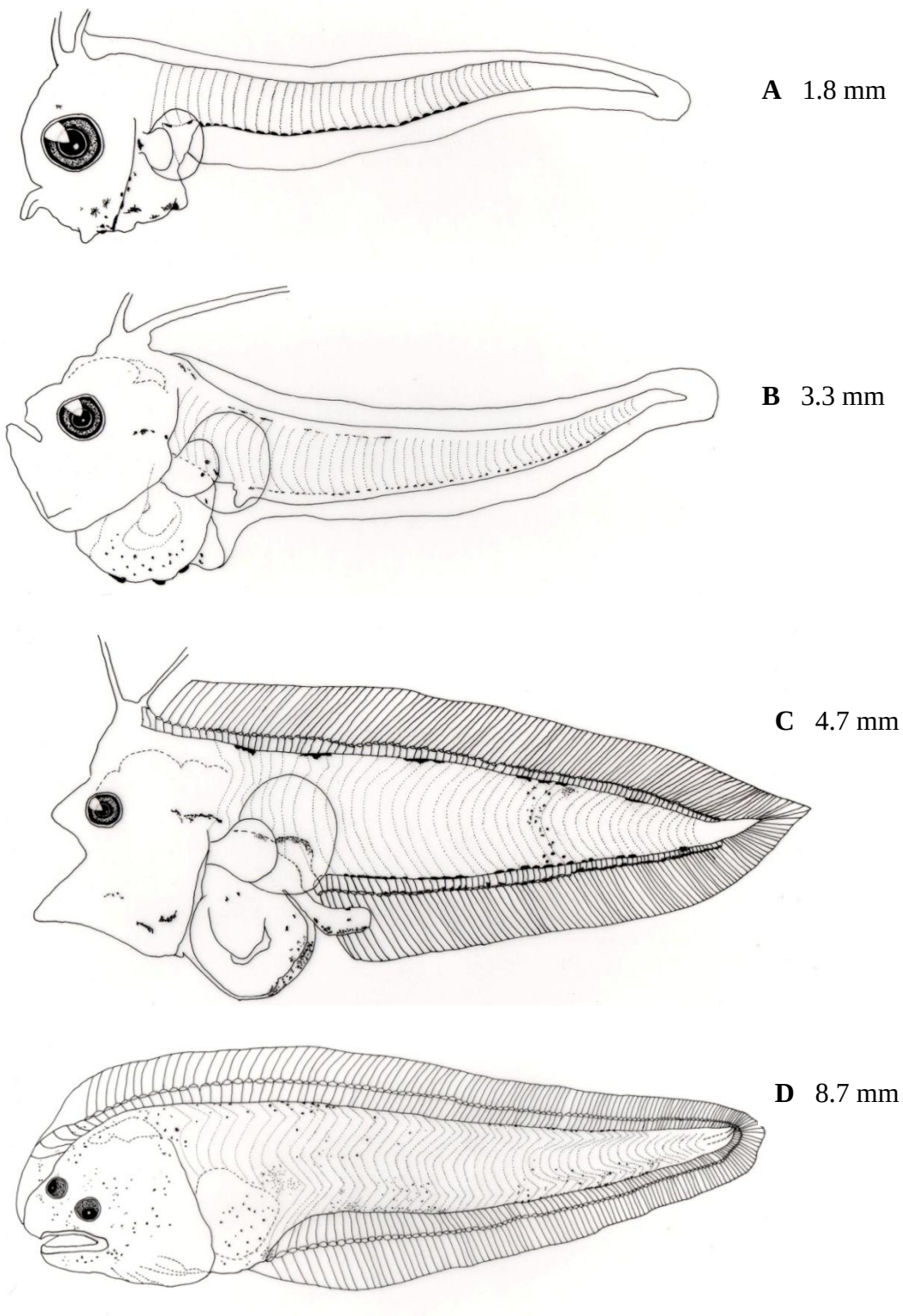

Figure 3.10. Larvae of *Cynoglossus* spp. from Matang mangrove estuary and adjacent coastal waters: **A - B**. Preflexion. **C**. Flexion. **D**. Transformation almost complete (Note: Both elongate dorsal rays broken)

Pigmentation: In cynoglossids, clusters and longitudinal of melanophores are initially found along the dorsal and ventral body margins, and later along the bases of dorsal and

anal fins and sometimes on the rays. More scattered pigment occurs at the base of the elongate dorsal rays and ventrally on the head and trunk, snout, jaws, branchiostegal membrane, cleithral symphysis, pelvic-fin base, anus and gut. Pigment also appears on the dorsal surface of gas bladder. Larvae become heavily pigmented during metarmorphosis.

3.2.8 Family Scatophagidae

The following description is based on a 5.9 mm specimen.

Morphology: Postflexion scatophagid has a moderate depth, quadriangular and compressed body. There are 23 myomeres. The large head is very deep and round. The snout is blunt and often uneven in profile. The mouth is small to moderate and reaches the anterior margin of the pupil. The large eye is round. Head spination is remarkably developed and unique with bony plates. It has an elaborate series of blunt, broad spines and elevated ridges from the supraocular region, pterotic, posttemporal and preopercle. There is also a heavy, medial, bony process from the supraoccipital that merges with an inflated frontal shell. The preopercle and opercle are with triangular and trapezoidal areas or plates. Many of the ridges are ornamented marginally with very fine serrations. Small spinules appear on the trunk and tail.

In late preflexion larvae, a small complex of spines and ridges develop in the infraorbital region, and a ridge extends dorsally from the posttemporal spine (Trnski & Leis, in Leis & Carson-Ewart, 2000). By the time flexion is complete, the posttemporal ridge also has a granulate pad dorsally. A serrate supracleithral ridge and weak opercular spine develop at 5-8 mm. At this stage, the head is essentially a shell of joined, broad plates and ridges.

Pigmentation: Pigment gradually spreads to cover most of the body. The pelvic fin is heavily pigmented. It has pigment on the forehead.

Meristic Characters: Dorsal: X, 16; Anal: IV, 15; Pectoral: 17; Pelvic: I, 5 Caudal: 16

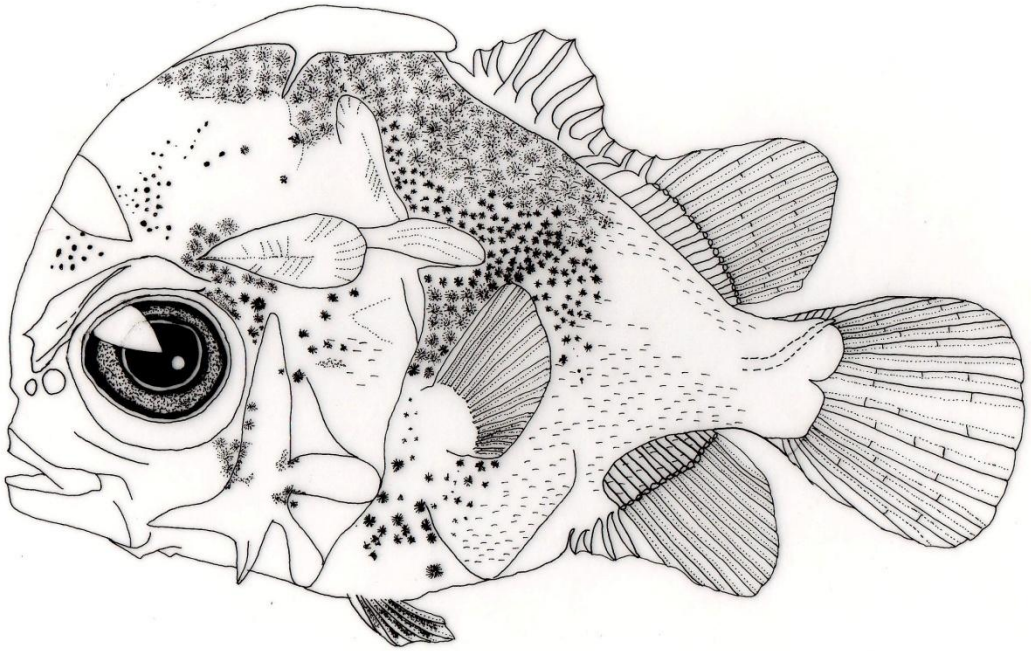

Figure 3.11. *Scatophagus argus* at 5.9 mm SL. (Note: myomere omitted)

3.2.9 Family Mugilidae

Morphology: Mugilid larvae are elongate to moderate in depth and compressed. There are 24 – 25 myomeres (12-15 + 9-13). The head is broad and moderate. They lack head spination. The short snout initially concave but become convex when larvae reach postflexion stage. The oblique mouth becomes relatively smaller when it grows. They have separate dorsal fins with only four spines in the anterior fin. The dorsal and anal-fin anlagen develop during flexion and by the time flexion is complete, incipient rays are present (Leis & Carson-Ewart, 2000). The four spines in the separate and posteriorly-placed first dorsal fin start to form in early postflexion. All dorsal and anal

fins are fully ossified by 6.2 mm. The gap between the vent and anal fin is very small to absent.

Pigmentation: Mugilids are moderate to heavily pigmented. Melanophores are usually present along the dorsal and lateral midlines of the trunk and tail, along the ventral midline of the tail, on the dorsal surface of the gut and brain and on the snout tip. Pigment generally spreads as the larvae grow. Larger larvae are often heavily pigmented over the entire head and body.

Figure 3.12. Mugilidae. Larva of morphospecies MUG1. Larvae either of *Liza melinoptera* or *L. subviridis* from Matang mangrove estuary: **A - B**. Postflexion.

3.2.10 Family Belonidae

Morphology: Belonids are characterized by their advanced development at hatching as there are no preflexion larvae (Leis & Carson-Ewart, 2000). Belonidae larvae are elongate, have slender body and cylindrical in cross section. The small head is elongate with a pointed snout. The jaws are short but lower jaw grows faster and is longer than

the upper jaw. Small canine teeth are present on both jaws of the specimen. The mouth reaches the anterior edge of the pupil. This specimen has serrate ridges on the head. It has additional serrations on the lower limb of anterior preopercle and posterior preopercle. Serration is also observed in supraocular ridge. Dorsal and anal fins are set far back on the body. Pelvic-fin buds are located posterior to midbody. A long preanal finfold is present and runs anteriorly from anus along the ventral midline. Melanophores are present along the pectoral-fin rays and were scattered over the connecting membranes.

Pigmentation: They are heavily pigmented over the entire body. Heavy more or less uniform melanophores are arranged at the dorsal part of the body. No pigment is present on the head part.

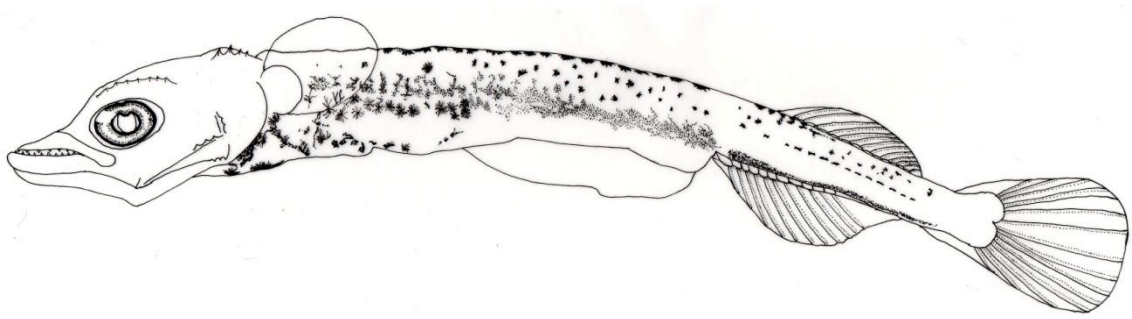

Figure 3.13. *Strongylura strongylura* from Matang mangrove estuary. 7.1 mm SL.

3.2.11 Other families

3.2.11.1 Family Scorpaenidae

Morphology: Description of scorpaenid is based on postflexion larvae. The larvae have moderate to deep body with a compressed tail and trunk. The head initially is small but becomes moderate to large with development. The trunk is wide. The gut is round and may reach one-third of the body. The gas bladder is small and is at the anterior portion

of the gut. The eyes are small and round. The well-developed and complex head spination, and the large fan-shaped pectoral fins which could reach to the anus are specialization of this larvae. Scorpaenid larvae have large preopercular and parietal spines which may be serrate. Other than that, supraocular, infraorbital, opercular, pterotic, posttemporal and cleithral spines are also present. Larvae are generally lightly pigmented. Pectoral fin-rays are scattered with melanophores.

3.2.11.2 Family Syngnathidae

Morphology: Syngnathidae have direct development into juveniles where the larvae resemble the adults and change proportions as they grow. Syngnathid larvae have full complement of rays and caudal fins but pelvic fins are absent.

3.2.11.3 Family Carangidae

Morphology: Carangid larvae have moderate to strongly compressed body with typically 24-25 myomeres. The head is moderate to large. The larvae have moderate to large round eyes. Gas bladder is prominent and pigmented. Preopercular and supraoccipital spination are distinctive, which is one of the specialization of carangid larvae. The larvae are lightly pigmented. Melanophores series are usually present along dorsal and ventral surfaces of trunk and tail.

3.2.11.4 Family Platycephalidae

Morphology: Platycephalid larvae are small to medium size, elongate fishes with a strongly depressed head. The body is round to ovoid in cross-section. The gut is fully coiled in preflexion stage and the head is round and moderate. Small eyes are round and laterally positioned. As the snout flattens, the head become large and wedge-shaped. Small villiform teeth are visible. Small preopercular spines are present and become

prominent with growth. Preopercular, suparocular, parietal, supracleithral and posttemporal spines are present. The fan-shaped pectoral rays are large. Platycephalid larvae have small melanophores at the dorsal lateral surface of the trunk and tail. Moderate melanophores are also scattered on the pectoral fin rays.

3.2.11.5 Family Leiognathidae

Morphology: Leiognathid larvae have moderate to deep body and are strongly compressed laterally. The moderate to large head is deeply ovate with a steep, blunt, concave snout. The mouth is small and protrusible. Small teeth are present in both jaws. The eyes are large and round. The small gas bladder is dorsal to the apex of the gut. The preopercular spines and serrate supraoccipital crest are present. Leiognathid larvae are lightly pigmented.

3.2.11.6 Family Bregmacerotidae

Morphology: Bregmacerotid larvae are compressed with moderate depth. They have high myomere (50-60). The head is moderate and has a very prominent lower jaw angle. The mouth is oblique and reaches to the anterior edge of the eye. There is no head spination. The larvae have paddle-like pectoral fin and early-forming pelvic fins and first dorsal fins. Some pigments are present on the gas bladder.

3.2.11.7 Family Terapontidae

Morphology: Body has a moderate depth and is laterally compressed, with 25 myomeres. The moderate head is compressed and slightly elongate. Gut is coiled and compact. The gas bladder is small and pigmented. Preopercular spines are present. The eyes are large and round. There is a moderate gap between anus and anal fin. Pigmentations are moderate.

3.2.11.8 Family Trichonotidae

Morphology: Trichonotid larvae are very elongate and ovoid in cross-section. The gut is long and straight. The head is moderate and elongate and dorsoventrally flattened. The mouth is large with tiny villiform teeth in both jaws. There is no head spination. The larva is sparsely pigmented.

3.2.11.9 Family Triacanthidae

Morphology: The head and trunk of triacanthid larvae are initially deep. It is almost round in cross-section. The tail is slender and compressed. The larvae lack head spination. The head and trunk are moderately pigmented.

3.2.11.10 Family Mullidae

Morphology: Mullid larvae are elongate to moderate in depth and laterally compressed, with myomere 23-25. The head is moderate in size and rounded dorsally. The snout is short and steeply sloped. The mouth is small to moderate in size. Pigment appeared in the dorsal surface of the gut for preflexion larvae. Small melanophores along the ventral midline of the tail are also present.

3.2.11.11 Family Tetraodontidae

Morphology: The head is moderate to large and ovoid to rotund. Snout is short and round and slightly elongate. The mouth is small and does not reach to the anterior edge of the eye. Teeth are formed in both upper and lower jaws. The eye is very large and there are no pelvic fins. Scales are formed in the form of small spinules on the belly. Pigment develops on the dorsal portion of the trunk.

3.2.11.12 Family Hemiramphidae

Morphology: Hemiramphidae larvae are elongate and moderately compressed. The gut is relatively thick, straight and long. The ovate head becomes elongate at a later stage. There is no head spination. Hemiramphid larvae are moderately to heavily pigmented.

3.2.12 Identification Key to the Main Fish Families of Fish Larvae

A brief identification key of the larval fish families described in this study is presented in Figure 3.14. Only Syngnathidae larvae have dermal plates and body rings. Larval fish without dermal plates and body rings are further divided into three categories; high, moderate and 20 myomere count. Larval groups in high myomere count (30-50) are grouped into gut with and without striations. *Stolephorus baganensis* is placed under gut with striations with dorsal fins overlapping the anal fins. *Thryssa kammalensis* has long anal fins whereas Clupeidae has shorter anal fins. Blenniidae and Trichonotidae have gut without striations with light to moderate pigmentations. Cynoglossidae, Belonidae and Hemiramphidae has moderate to heavy pigmentations.

Larvae of myomere ranging from 22-40 are further divided into large and small pectoral fins. Scatophagidae has early forming pelvic fins. The group where pelvic fins which are not formed early in larvae are subdivided into the presence of gap width between anus and origin anal fin. Sciaenidae, Terapontidae, Ambassidae and Leiognathidae has small to large gap between anus and origin of anal fin. No gaps appear in Gobiidae, Carangidae, Mugilidae, Mullidae and Triacanthidae. Tetraodontidae has 20 myomere with no pelvic fins.

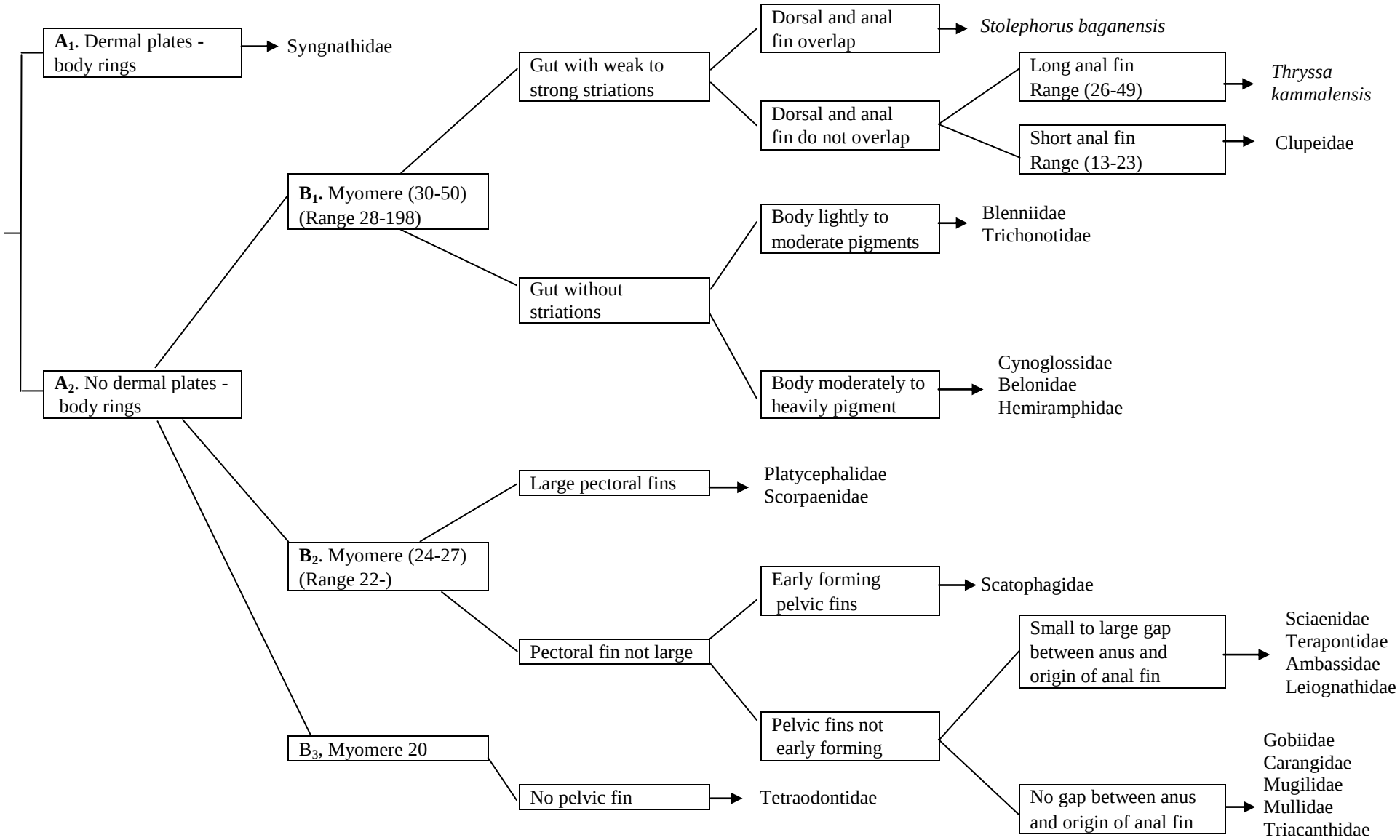

Figure 3.14. Main categories (A_1, A_2) and subcategories (B_1, B_2, B_3) which families in this study were allocated to help in the identification of their larvae.

3.3 DISCUSSION

Not all larval identification could be made to the species or generic level in the present study. This is due to the serious lack of larval identification keys for the region and very few larval fish studies in the country and region. The very high biodiversity of fish species (138 species in the present study) has put in additional taxonomic problem for this region. Reliable identification keys of tropical mangrove larval fish are very limited. Among them is Jeyaseelan (1998) which described 77 species occurring frequently in mangrove waters from southern India, Thailand and the Philippines. Nevertheless, this manual book only serves as a basic document for the identification of early developmental stages of mangrove fish with brief description of fish larva. Jeyaseelan (1998) excluded the Gobiidae due to their high diversity, complexity and uncertainty taxonomic characteristics. He only described commercially important fish species. Another identification reference of fish larvae in the Straits of Malacca is Kawaguchi (2003) which only serves as a guide for beginners to familiarize with larval fish study. Kawaguchi (2003) also stressed that the scarcity of larval fish taxonomy study is mainly due to the limited number of scientists engaging in this field and poor establishment of adult taxonomy of Indo-Pacific coastal fishes.

Another taxonomic problem is due to the co-presence of several species and genera (same family) in the same sampling site. Not all larval fish for each taxon were caught at each developmental stage. Some larval fish were represented by a single specimen e.g. Trichonotidae, Triacanthidae, Belonidae, Tetraodontidae and Hemiramphidae. This scarcity of larval fish for each developmental stage or incomplete series makes it very difficult to trace the larval series of similar morphotype to its identifiable juvenile. Besides that, difficulties encountered during identification of some larval fish families are likely to be confused with closely related families. For example,

engraulid larvae shared many of the morphological characteristics with clupeid larvae. Other elongate larvae are also often confused with engraulid larvae, for example trichinotids and synodontids. Nevertheless, engraulid larva is identifiable as it has distinct cross-hatched muscle fibres and anterior migration of the dorsal fin. Another example is the Ambassidae. It has 24 myomeres, limited head spination and tightly coiled guts and are likely to be confused with apogonids, gerrids, sparids, terapontids and nemipterids. Ambassid larva is distinguished by deeply-notched continuous dorsal fins, conspicuous gas bladder and fin ray counts.

The environmental factors may modify the appearance of pigment in larval fish (Young et al., 1995). Some studies show that there is possibility of differences in melanophore distribution patterns among the same species. This was shown between reared and wild-caught specimens of *Acentrogobius pflaumii* (Mori, 1988). Fukuhara (1983) and Powles and Markle (1984) also noticed heavier pigment in laboratory reared *Engraulis japonica* than the wild-caught specimens. Pigmentation pattern that were found in preflexion larvae may disappear or replaced by other patterns in postflexion (Moser, 1981).

In the present study, the larval fish most likely to be present were traced from juveniles and the presence of adults from the same area. Gobiidae larvae were mostly small and very difficult to identify due to the co-presence of at least 17 species from 14 genera (Then, 2008). For oxudercine gobies, morphological characteristics are similar to those of other gobiid fishes where their melanophores appear over the gas bladder, on the intestine and along the ventral midline of the tail (Shiogaki & Dotsu, 1988). Due to these similarities, it is quite difficult to identify the larvae. Based on the presence of young juveniles, the most common species were *Glossogobius giuris*, and the less

common species such as *Oxyurichthys microlepis*, *Parapocryptes seperaster*, *Pseudapocryptes elongates*, *Trypauchen vagina*, *Ctenotrypauchen microcephalus* and *Oxuderces dentatus*.

Species likely for Engraulidae in MMFR are *Stolephorus* (*S. baganensis* and *S. indicus*) and *Thryssa* (*T. kammalensis*, *T. hamiltonii* and *T. mystax*). Most of the engraulid larvae consist of *Stolephorus baganensis* and *Thryssa kammalensis* based on descriptions by Sarpedonti et al. (2000). Based on the presence of their youngest juveniles in the area, clupeid comprised of the following species, ranked by abundance: *Anodontostoma chacunda*, *Escualosa thoracata*, *Nematolosa nasus* and *Sardinella gibbosa*. The Sciaenidae is one of the most diverse family in the study site, comprising 14 species and 8 genera, with *Johnius* (7 species) being the most speciose (Then, 2008). The collected larvae of different ontogenetic stages were very difficult to distinguish even to the generic level; the recorded genera were *Johnius, Dendrophyssa, Nibea, Otolithes, Otolithoides, Aspericorvina, Panna and Pennahia*. Furthermore, sciaenid larvae are relatively nondescribed, particularly the preflexion stages.

Ambassidae larvae comprised of *Ambassis gymnocephalus* where most juveniles and adults are positively identified. Cynoglossidae comprised of four *Cynoglossus* spp. (*C. bilineatus, C. lingua, C. puncticeps* and *C. cynoglossus*), whose larval stages have yet to be positively identified. No adult blenniids have been captured in the present study area. Blenniid larvae consisted of *Omobranchus sp*. Mugilidae is likely identified as *Liza melinoptera* or *L. subviridis*. Most of the Scorpaenidae are mainly *Vespicula trachinoides*. Around 85% of Syngnathidae caught were pipefish (*Ichthyocampus carce*) while the remaining were seahorse (*Hippocampus trimaculatus*). Carangidae larvae

arelikely identified as *Scomberoides* and *Caranx* spp. Platycephalidae larvae are likely those of *Platycephalus indicus*.

Leiognathidae larvae are represented by *Leiognathus brevirostris, L. equulus* and two species of *Secutor*. Larvae of the reportedly deep-water spotted codlet, *Bregmaceros mcclellandi* were caught in the offshore waters. Terapontidae larvae are identified as *Terapon theraps*. Trichonotidae larvae are likely *Trichonotus* sp. Triacanthidae larvae are likely represented by *Tripodichythes blochii* or *Triacanthus biaculeatus*. Mullidae larvae are identified as *Upeneus sulphureus.* Tetraodontidae could be those of *Tetraodon fluviatilis* or *Chelonodon patoca*. Belonidae larva is represented by *Strongylura strongylura* while Hemiramphidae larvae are likely *Zenarchopterus dispar*.

In the present study, the family is used as the 'ecological unit' due to the taxonomic problem. There are however other reasons to use the family. The dominant species of the same family often appear together spatially, e.g. *Thryssa kammalensis* and *Stolephorus baganensis* (e.g. Sarpedonti & Chong, 2008; Then, 2008), and several common species of Sciaenidae such as *Johnius belangerii*, *Johnius carouna*, *Johnius volgeri* and *Pennahia anea*, are found in the same site (Then, 2008) although occupying different feeding niches (Yap et al., 1996). Because of this, the taxonomical difficulty and the need to maintain some consistency in the description and display of the fish taxa, the larval assemblage was compared at the family level in subsequent chapters of thesis where the main focus was on larval ecology.

Larval identity, without the culture of identified adults, often cannot be confirmed. Hence, positive identification should be carried out using techniques in

molecular biology based on DNA analysis such as COI, d-loop and DNA barcoding. This will provide a very powerful approach in solving existing taxonomic dilemmas. In the Great Barrier Reef, Australia, a study was carried out involving larvae identification to the genus or species level by comparison with phylogenetic tree of tropical marine fish species using mtDNA *HVR1* sequence data (Pegg et al., 2006). Other studies on identification of larvae and juveniles based on molecular markers include Aoyama et al. (1999), Garcia-Vazquez et al. (2006), Li et al. (2006), Pegg et al. (2006), Robertson et al. (2007) and Chen et al. (2010). Yokoo et al. (2009) used a combination of morphological and molecular methods to identify *Acentrogobius* species in a mangrove estuary in Sikao Creek, Thailand.

3.4 CONCLUSIONS

Identification of larval fish to the family level is based on the key characters as follows: e.g. body shape, myomere counts, shape of the gut, gas bladder, head spination, eyes, fin formation and pigmentation patterns. The present study has failed to gather meaningful constructs of larval series that could be confidently traced to the specific or generic level, except for a few species. This is due to the serious lack of taxonomic keys, large number of species within genus for some families, incomplete larval series, and uncertainty in assignment to morphospecies (e.g. due to variability in pigmentation). Larval cultures or/and molecular markers are necessary to help unravel the taxonomic problem.

CHAPTER 4

SPATIO-TEMPORAL CHANGES IN ABUNDANCE OF FISH LARVAE

Summary of Important Findings

A total of 92,934 fish larvae, representing 19 families, were collected in monthly samples from the Sangga Kecil estuary (Matang Mangrove Forest Reserve) and adjacent coastal waters from May 2002 to October 2003. Larval fish community using mangrove estuaries and nearshore waters mainly consists of a few key families of residents (e.g. Gobiidae) and euryhaline fishes (e.g. Engraulidae), whereas the wider diversity of other fish families in the estuary that were not collected as larvae suggest that they must have entered the estuary as juveniles. Larval fish assemblages were numerically dominated by Gobiidae (50.1%) and Engraulidae (38.4%). Larval fish abundance including their ontogenetic stages differed spatially and temporally. Three peaks of total larval fish were observed; March 2003 (992 ± 986 N.100m^{-3}), October 2003 (980 ± 1,440 N.100m^{-3}) and August 2002 (656 ± 457 N.100m^{-3}). These peaks coincided with the intermonsoon periods of variable winds and high rainfall, except the August peak when wind forcing was high. Two peaks of recruitment time were identified for Gobiidae in March and October. Spawning and resulting preflexion larvae of Engraulidae occurred between June to December in offshore waters, followed by the higher abundance of postflexion larvae between October-January in mangrove estuaries. Estuarine preflexion gobiid larvae were ubiquitous in the coastal and estuarine waters. Larval stages of euryhaline species that were spawned in offshore waters such as Engraulidae and Clupeidae were largely advected into mangrove areas at the postflexion stages. Larvae of other euryhaline fishes (Sciaenidae, Blenniidae and Cynoglossidae) that may have spawned inside the estuary were, however, exported to offshore waters. Other families were scarce and represent only < 1% of the total fish larvae. Their

presence might as a result of tidal transport of coastal water from the adjacent coastal areas. The adult fish families and the existing larval fish population in the Matang estuary is quite disconnected given that the collective number of juvenile and adult fish families was 53 while the number of larval families was only 17.

4.1 INTRODUCTION

Fisheries are one of the important sectors in Malaysia economy which produced 1,870,000.81 tonnes of fish resources with a value of RM 8,683.81 million year^{-1} (Annual Fisheries Statistics, 2009). Relatively little attention is given to mangrove fish larval ecology in Malaysia. The spatio-temporal variations of larval fish communities among mangrove estuaries in Malaysia are not well understood. Therefore, study of fish larvae and their ecology in Malaysia is crucial in defining spawning grounds as well as nursery grounds within the estuary which will aid in management and conservation efforts to protect both fishes and their habitats from drastic changes.

The variations in species composition and seasonal abundance of fish larvae were monitored over 18 months. Analysis of variance was used to assess temporal and spatial fluctuations of the larval fish abundance. Developmental stages of dominant species were determined in an effort to find out whether fishes migrate into the mangroves from adjacent coastal waters, or whether they are spawned within the mangroves and remain there. With this information, their recruitment and strategy adopted to enter or disperse to nearshore waters could be elucidated.

The specific objectives of this study were (1) to identify and compare the ichthyo-assemblages in estuary and offshore waters, (2) to elucidate the spatio-temporal distribution and abundance of fish larvae in the mangrove and offshore watersand (3) to

determine the type and extent of estuarine use by fish species (for the purpose of spawning, feeding, or/and nursing).

4.2 RESULTS

4.2.1 Larval Fish Assemblages

A total of 92,934 fish larvae, representing 19 families were collected between May 2002 and October 2003 throughout all the stations inside the mangrove estuary and offshore waters (see Appendix 4.1). The larval fish assemblages were not so diverse and were numerically dominated by larvae of just 4 families (> 97.5%). Gobiidae was the most abundant family comprising 50.1% (mean 158.1 ± 433.8 N.100m^{-3}) of the catch in the whole estuary, followed by Engraulidae (38.4%) (122.6 ± 263.1 N.100m^{-3}), Clupeidae (5.8%) (17.9 ± 123.4 N.100m^{-3}) and Sciaenidae (3.2%) (11.6 ± 64.4 N.100m^{-3}). Other families that were not well represented and contributing less than 1% were Ambassidae (0.7%), Blenniidae (0.6%), Cynoglossidae (0.6%), Scorpaenidae (0.07%), Carangidae (0.05%), Syngnathidae (0.05%), Platycephalidae (0.03%), Scatophagidae (0.01%), Bregmacerotidae (<0.01%), Leiognathidae (<0.01%), Terapontidae (<0.01%), Triacanthidae (<0.01%), Trichonotidae (<0.01%), Mullidae (<0.01%) and Mugilidae (<0.01%). Some unidentified fish larvae made up 0.37% of the total larvae. No fresh water fish species were collected in this study.

4.2.2 Spatio-temporal Changing Patterns of the Abundance of Total Larval Fishes

Mean total abundance of fish larvae differed but not significantly ($P > 0.05$) between the seven stations, viz. Station 1 (472 ± 874N.100m^{-3}), Station 2 (213 ± 265 N.100m^{-3}), Station 3 (311 ± 460N.100m^{-3}), Station 4 (426 ± 863N.100m^{-3}), Station 5 (303 ± 515N.100m^{-3}), Station 6 (259 ± 318N.100m^{-3}) and Station 7 (302 ± 555N.100m^{-3}) (Table 4.1). This indicated that the larvae were homogenous distributed among the

studied stations in the mangrove estuary. The mangrove estuary stations generally showed higher total abundance as compared to the offshore stations. A familial analysis of abundance showed significant difference between the stations for some families (e.g. Gobiidae, Engraulidae, Clupeidae, Sciaenidae, Cynoglossidae, Ambassidae, Blenniidae, Scorpaenidae and Syngnathidae.)

Table 4.2 shows the mean density of fish larvae families and total density at different months from May 2002 to October 2003. The mean total density was significantly different between months ($P < 0.001$). Three peaks were observed with the highest mean in March 2003 (992 ± 986 N.100 m^{-3}) followed by October 2003 (980 ± 1,440 N.100 m^{-3}) and August 2002 (656 ± 457 N.100 m^{-3}) (Figure 4.1). The lowest mean density was in May 2003 with only 22 ± 28N 100 m^{-3}.

Mean density of fish larvae at different months and stations are shown in Figure 4.2. At Station 1, sampling only started in November 2002. The fish larvae were abundant from December 2002 to March 2003 with highest in March 2003 (2844.3 ± 1,449.2N.100 m^{-3}). At Station 2, fish larvae ranged from 5.3 ± 1.5 N.100m^{-3} to 623.1 ± 422.4 N.100 m^{-3}. Total fish larvae appeared to be higher from June 2002 to September 2002. In Station 3, mean density of fish larvae were abundant from July to September, December 2002, March and October 2003. From July to September 2002, mean density ranged from 470.6 ± 509.5N.100 m^{-3} to 930.2 ± 49.7 N.100m^{-3}. Highest density of total fish larvae were recorded in March 2003 (1228.7 ± 72.1 N.100m^{-3}). In Station 4, total mean fish larvae were highest in October 2003 (2,498.8 ± 3190.4 N.100 m^{-3}). Other peaks were in August 2002, January and March 2003, ranging from 916.4 ± 865.3 to 1098.3 ± 121.1 N.100m^{-3}. At the river mouth in Station 5, total fish larvae were highest in October (1600.4 ± 1,522.7 N.100 m^{-3}). Total mean density of fish larvae was

abundant in 5 months (e.g. August, September, December 2002, March and August 2003), ranging from 455.6 ± 432.1 N.100 $m^{-3}$to 807.1 ± 458.1 N.100 m^{-3}. In Station 7, two peaks appeared in June and October 2003 with mean density of 1206.5 ± 730.9 N.100m^{-3} and 1452.9 ± 1919.1 N.100 m^{-3}, respectively. Total mean fish larvae density was below 400 N.100m^{-3} in other months.

Table 4.1. Numbers of sampled fish larvae and their mean density (N.100m^{-3}) by family and station. Matang mangrove estuary (stations 1-5) and adjacent coastal waters (stations 6-7).

Family	Total Larva		Station							Average Mean
			1	2	3	4	5	6	7	
Gobiidae	46562	Mean	464.98	138.90	203.28	215.38	127.82	32.98	28.00	158.06
		±SD	871.25	212.05	390.31	563.34	408.47	82.10	112.64	433.76
Engraulidae	35671	Mean	3.91	68.82	99.64	201.48	164.00	149.99	124.22	122.58
		±SD	4.39	122.42	232.48	441.68	244.80	240.20	255.41	263.10
Clupeidae	5401	Mean	0.63	2.33	1.38	2.92	1.86	20.00	98.47	17.91
		±SD	1.73	11.88	3.59	10.37	3.62	59.54	319.34	123.35
Sciaenidae	2958	Mean	1.26	0.43	2.26	2.96	3.96	35.73	32.89	11.59
		±SD	3.38	1.58	7.55	14.00	8.11	129.42	101.21	64.37
Cynoglossidae	554	Mean	0.00	0.02	0.02	0.15	0.38	4.74	10.27	2.22
		±SD	0.00	0.14	0.12	0.46	1.42	20.38	29.28	13.78
Ambassidae	674	Mean	0.65	0.21	1.80	0.37	1.12	7.79	2.43	2.13
		±SD	2.13	1.02	9.50	1.72	2.46	15.33	3.43	7.66
Blenniidae	558	Mean	0.04	0.83	2.26	2.99	3.22	3.98	0.17	2.07
		±SD	0.20	1.43	5.02	7.28	8.50	11.48	0.48	6.69
Scorpaenidae	67	Mean	0.00	0.02	0.00	0.00	0.00	0.51	1.50	0.29
		±SD	0.00	0.10	0.00	0.00	0.00	1.93	5.78	2.30
Syngnathidae	44	Mean	0.04	0.17	0.33	0.36	0.16	0.05	0.00	0.17
		±SD	0.18	0.45	0.70	0.90	0.45	0.20	0.00	0.53
Carangidae	46	Mean	0.00	0.02	0.07	0.02	0.02	0.03	0.91	0.15
		±SD	0.00	0.15	0.43	0.13	0.10	0.17	4.00	1.50
Platycephalidae	26	Mean	0.00	0.00	0.00	0.00	0.00	0.69	0.03	0.11
		±SD	0.00	0.00	0.00	0.00	0.00	3.45	0.14	1.36
Scatophagidae	11	Mean	0.00	0.02	0.00	0.16	0.02	0.03	0.03	0.04
		±SD	0.00	0.14	0.00	0.72	0.10	0.15	0.14	0.30
Leiognatidae	5	Mean	0.00	0.00	0.09	0.02	0.00	0.00	0.00	0.02
		±SD	0.00	0.00	0.40	0.12	0.00	0.00	0.00	0.16
Bregmacerotidae	5	Mean	0.03	0.00	0.00	0.00	0.00	0.05	0.05	0.02
		±SD	0.13	0.00	0.00	0.00	0.00	0.20	0.18	0.11
Terapontidae	2	Mean	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.01
		±SD	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.10
Trichonotidae	1	Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.003
		±SD	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.05
Triacanthidae	1	Mean	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.004
		±SD	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.06
Mullidae	2	Mean	0.03	0.00	0.00	0.00	0.00	0.03	0.00	0.01
		±SD	0.16	0.00	0.00	0.00	0.00	0.15	0.00	0.08
Mugilidae	1	Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.003
		±SD	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.039
Unidentified	345	Mean	0.54	0.90	0.21	0.11	0.55	2.67	2.94	1.14
		±SD	1.55	4.39	0.71	0.45	1.68	9.12	4.85	4.52
Total	92934	Mean	472.11	212.67	311.34	426.97	303.11	259.30	301.96	318.51
		±SD	873.93	264.86	459.48	862.56	515.28	318.31	554.95	570.38

Table 4.2. Mean density of fish larvae families by month in Matang mangrove estuary and adjacent coastal waters.

Month		May 2002	June	July	August	September	October	November	December	January 2003	February	March	April	May	June	July	August	September	October
Gobiidae	Mean	47.87	60.76	232.66	60.04	311.52	19.67	56.48	141.12	85.67	79.57	921.94	26.29	10.50	18.01	29.30	35.54	12.70	625.43
	± SD	58.97	167.66	277.20	50.53	357.56	35.83	100.33	223.52	179.51	281.89	1013.13	40.18	28.37	61.34	42.07	62.91	20.98	944.91
Engraulidae	Mean	79.25	114.53	170.77	563.70	154.13	188.07	28.41	223.89	236.45	12.09	44.60	19.76	3.72	8.79	67.94	128.80	13.79	278.66
	± SD	88.45	91.72	177.27	447.47	155.15	319.43	60.44	328.42	458.80	16.01	78.46	30.71	5.15	20.58	104.29	181.95	24.74	545.23
Clupeidae	Mean	2.12	0.12	0.06	0.00	0.67	8.08	2.90	27.10	0.74	1.99	0.34	53.28	5.85	175.12	0.62	2.71	16.68	4.65
	± SD	3.54	0.30	0.20	0.00	1.40	17.08	8.29	50.06	2.01	5.12	0.92	93.13	12.87	477.37	1.02	10.14	39.91	11.89
Sciaenidae	Mean	0.48	1.88	2.44	26.12	90.36	4.93	0.41	8.88	0.23	0.00	13.72	0.19	0.08	0.42	5.78	13.72	0.42	46.90
	± SD	1.41	2.20	6.38	26.07	221.54	11.80	0.93	9.61	0.62	0.00	22.40	0.72	0.31	0.85	11.28	23.92	0.72	149.27
Cynoglossidae	Mean	0.00	0.56	0.00	0.23	17.41	1.63	0.09	0.92	0.00	0.00	0.73	0.00	0.00	0.05	0.15	5.51	0.39	12.43
	± SD	0.00	1.13	0.00	0.37	34.35	3.18	0.23	2.37	0.00	0.00	1.42	0.00	0.00	0.18	0.35	12.79	1.24	42.73
Ambassidae	Mean	2.10	6.31	0.00	0.06	0.06	3.97	1.72	0.23	1.96	0.00	4.41	2.24	0.92	8.02	0.32	1.00	2.77	1.38
	± SD	3.63	16.22	0.00	0.18	0.22	9.43	4.48	0.55	3.58	0.00	16.12	2.95	1.47	16.04	1.12	2.39	8.28	4.25
Blenniidae	Mean	2.37	5.86	0.06	2.46	0.85	2.53	1.02	0.34	0.00	0.60	0.00	2.70	0.85	1.30	3.54	4.81	2.52	5.72
	± SD	3.76	14.01	0.20	3.20	2.39	4.65	1.66	0.80	0.00	1.17	0.00	3.70	1.84	2.35	7.52	10.66	4.02	18.10
Scorpaenidae	Mean	0.00	0.00	0.00	0.00	1.20	0.35	0.05	0.12	0.00	0.00	0.04	0.00	0.00	0.00	0.00	1.07	0.00	2.17
	± SD	0.00	0.00	0.00	0.00	3.23	0.83	0.19	0.28	0.00	0.00	0.16	0.00	0.00	0.00	0.00	3.56	0.00	8.13
Syngnathidae	Mean	0.49	0.12	0.31	0.31	0.36	0.00	0.00	0.15	0.06	0.05	0.00	0.00	0.00	0.06	0.22	0.30	0.05	0.63
	± SD	0.69	0.28	0.65	0.65	0.86	0.00	0.00	0.55	0.22	0.18	0.00	0.00	0.00	0.22	0.55	0.63	0.20	1.26
Carangidae	Mean	0.00	2.49	0.00	0.10	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00
	± SD	0.00	6.38	0.00	0.32	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.00	0.00	0.00	0.00
Platycephalidae	Mean	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	1.72	0.00	0.00
	± SD	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.00	5.49	0.00	0.00
Scatophagidae	Mean	0.49	0.00	0.00	0.06	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.06	0.00	0.00
	± SD	1.23	0.00	0.00	0.18	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.24	0.00	0.00
Leiognathidae	Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.15
	± SD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.55
Bregmacerotidae	Mean	0.00	0.12	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.07	0.00	0.00
	± SD	0.00	0.28	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.27	0.00	0.00
Mullidae	Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.07	0.00
	± SD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.25	0.00
Terapontidae	Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	± SD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Triachantidae	Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00
	± SD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00

Table 4.2 (continued)

Month		May 2002	June	July	August	September	October	November	December	January 2003	February	March	April	May	June	July	August	September	October
Trichonotidae	Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
	± SD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00
Mugilidae	Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	± SD	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unidentified	Mean	1.45	1.61	1.49	3.18	1.30	0.39	0.19	2.12	0.08	0.00	5.83	0.19	0.00	0.05	1.00	0.51	0.15	1.53
	± SD	3.23	4.93	2.45	8.17	2.72	0.90	0.55	4.54	0.29	0.00	14.17	0.40	0.00	0.19	2.39	1.13	0.39	3.86
Total	Mean	136.62	194.37	407.90	656.24	578.08	229.62	91.36	404.87	325.35	94.30	991.73	104.81	21.93	211.99	108.87	195.89	49.55	979.66
	± SD	109.18	168.12	335.46	457.48	358.36	321.31	117.56	399.44	468.03	278.40	985.78	92.52	27.86	472.03	123.84	208.31	51.86	1440.06

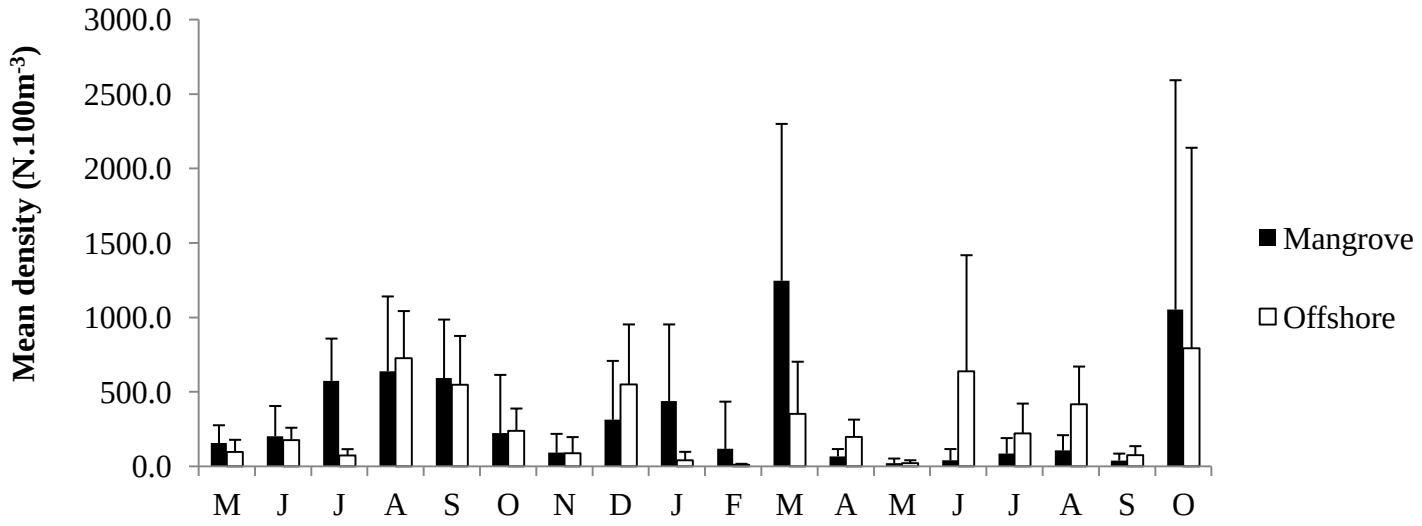

Figure 4.1. Monthly variation of mean density (±SD) of total fish larvae (N.100m^{-3}) in the Matang mangrove estuary and offshore waters from May 2002 to October 2003.

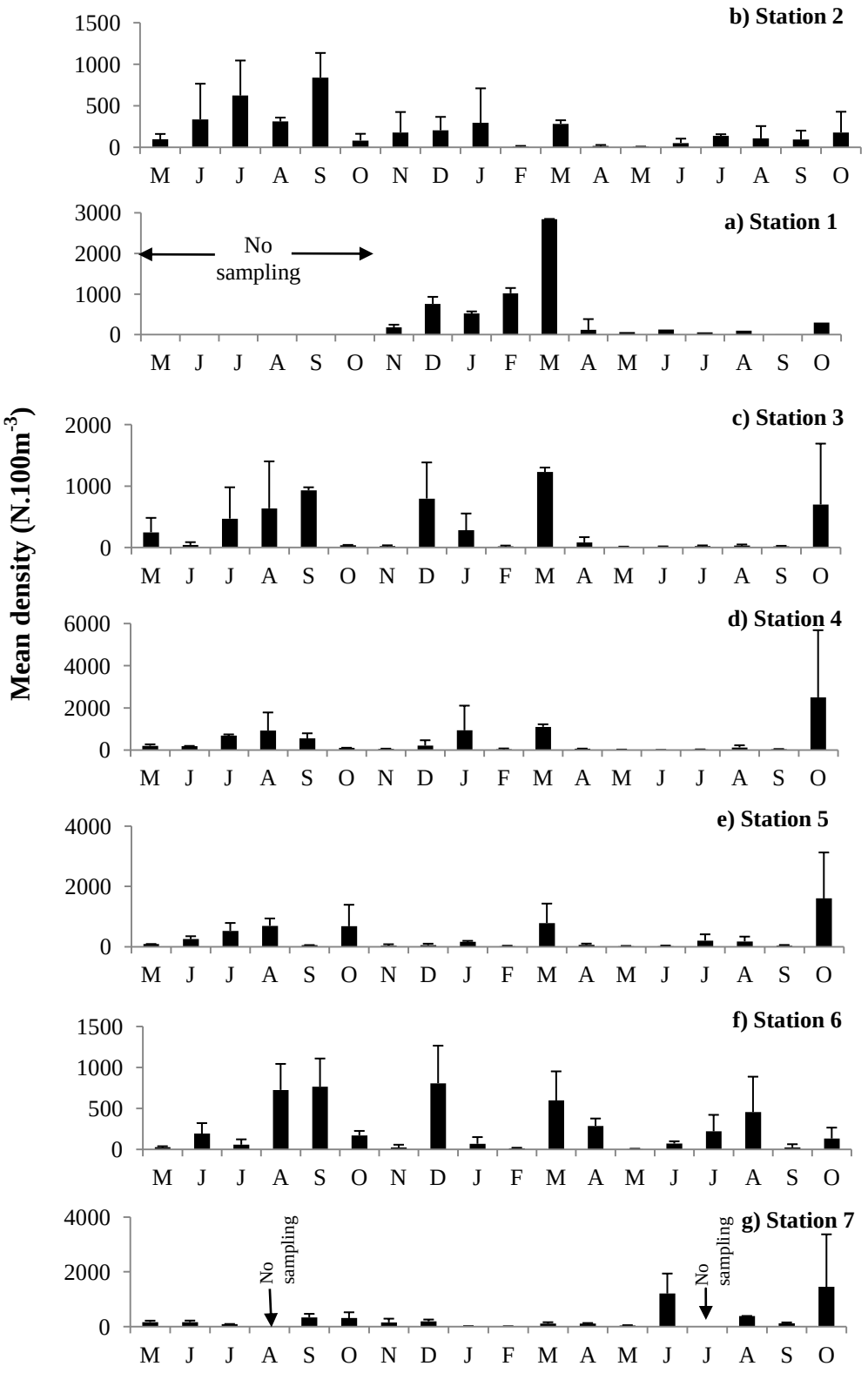

Figure 4.2. Monthly variation of mean total density (±SD) of larval fish by stations from May 2002 to October 2003. (Note different scale bar)

4.2.3 Spatio-temporal Variations in Abundance of Fish Larvae

4.2.3.1 Gobiidae

Gobiidae was the most abundant family, comprised 50.1% (mean 158 ± 433.8 N.100m^{-3}) of the total abundance throughout the 18 months of sampling (Table 4.3). During the 18 months of sampling, the abundance of gobiids ranged from 10.5 N.100m^{-3} (May 2003) to 921.9 N.100m^{-3} (March 2003). One-way ANOVA results showed significant difference in total abundance of Gobiidae among the months, with higher abundance in March and October 2003 ($P < 0.001$). The highest abundance was recorded in March 2003 which comprised of 93% (921.9 ± 1013.1 N.100m^{-3}) of the total fish larval population. This was followed closely by October 2003 which comprised of 63.8 % (mean 625.4 ± 944.9 N.100m^{-3}) of the total fish larval population (Figure 4.3a).

In mangrove estuary, mean density of Gobiidae ranged from 15 to 1228 N.100m^{-3}, with a mean of 207 ± 502 N.100m^{-3}. The highest mean abundance was found at Station 1 which accounted for 98.5% (465 ± 871 N.100m^{-3}) of the total larval population (Table 4.4, Figure 4.3b). Their abundance in Station 1 was significantly higher than all stations in the ANOVA analysis ($P < 0.001$). However, their density decreased towards offshore waters where at Station 7, larval density only reached 28 ± 112 N.100m^{-3} (9 % of the total abundance) (Table 4.4). In the offshore waters, mean density of gobiid larval ranged from 0 to 183 N.100m^{-3}. Mean density of Gobiidae larvae at different months and station are shown in Figure 4.4.

Preflexion gobiid larvae were consistently present at all months (generally > 40%, with nine out of 18 months showing > 90%). The abundance of preflexion stage of gobiid larvae were significantly higher in the months of May 2002 (98%), February and March 2003,which recorded 99.5% of the total gobiids of that month. There were also

ubiquitous and consistently observed at all stations (> 80%, see Figure 4.54b), with highest mean density in Station 1 (427.7 ± 876.9 $N.100^{-3}$) (Figure 4.5a). At Station 1, most of the gobiid larval consisted of preflexion stage from December 2002 to March 2003 except for January 2003 where 37% comprised of postflexion stage (213.2 ± 121.8 $N.100m^{-3}$). Mean abundance of flexion and postflexion stages were only recorded less than 10.0 $N.100m^{-3}$ of the total mean density. Flexion stage of gobiid larvae was abundant at Station 2 in June 2002 (154.4 ± 214.6 $N.100^{-3}$).

Table 4.3. Monthly mean density of Gobiidae from May 2002 to October 2003 in relation to their developmental stages.

Month	Preflexion			Flexion			Postflexion			Total Gobiidae	
	Mean	±SD	%	Mean	±SD	%	Mean	±SD	%	Mean	±SD
May-02	45.5	56.9	95.0	1.4	2.4	2.9	1	2.2	2.1	47.9	59
June	25.3	62.7	41.6	27.9	87.8	45.9	5	17.4	8.2	60.8	167.7
July	201.7	241.7	86.7	9.5	14.5	4.1	22	36.7	9.5	232.7	277.2
August	20.6	23.1	34.3	8.2	11.7	13.7	31.2	32.2	52.0	60	50.5
September	290.4	352.8	93.2	1.1	2.7	0.4	20	45.5	6.4	311.5	357.6
October	13.4	30.6	68.0	3	5.5	15.2	3.3	5.2	16.8	19.7	35.8
November	53.5	98.6	94.7	1.7	3.1	3.0	1.3	2	2.3	56.5	100.3
December	134.5	215.8	95.3	3.8	11.1	2.7	2.9	5.8	2.1	141.1	223.5
Jan-03	46.4	124.7	54.1	2.2	8.2	2.6	37.1	82.6	43.3	85.7	1795
February	79.2	280.6	99.5	0.4	1.3	0.5	0	0	0.0	79.6	281.9
March	917	1011	99.5	0	0.2	0.0	4.9	3.9	0.5	921.9	1013
April	13.6	23.9	51.7	5.6	11.1	21.3	7.2	7.5	27.4	26.3	40.2
May	9.5	26	90.5	1	2.5	9.5	0.1	0.3	1.0	10.5	28.4
June	7.6	24	42.2	5.8	21.4	32.2	4.5	15.9	25.0	18	61.3
July	14.2	20.6	48.5	3.2	8.4	10.9	11.9	21.9	40.6	29.3	42.1
August	32.8	59.8	92.4	0.9	2.3	2.5	1.8	3.9	5.1	35.5	62.9
September	10.4	15.4	81.9	0.9	2.3	7.1	1.5	3.5	11.8	12.7	21
October	603.6	925.1	96.5	12.7	16.9	2.0	9.1	10	1.5	625.4	944.9
Total Mean	**144.4**	**426**		**4.8**	**22**		**8.9**	**27.6**		**158.1**	**434**

Table 4.4. Mean density of Gobiidae at seven stations (1-5: mangrove estuary, 6-7: offshore waters) and *P* value of one-way ANOVA among the stations in relation to their developmental stages.

Developmental Stages		Station 1	2	3	4	5	6	7	*P*-level
Preflexion	Mean	427.7	110.2	188.4	204.4	121.4	29.3	26.4	<0.001**
	±SD	876.9	186.3	386.0	553.8	397.9	81.4	104.5	
Flexion	Mean	8.2	12.2	3.9	4.2	3.2	1.7	1.1	<0.05*
	±SD	18.6	51.3	8.1	8.1	9.6	6.6	6.0	
Postflexion	Mean	29.1	16.4	11.0	6.8	3.2	2.0	0.7	<0.001**
	±SD	67.0	28.6	28.0	15.6	5.2	5.6	2.4	
Total	Mean	465.0	138.9	203.3	215.4	127.8	33.0	28.0	<0.001**
	±SD	871.3	212.0	390.3	563.3	408.5	82.1	112.6	

*significance at $P< 0.05$, ** significance at $P< 0.01$

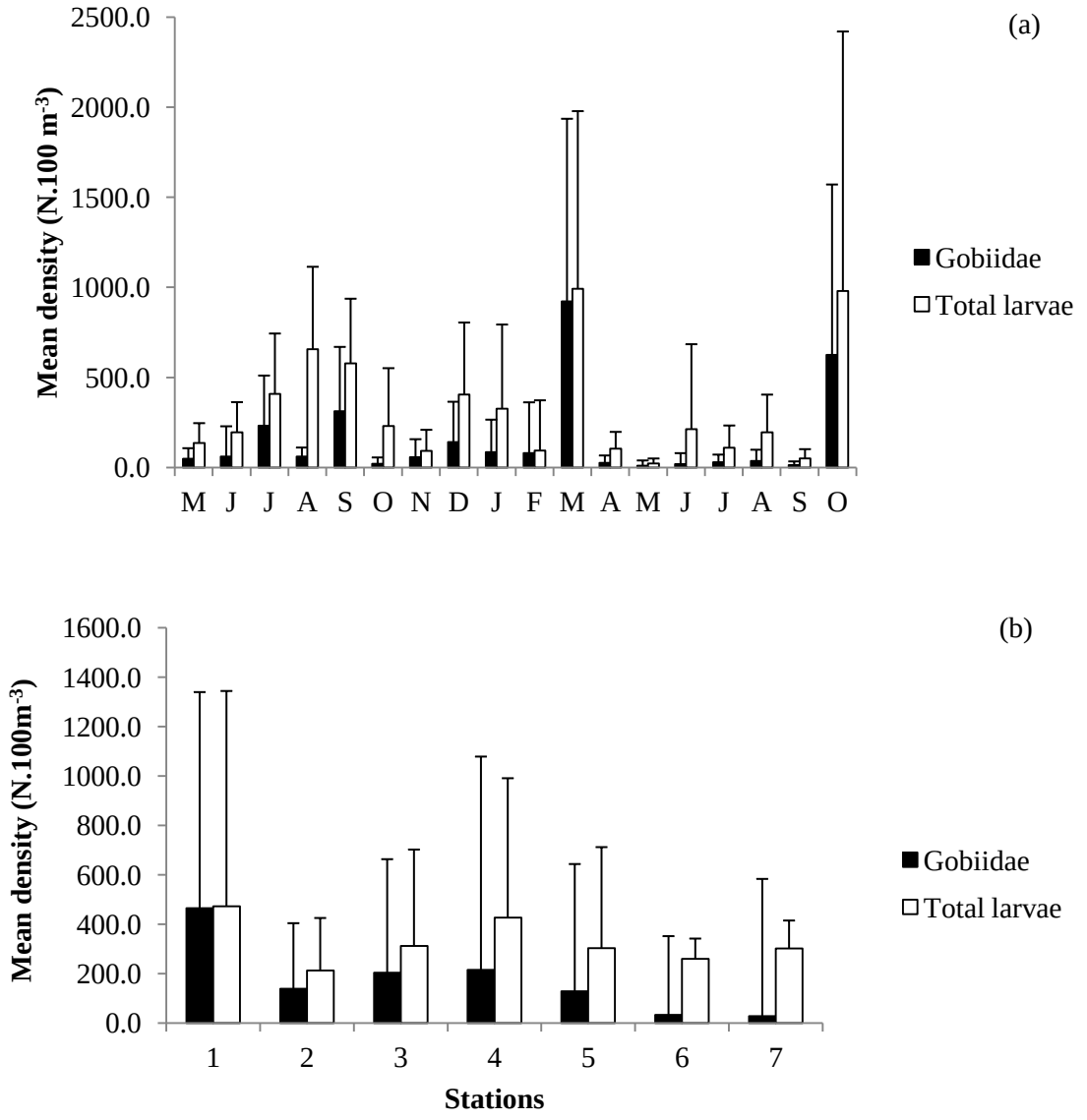

Figure 4.3. Temporal (a) and spatial (b) variations of mean abundances (±SD) of the total fish larvae and larval gobiids (N.100m^{-3}) in Matang Mangrove estuary (Station 1-5) and offshore waters (Station 6 & 7).

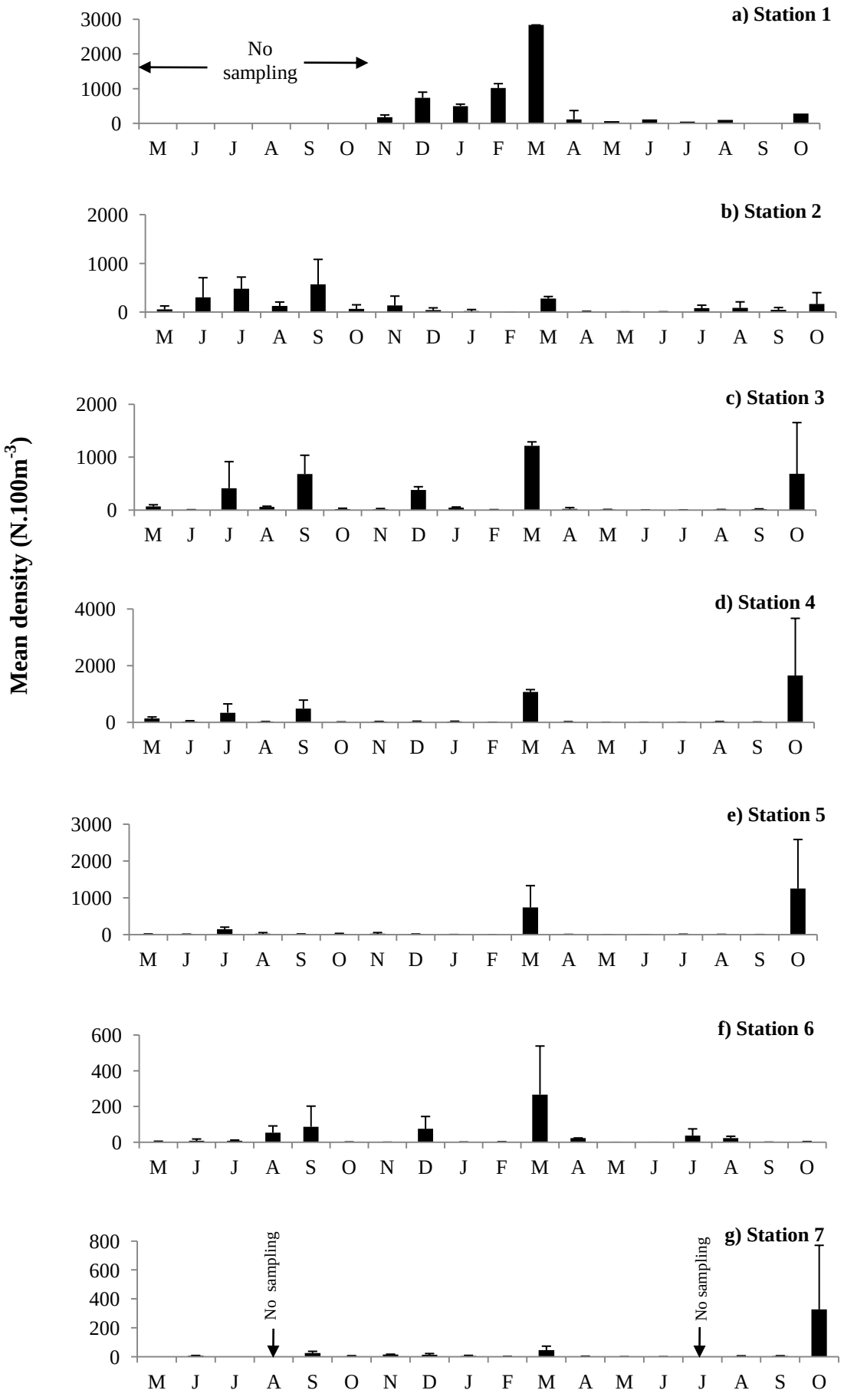

Figure 4.4. Mean density (N.100m^{-3}) of larval Gobiidae at different stations from May 2002 to October 2003. (Note different scale bar)

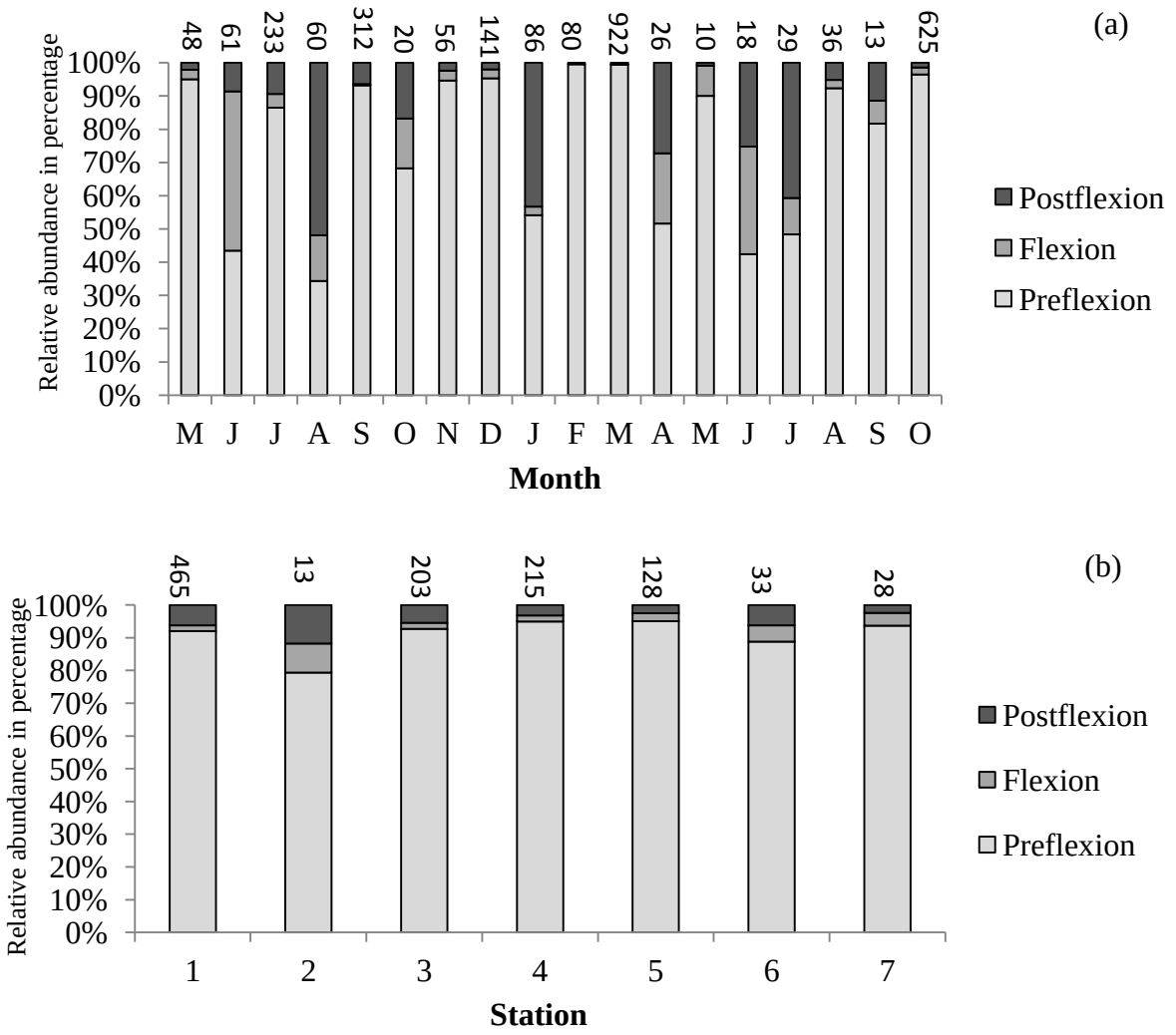

Figure 4.5. Temporal (a) and spatial (b) variations of the relative abundances of larval Gobiidae by developmental stages in Matang Mangrove estuary and offshore waters. Mean abundance (N.100 m^{-3}) at each month and station is indicated.

4.2.3.2 Engraulidae

Engraulidae larvaewas abundant during most of the sampling period but the abundance was significantly different among the 18 months ($P < 0.05$) (Table 4.5 & Figure 4.6a). Nevertheless, the density of the engraulid larvae did not vary greatly between months. Average percentage composition of engraulids was 38.4% over the 18 months of survey. Three peaks were observed where total mean engraulid larvae was highest in August 2002 (563.7 ± 447.5 N.100m^{-3}) which made up 85.9% of the total fish larval population. ANOVA results also showed significantly higher abundance in this month

($P < 0.01$) compared to other months. Another two peaks were also observed in the months of December 2002 and January 2003 with the mean density of 223.9 ± 328.4 N.100m^{-3} and 236.5 ± 458.8 N.100m^{-3}, respectively (see Figure 4.6a and Table 4.5). The minimum monthly average was 3.7 ± 5.1 N.100m^{-3} which was observed in May 2003.

Engraulidae larvae were present throughout the year at all stations in the MMFR. In the mangrove estuary, engraulid abundance ranged from 5 to 546 N.100m^{-3} while it ranged from 7 to 633 N.100m^{-3} in offshore waters. However, in contrast to Gobiidae, Engraulidae was relatively more abundant at Stations 6 (150 ± 240 N.100m^{-3}) and 7 (124 ± 255 N.100m^{-3}) in offshore waters where they constituted 58% and 41% of the total larvae respectively (Figure 4.7b). This clearly shows increasing catches of engraulid larvae from the mangrove waters to the coastal waters. Nevertheless, Engraulidae was most abundant at Station 4 (201.5 ± 441.7N.100m^{-3}) for the entire 18 months sampling. Three peaks (> 800 N.100m^{-3}) in August, January and October 2003 attributed to the high abundance of engraulids (Table 4.6 & Figure 4.8d). Station 5 recorded the second highest engraulid density, which has a total density of 164.0 ± 244.8 N.100 m^{-3}.Towards offshore in Station 6, engraulid larval were abundant in August 2002 (633.6 ± 269.6 N.100m^{-3}) and December 2002 (715.4 ± 379.7 N.100m^{-3}) (Figure 4.8f). Highest density in Station 7 was recorded in October 2003 (720 ± 960.1 N.100m^{-3}) (Figure 4.8g). *Stolephorus* spp. was observed to be abundant at Station 4 in October 2003. *Thryssa* spp. was abundant in January 2003, at the same station.

Offshore stations had a larger proportion of preflexion stage while mangrove areas had a larger proportion of postflexion stage (> 60%) (Figure 4.7 b). Preflexion of Engraulidae were most abundant in Station 6 and 7 with mean density of 128.6 ± 234N.100m^{-3} and 111.6 ± 234.4 N.100m^{-3}respectively (see Table 4.6).

Table 4.5. Monthly mean density of Engraulidae from May 2002 to October 2003 in relation to their developmental stages.

Month	Preflexion			Flexion			Postflexion			Juvenile			Total	
	Mean	±SD	%	Mean	±SD	%	Mean	±SD	%	Mean	±SD	%	Mean	±SD
May02	27.3	54.5	34.4	2.8	3.5	3.5	47.9	86.4	60.4	1.3	2.9	1.6	79.3	88.5
June	78.6	84.1	68.6	16.3	20.1	14	19.5	26.5	17	0.2	0.6	0.2	114.5	91.7
July	53.3	106.2	31.2	30	57.7	18	86.6	87.6	50.7	0.9	2.5	0.5	170.8	177.3
August	496.7	470	88.1	35.1	36.6	6.2	31.9	42.8	5.66	0	0	0	563.7	447.5
September	61.9	89.9	40.2	2.1	2.9	1.4	90.1	164.4	58.5	0	0	0	154.1	155.1
October	101	124.4	53.7	10.9	16.8	5.8	76.2	227.3	40.5	0	0	0	188.1	319.4
November	14.5	44.1	51.1	2.5	7.3	8.8	11.4	20.5	40.1	0	0	0	28.4	60.4
December	109.8	277.5	49	7.9	16.3	3.5	91.5	170.2	40.9	14.7	52.9	6.6	223.9	328.4
January 03	1.7	5.2	0.72	20.7	59.8	8.8	213.7	404.4	90.4	0.4	0.8	0.2	236.5	458.8
February	3.1	3.3	25.6	0.8	1.7	6.6	8.1	15.8	66.9	0	0	0	12.1	16
March	13	29	29.1	8.2	13.4	18	23.4	42.9	52.5	0	0.2	0	44.6	78.5
April	10.8	17.1	54.5	2.3	5.5	12	6.6	20.3	33.3	0	0	0	19.8	30.7
May	1.2	3.4	32.4	0	0	0	2.5	4.6	67.6	0	0	0	3.7	5.1
June	1	3.1	11.4	0.4	0.8	4.5	7.4	20.4	84.1	0	0	0	8.8	20.6
July	45.2	84.1	66.6	5.9	9.1	8.7	16.8	20.5	24.7	0	0	0	67.9	104.3
August	115.8	181	89.9	4.9	8.2	3.8	8.1	9	6.29	0	0	0	128.8	181.9
September	0.7	1.9	5.07	0.3	0.9	2.2	12.8	24.8	92.8	0	0	0	13.8	24.7
October	126.5	339	45.4	16	30.1	5.7	136.1	415.7	48.8	0.1	0.3	0	278.7	545.2
Total mean	**63.4**	**183.6**		**8.8**	**25**		**49.4**	**168.1**		**1**	**12.5**		**122.6**	**263.1**

Table 4.6. Mean density of Engraulidae at seven stations (1-5: mangrove estuary, 6-7: offshore waters) and *P* value of one-way ANOVA among the stations in relation to their developmental stages.

Developmental Stages		Station 1	2	3	4	5	6	7	*P*-level
Preflexion	Mean	0.8	4.3	30.8	59.3	89.5	128.6	111.6	<0.01**
	±SD	1.7	16.7	162.7	232.1	161.6	234.0	234.4	
Flexion	Mean	0.4	4.5	4.4	20.5	13.1	6.9	8.2	<0.01**
	±SD	1.6	12.4	11.4	53.6	16.2	11.5	19.9	
Postflexion	Mean	2.5	59.9	58.8	121.7	61.0	14.5	4.4	<0.01**
	±SD	4.1	120.3	139.3	352.6	137.2	30.6	7.6	
Juvenile	Mean	0.1	0.1	5.6	0.0	0.4	0.0	0.1	0.323
	±SD	0.5	0.9	31.8	0.2	1.6	0.1	0.4	
Total	Mean	3.9	68.8	99.6	201.5	164.0	150.0	124.2	<0.01**
	±SD	4.4	122.4	232.5	441.7	244.8	240.2	255.4	

*significance at $P < 0.05$, ** significance at $P < 0.01$

Nevertheless, preflexion larvae were also observed to be abundant at Station 3 and 4 in August 2002 density of with 493.8 ± 686.2 N.100m^{-3} and 738.7 ± 924.2 N.100m^{-3} respectively. Highest density of flexion and postflexion (early juveniles) larvae were recorded in Station 4 with density of 20.5 ± 53.6 N.100m^{-3} and 121.7 ± 352.6 N.100m^{-3}, respectively. Flexion larvae were abundant in July, August 2002 and January 2003. Two peaks of postflexion were observed at Station 4 in January and October 2003.

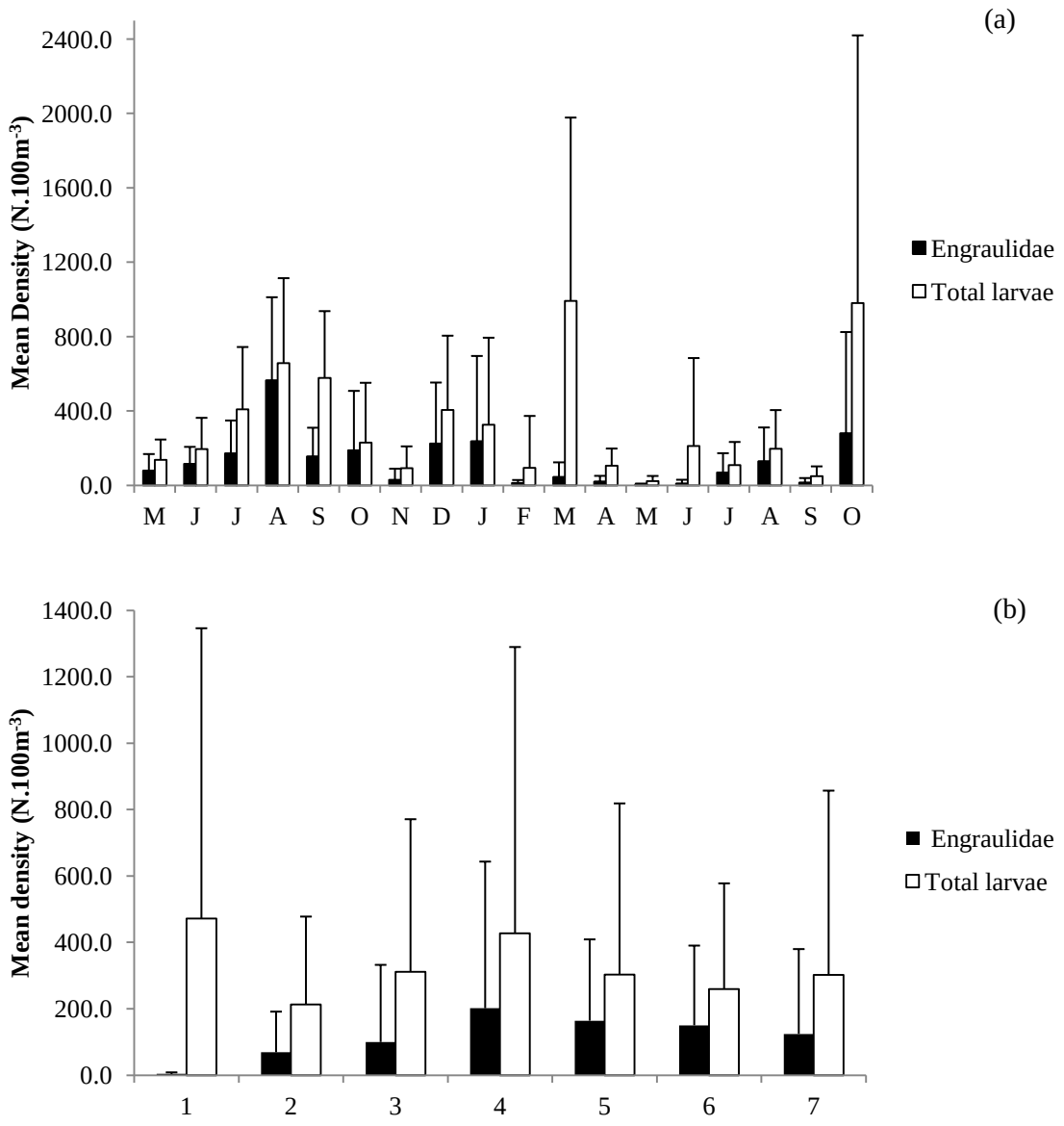

Figure 4.6. Temporal (a) and spatial (b) variations of mean abundances (±SD) of the total fish larval and larval Engraulid (N.100m^{-3}) in Matang Mangrove estuary and offshore waters.

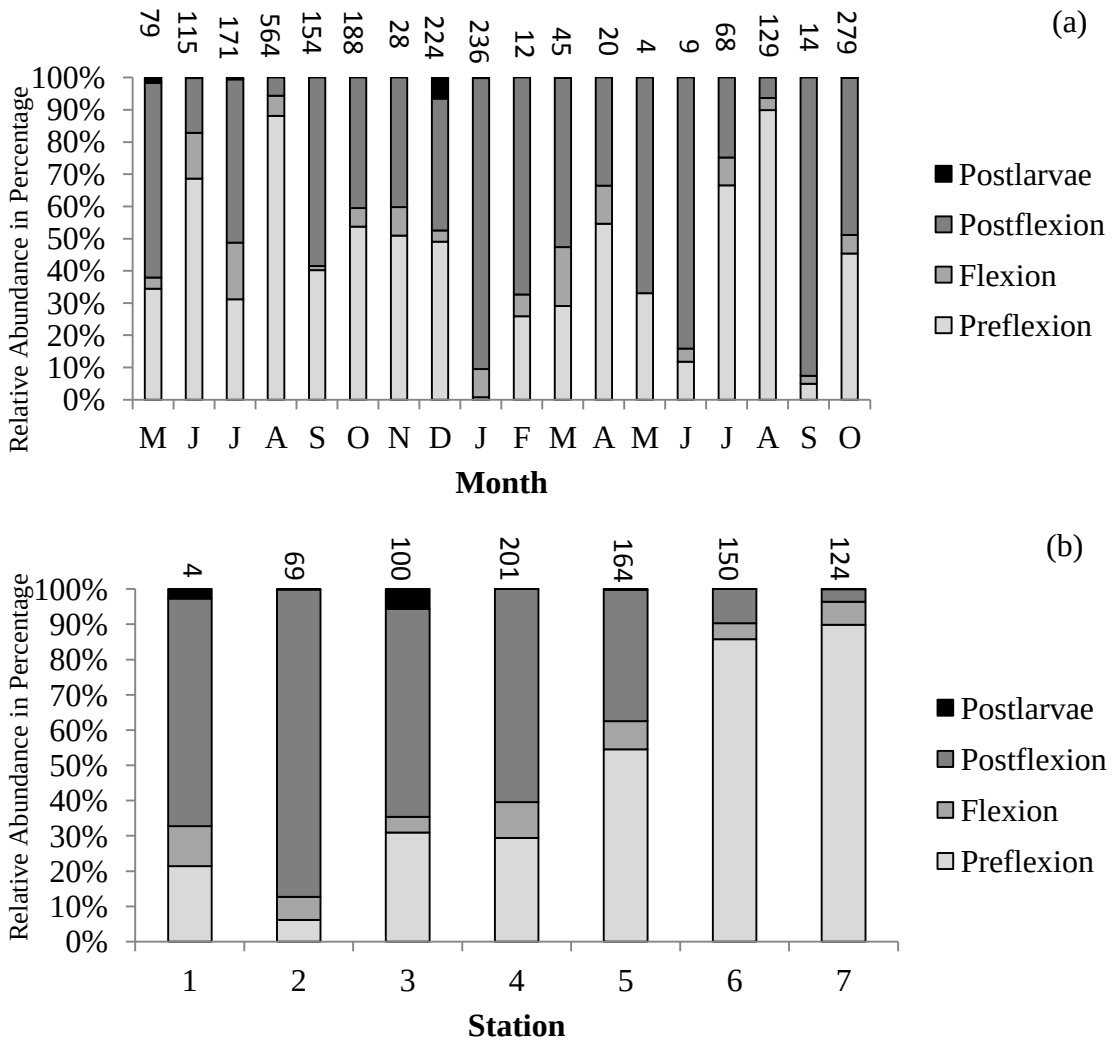

Figure 4.7. Temporal (a) and spatial (b) variations of the relative abundances of larval Engraulidae by developmental stages in Matang Mangrove estuary and offshore waters. Mean abundance (N.100m^{-3}) at each month and station is indicated.

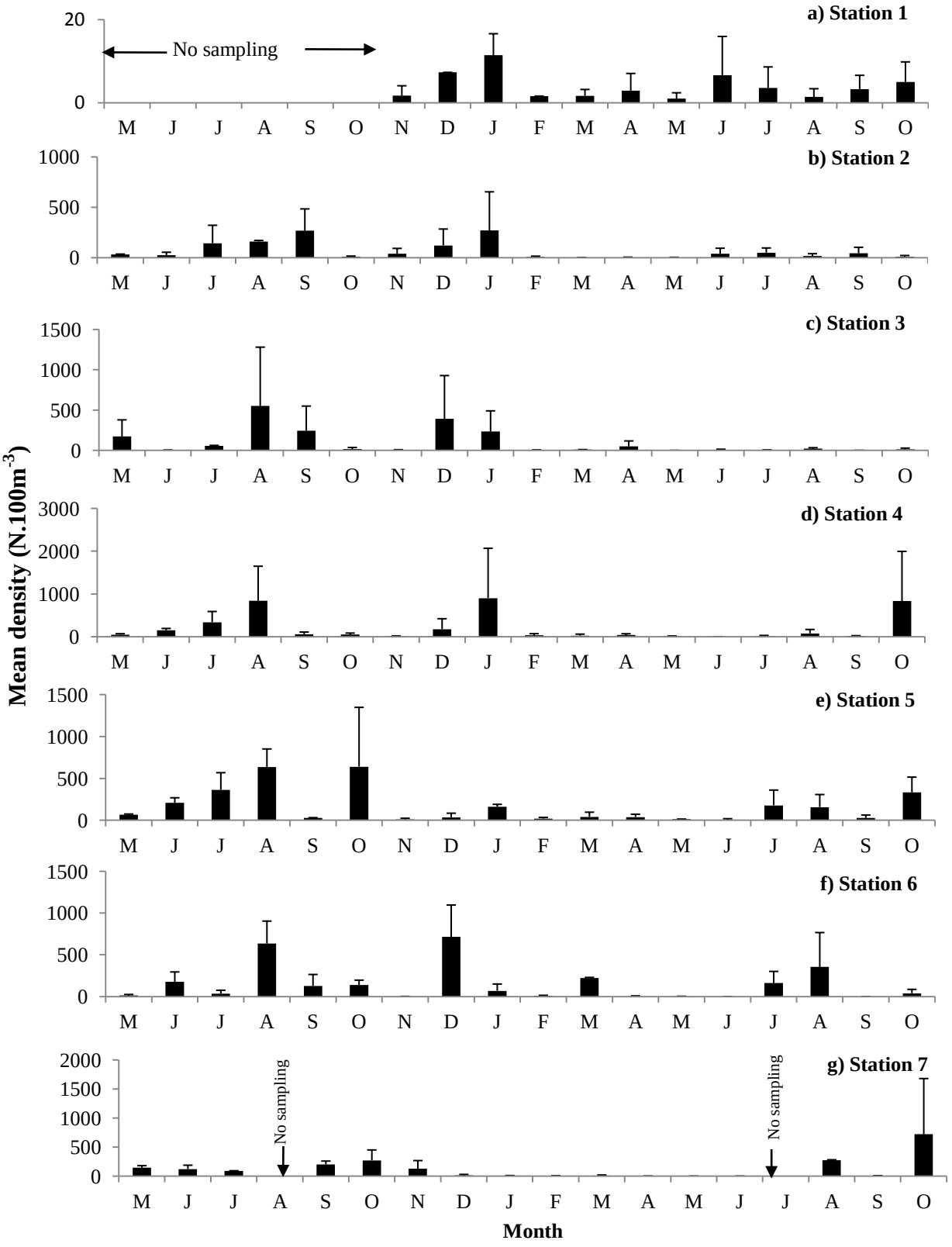

Figure 4.8. Mean density of larval Engraulidae at different stations from May 2002 to October 2003. (Note different scale bar)

4.2.3.3 Clupeidae

The clupeids were found throughout the 18 months sampling except in August 2002 (Table 4.7). They represented a small percentage (less than 4%) of the total fish larvae population with exceptions in April and June 2003 with 50.9% and 82.6% respectively (Figure 4.9a). Highest density of clupeid was recorded in June 2003 with 175.1 ± 477.4 $N.100m^{-3}$. This was followed by April, when the mean density was 53.3 ± 93.1 $N.100m^{-3}$. During this month, mean density of preflexion stage of clupeids was 21.4 ± 41.3 $N.100m^{-3}$, whereas density of flexion stage was 19.7 ± 42.3 $N.100m^{-3}$.

Clupeidae was found abundantly at offshore waters whereby highest abundance (98.5 ± 319.3 $N.100m^{-3}$) was recorded in Station 7 (Table 4.8), contributing 32.6% of the total larvae population (Figure 4.9b).The preflexion stage larvae contributed 92.3% of the total clupeids (Figure 4.10b) at Station 7 in June 2003 (Figure 4.11f). Preflexion stage larvae decreased in abundance towards the mangrove estuary (< 3 $N.100m^{-3}$). Flexion stage of larvae was mostly recorded in offshore stations, being abundant in April 2003 (92.6 ± 81.8 $N.100m^{-3}$). The abundance of postflexion stage increased from offshore stations to mangrove estuary. In mangrove estuary, higher abundance were recorded at Station 2 in December 2002 (Figure 4.11b), and at Station 3 in October 2002 (Figure 4.11c). All developmental stages of clupeid larvae were significantly different between stations ($P < 0.05$) (Table 4.8).

Table 4.7. Mean density of Clupeidae from May 2002 to October 2003 in relation to their developmental stages.

	Preflexion			Flexion			Postflexion			Total	
Month	**Mean**	**±SD**	**%**	**Mean**	**±SD**	**%**	**Mean**	**±SD**	**%**	**Mean**	**±SD**
May 02	0.3	1.2	14.3	0.2	0.5	9.5	1.6	3.1	76.2	2.1	3.5
June	0	0	0	0	0	0	0.1	0.3	100	0.1	0.3
July	0	0	0	0	0	0	0.1	0.2	100	0.1	0.2
August	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0.7	1.4	100	0.7	1.4
October	0	0	0	0	0	0	8.1	17.1	100	8.1	17.1
November	0	0	0	0	0	0	2.9	8.3	100	2.9	8.3
December	13.5	33.8	49.8	1.8	4.3	6.6	11.8	21.9	43.5	27.1	50.1
January 03	0	0	0	0.1	0.2	14	0.7	1.9	100	0.7	2
February	0	0	0	0.1	0.2	5	1.9	5.1	95	2	5.1
March	0	0	0	0	0.2	0	0.3	0.9	100	0.3	0.9
April	21.4	41.3	40.2	19.7	42.3	37	12.1	20.1	22.7	53.3	93.1
May	4.6	11.9	78	0.7	1.3	12	0.6	1	10.2	5.9	12.9
June	171.9	472	98.2	2.6	5.7	1.5	0.6	0.8	0.34	175	477.4
July	0	0	0	0	0	0	0.6	1	100	0.6	1
August	2.6	9.9	96.3	0	0	0	0.1	0.2	3.7	2.7	10.1
September	16.2	40	97	0.2	0.7	1.2	0.1	0.5	0.6	16.7	39.9
October	0	0	0	2.1	7.5	45	2.6	5.1	55.3	4.7	11.9
Total Mean	**1**	**9.7**		**1.6**	**11.3**		**2.5**	**9.1**		**17.9**	**123**

Table 4.8. Mean density of Clupeidae at seven stations (1-5: mangrove estuary, 6-7: offshore waters) and *P* value of one-way ANOVA among the stations in relation to their developmental stages.

Clupeidae		**Station**							
		1	**2**	**3**	**4**	**5**	**6**	**7**	***P*-level**
Preflexion	Mean	0.0	0.0	0.0	0.0	0.0	8.5	90.9	< 0.01**
	±SD	0.0	0.0	0.0	0.0	0.0	26.9	315.7	
Flexion	Mean	0.0	0.2	0.1	0.0	0.3	6.4	4.1	<0.01**
	±SD	0.2	1.1	0.2	0.0	1.0	25.8	12.5	
Postflexion	Mean	0.6	2.1	1.3	2.9	1.6	5.1	3.4	<0.05*
	±SD	1.7	11.7	3.6	10.4	3.1	13.8	9.6	
Total	Mean	0.6	2.3	1.4	2.9	1.9	20.0	98.5	<0.05*
	±SD	1.7	11.9	3.6	10.4	3.6	59.5	319.3	

*significance at $P<0.05$, ** significance at $P<0.01$

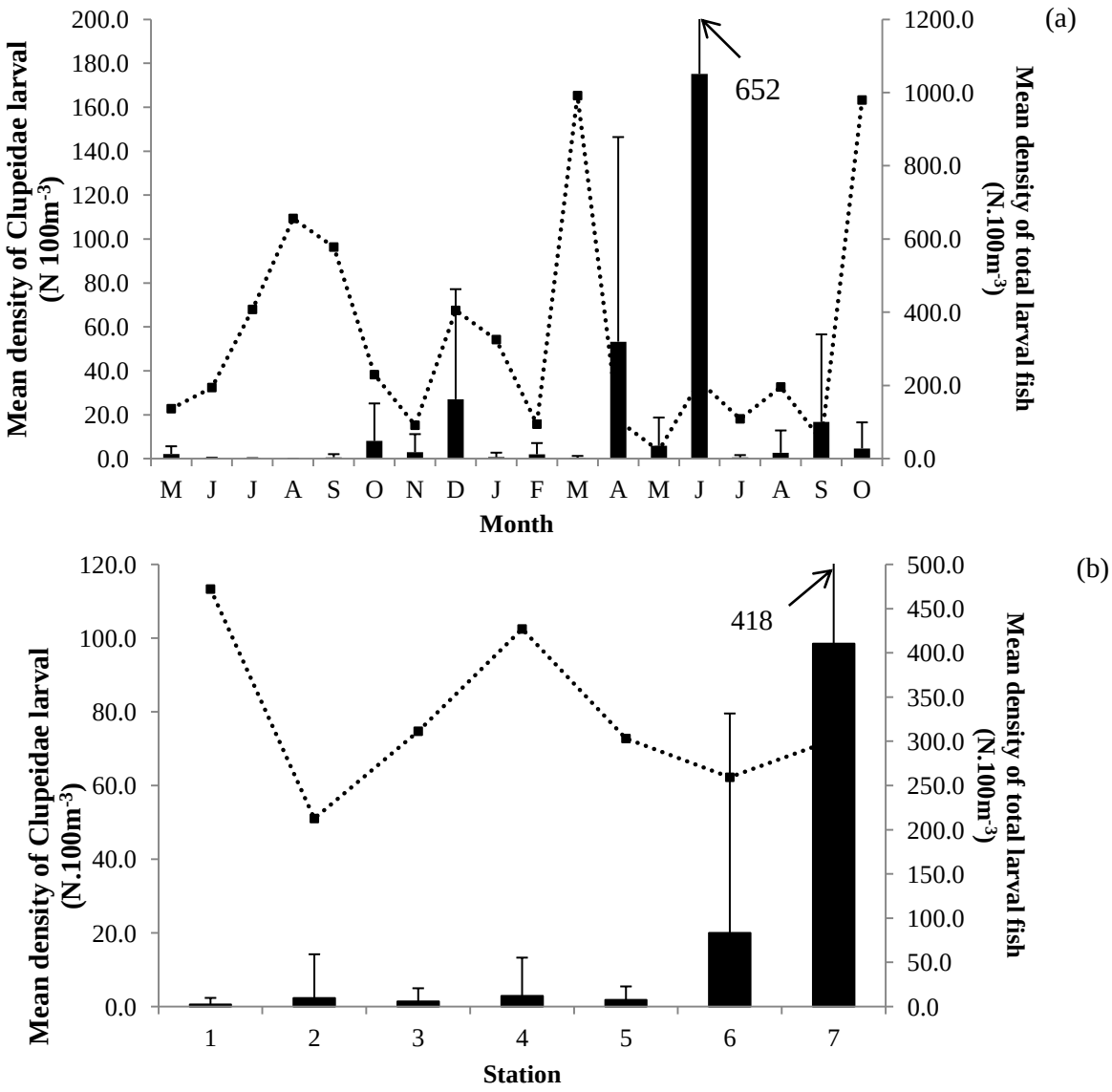

Figure 4.9. Temporal (a) and spatial (b) variations of mean abundances (±SD) of the total fish larvae (right vertical axis, dotted line) and larval clupeids (N.100m^{-3}) (left vertical axis, bar graph) in Matang Mangrove estuary and offshore waters.

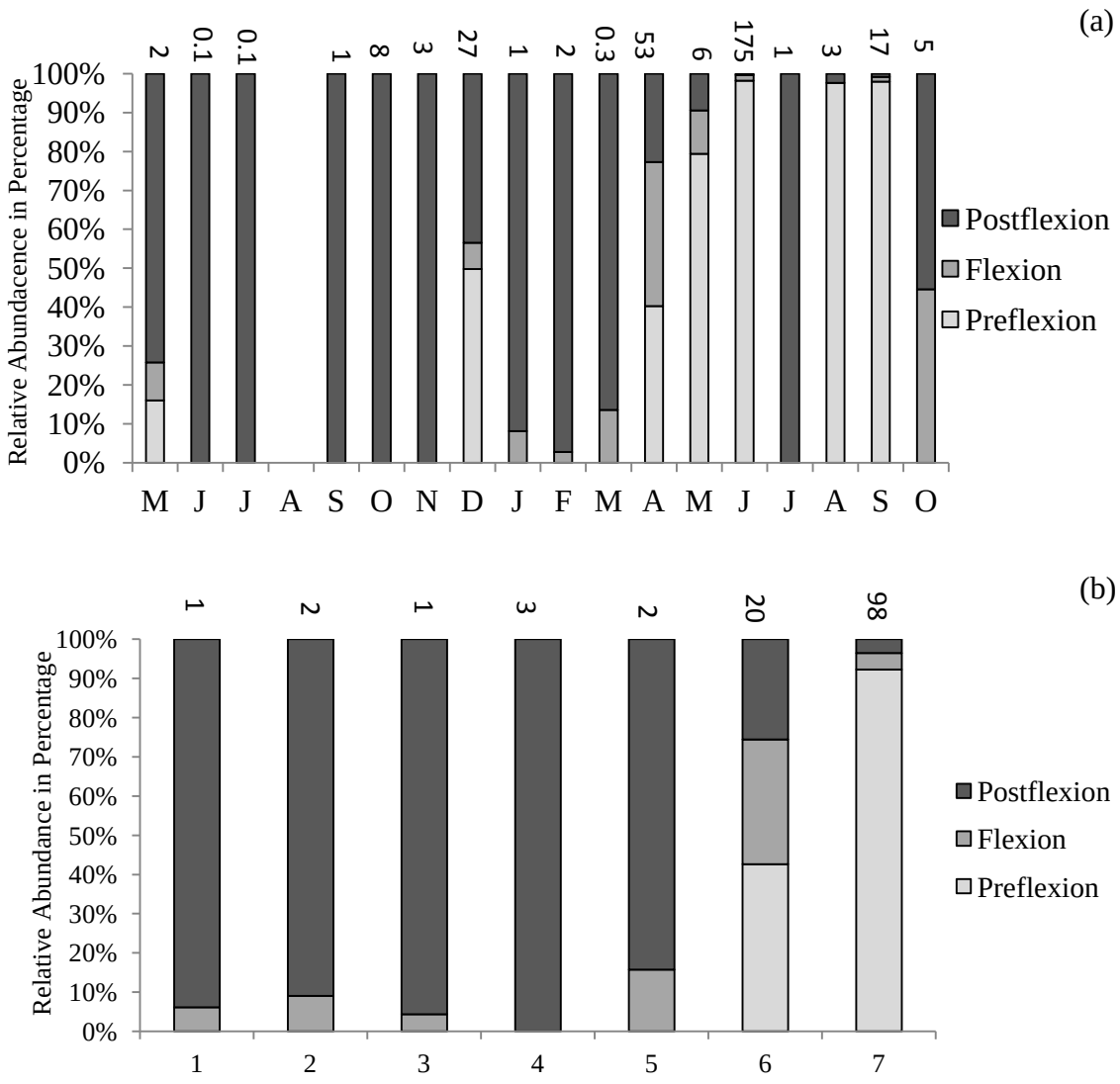

Figure 4.10. Temporal (a) and spatial (b) variations of the relative abundances of larval Clupeidae by developmental stages in Matang Mangrove estuary and offshore waters. Mean abundance (N.100m^{-3}) at each month and station is indicated.

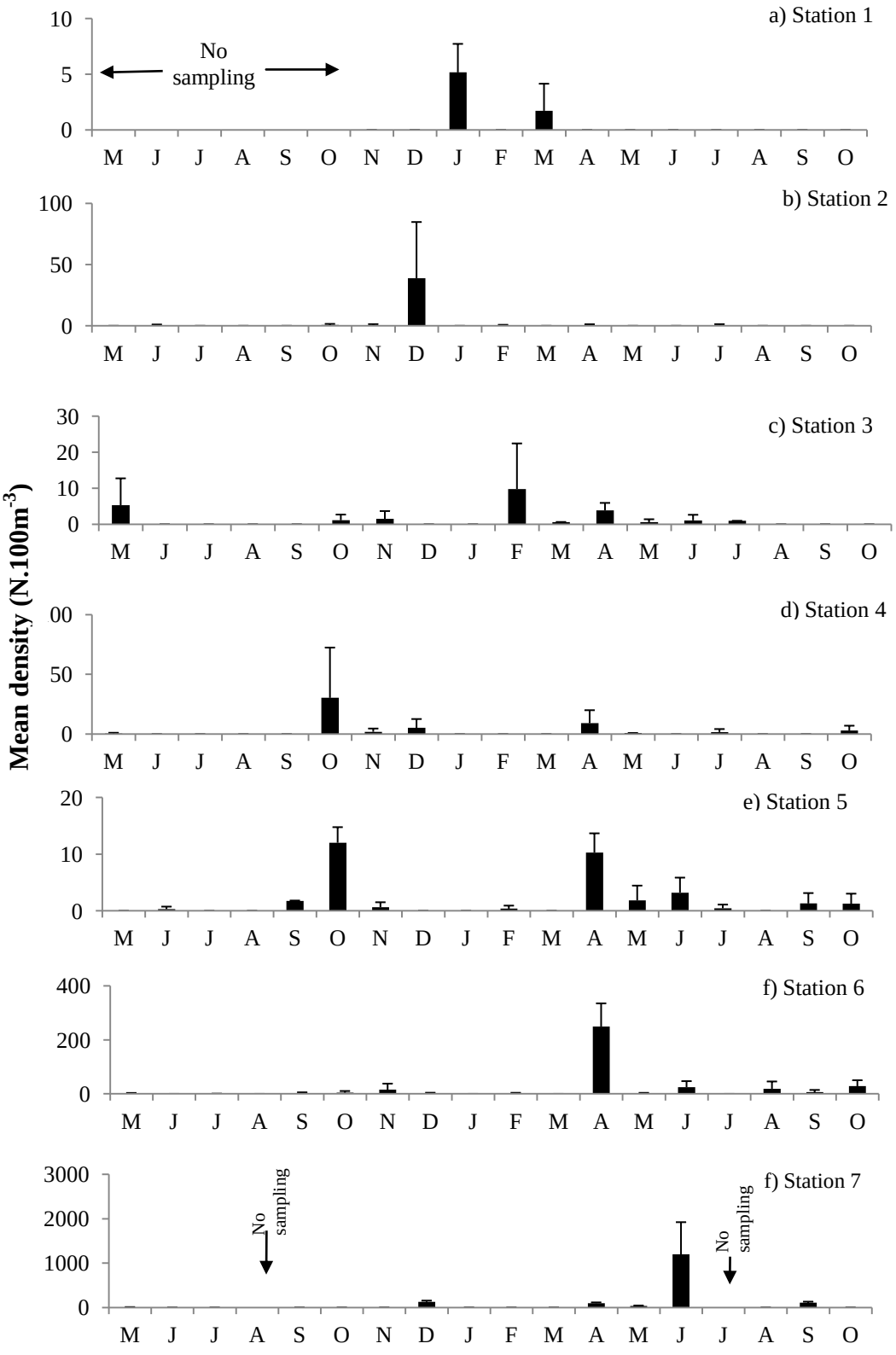

Figure 4.11. Mean density (N.100m^{-3}) of larval Clupeidae at different stations from May 2002 to October 2003. (Note different scale bar)

4.2.3.4 Sciaenidae

Sciaenidae was present throughout the 18 months sampling except in February 2003. The highest density was recorded in September 2002 (90.4 ± 221.5 N.100m^{-3}), followed by October 2003 (mean 46.9 ± 149.3N.100m^{-3}) (Table 4.9). The mean density in September 2002 represented 15.6% of the total fish larvae population of that month (Figure 4.12a). Sciaenid larvae were more abundant in offshore areas, with 35.7 ± 129.4 N.100m^{-3} and 32.9 ± 101.2 N.100m^{-3} at Station 6 and Station 7 respectively, as compared to the mangrove estuary with means that were less than 4 N.100m^{-3} (Table 4.10, Figure 4.12b). Sciaenid larvae in Station 6 and Station 7 consisted of 13.8% and 10.9% of the total fish population respectively. At Station 6, 99% of the total sciaenids consisted of preflexion larvae. At Station 7, 47% of total sciaenid larvae comprised of preflexion and 52% were postflexion larvae (Figure 4.13b).

In the mangrove estuary, preflexion larvae were mainly found abundantly in August 2002 at Stations 2-5 (Figures 4.14 b-e), ranging from 4.1 ± 5.8 N.100m^{-3} to 41.7 ± 59.2 N.100m^{-3}. Highest density of preflexion stage of Sciaenidae larvae was recorded at Station 6 in September 2002 (461.9 ± 438.6 N.100m^{-3}) (Figure 4.14 f). Postflexion larvae comprised of 93.1% (276.1 ± 390.5 N.100m^{-3}) of the total larvae in October 2003 at Station 7.

Table 4.9. Mean density of Sciaenidae from May 2002 to October 2003 in relation to their developmental stages.

Month	Preflexion			Flexion			Postflexion			Total	
	Mean	±SD	%	Mean	±SD	%	Mean	±SD	%	Mean	±SD
May 02	0.5	1.41	100	0	0	0	0	0	0	0.48	1.41
June	1.9	2.2	100	0	0	0	0	0	0	1.88	2.2
July	2.6	5.79	106	0.17	0.6	7	0	0	0	2.44	6.38
August	26	26.1	100	0	0	0	0.08	0.3	0.3	26.12	26.1
September	90	222	100	0	0	0	0	0	0	90.36	222
October	4.9	11.8	100	0	0	0	0	0	0	4.93	11.8
November	0.4	0.81	90	0.04	0.2	9.8	0	0	0	0.41	0.93
December	8.9	9.61	100	0	0	0	0	0	0	8.88	9.61
January 03	0.1	0.29	35	0	0	0	0	0	0	0.23	0.62
February	0	0	0	0	0	0	0	0	0	0	0
March	13	22	97	0.1	0.2	0.7	0.28	0.7	2	13.72	22.4
April	0.2	0.72	100	0	0	0	0	0	0	0.19	0.72
May	0.1	0.31	100	0	0	0	0	0	0	0.08	0.31
June	0.3	0.79	71	0.06	0.2	14	0.06	0.2	14	0.42	0.85
July	5.7	11.3	98	0.09	0.3	1.6	0	0	0	5.78	11.3
August	14	23.9	100	0	0	0	0	0	0	13.72	23.9
September	0.4	0.72	100	0	0	0	0	0	0	0.42	0.72
October	7.1	9.73	15	0.35	1.3	0.7	39.45	148	84	46.9	149
Total Mean	**9.2**	**53**		**0.05**	**0.4**		**2.38**	**36**		**11.6**	**64**

Table 4.10. Mean density of Sciaenidae at seven stations (1-5: mangrove estuary, 6-7: offshore waters) and *P* value of one-way ANOVA among the stations in relation to their developmental stages.

Developmental Stages		Station 1	2	3	4	5	6	7	*P*-level
Preflexion	Mean	1.3	0.4	2.3	3.0	3.9	35.5	15.5	<0.01**
	±SD	3.4	1.4	7.5	14.0	8.1	129.4	28.9	
Flexion	Mean	0.0	0.0	0.0	0.0	0.0	0.1	0.2	<0.05*
	±SD	0.0	0.2	0.0	0.0	0.1	0.4	0.9	
Postflexion	Mean	0.0	0.0	0.0	0.0	0.0	0.1	17.3	<0.01**
	±SD	0.0	0.1	0.0	0.0	0.0	0.5	97.6	
Total	Mean	1.3	0.4	2.3	3.0	4.0	35.7	32.9	<0.01**
	±SD	3.4	1.6	7.5	14.0	8.1	129.4	101.2	

*significance at P< 0.05, ** significance at $P < 0.01$

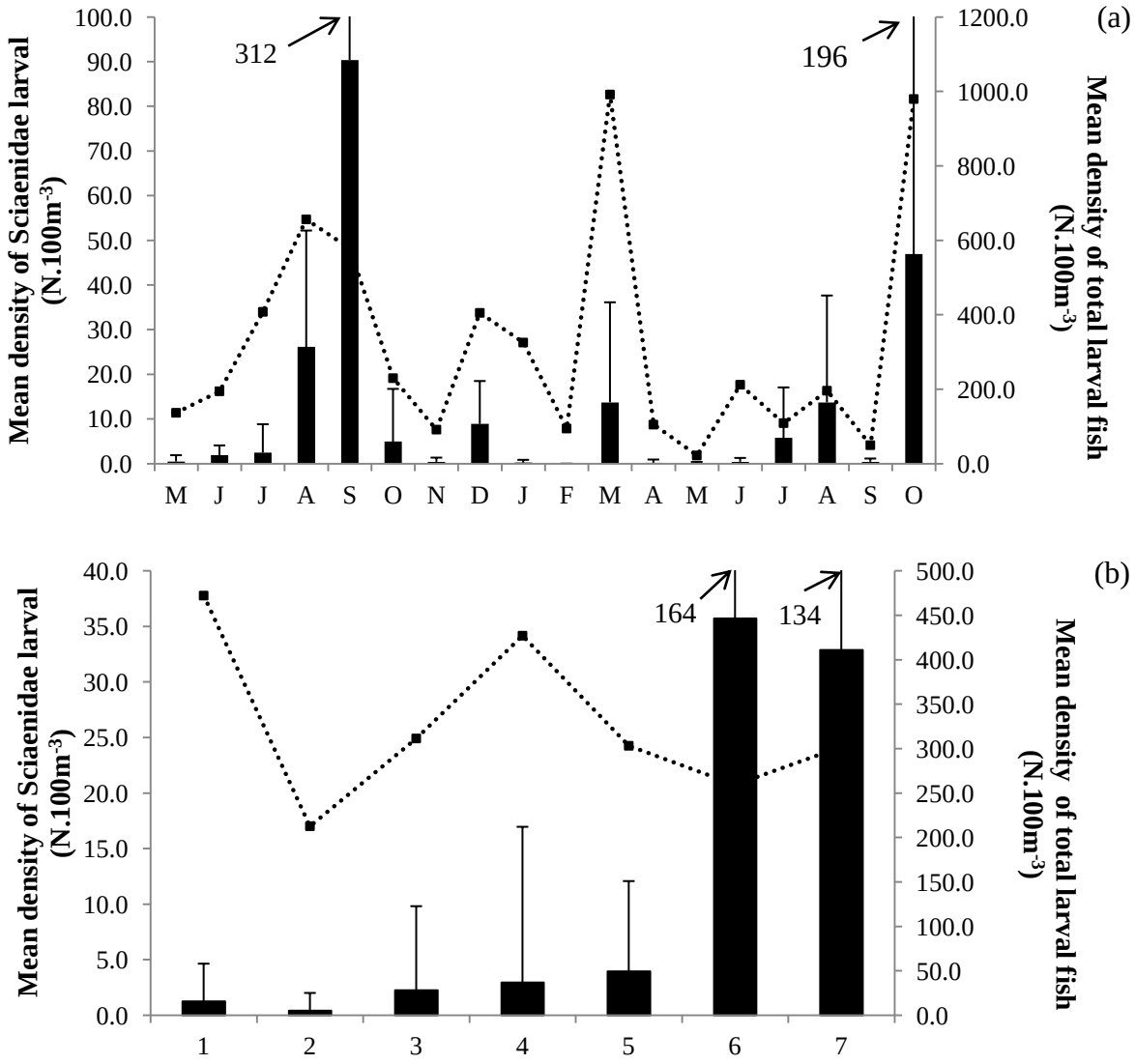

Figure 4.12. Temporal (a) and spatial (b) variations of mean abundances (±SD) of the total fish larvae (right vertical axis, dotted line) and larval sciaenids (in N.100m^{-3}) (left vertical axis, bar graph) in Matang Mangrove estuary and offshore waters.

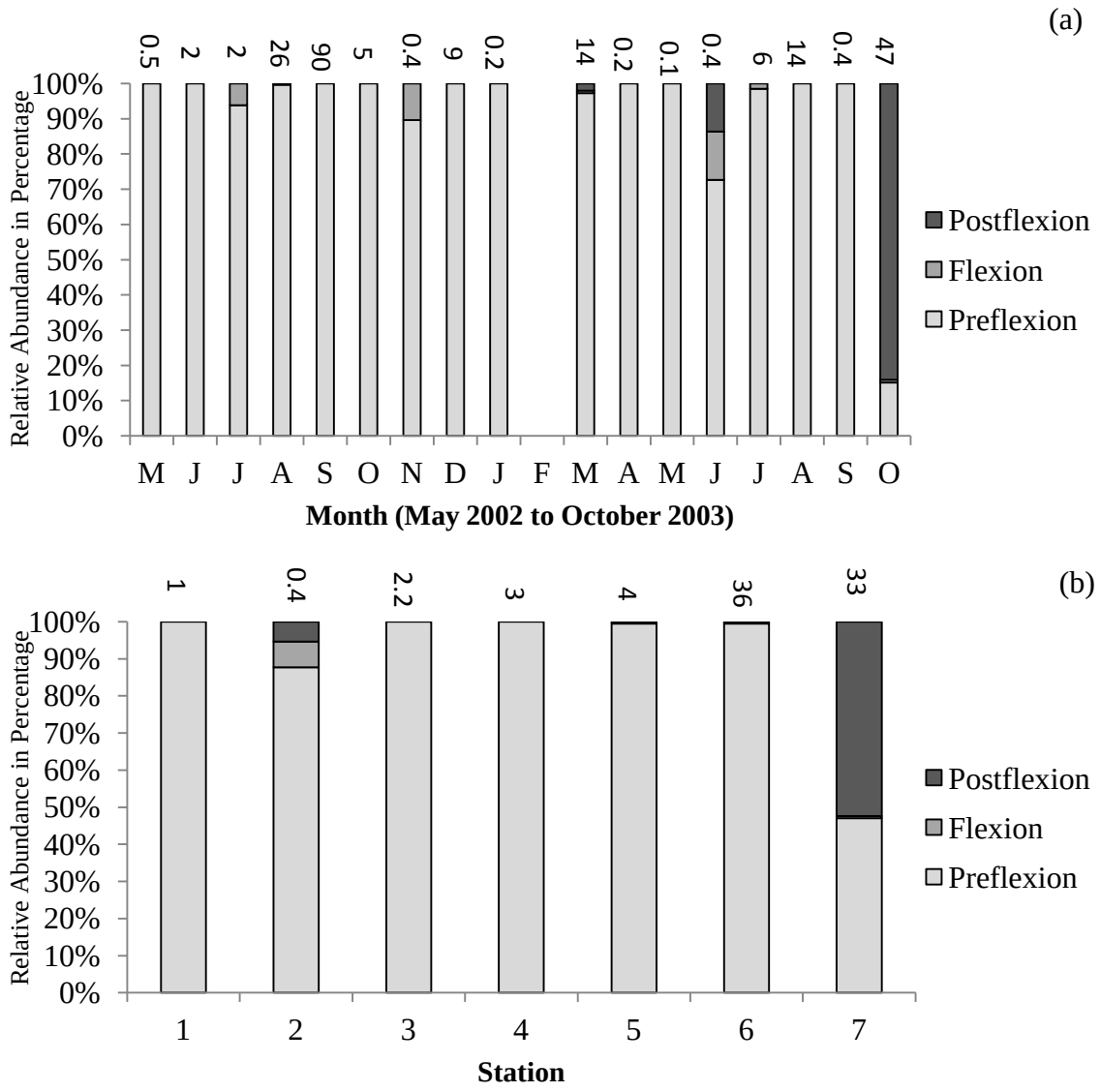

Figure 4.13. Temporal (a) and spatial (b) variations of the relative abundances of larval Sciaenidae by developmental stages in Matang Mangrove estuary and offshore waters. Mean abundance (N.100m^{-3}) at each month and station is indicated.

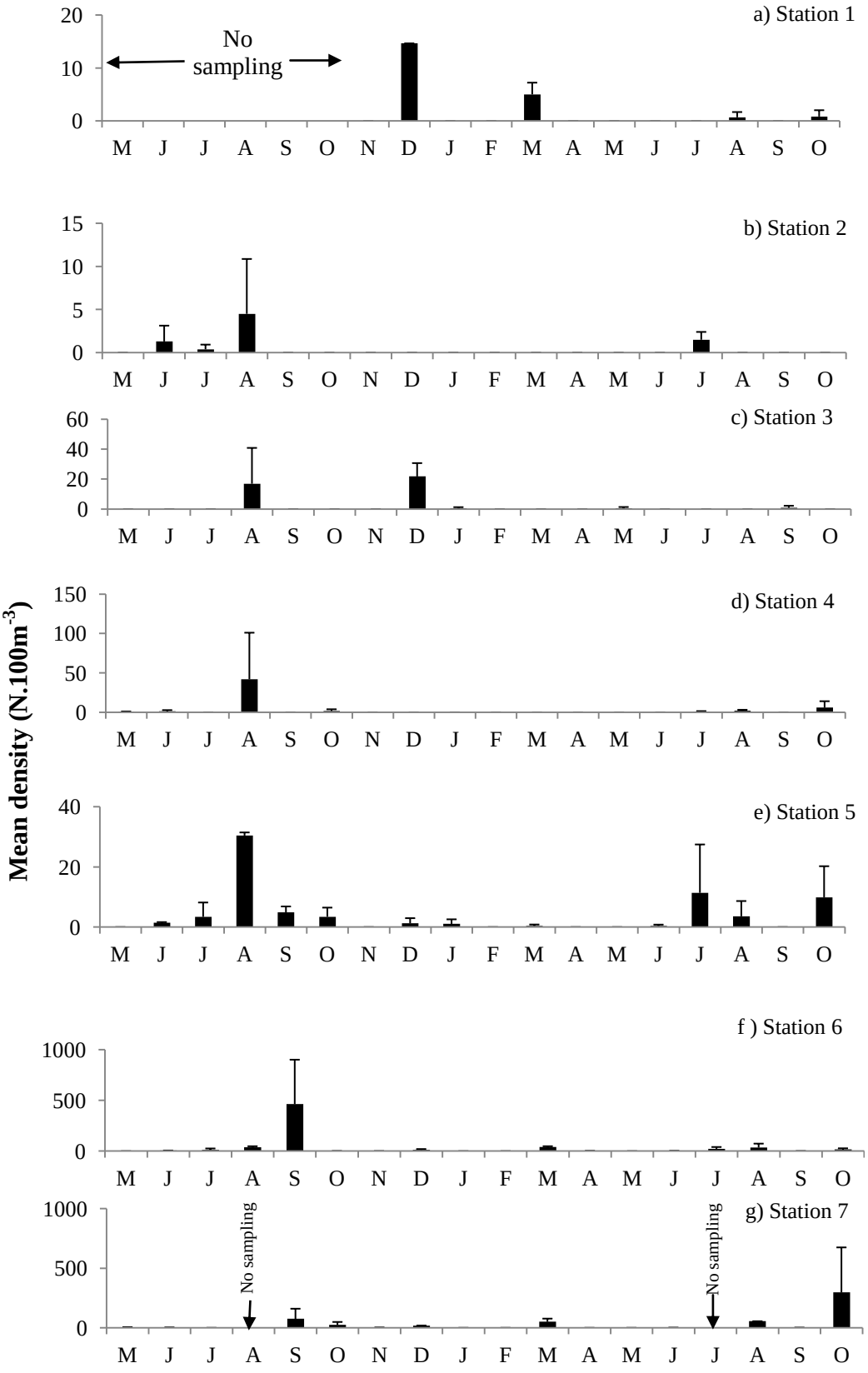

Figure 4.14. Mean density (N.100m^{-3}) of larval Sciaenidae at different stations from May 2002 to October 2003. (Note different scale bar)

4.2.3.5 Ambassidae

The ambassid larvae represented less than 1% of the total fish larval population. The mean density ranged from 0 to 8.0 ± 16.0 N.100m^{-3} (with highest density in June 2003 (8 ± 16 N.100m^{-3}) (Table 4.11; Figure 4.15a). Preflexion larval were only found in May 2002 and January 2003 in the mangrove waters. At the offshore areas, preflexion larvae were found in October, December 2002, April and May 2003.

Postflexion larvae dominated most of the catch throughout the year (Figure 4.16a), with the highest recorded in June 2003 (26.5 ± 21.7 N.100m^{-3}) at the offshore waters (Table 4.12), where 96% were observed in Station 6. The abundance of postflexion stage larvae in offshore areas was significantly ($P < 0.05$) higher than inside the mangrove estuary. In Station 6, total mean ambassid larvae ranged from 0.4 ± 0.5 N.100m^{-3} to 44.9 ± 4.3 N.100m^{-3} whereas in Station 7, it ranged from from 0.6 ± 0.9 N.100m^{-3} to 8.0 ± 5.7 N.100m^{-3} (Figure 4.17 f & g). Although there was no clear spatial separation of ontogenetic stages, the uppermost station (Station 1) contained more than 60% preflexion larvae and later stage larvae were found more towards offshore waters (Figure 4.16b).

4.2.3.6 Blenniidae

Monthly abundance of blenniid larvae ranged from 0 to 5.9 N.100m^{-3} (absent in two out of 18 months; January and March 2003) (Table 4.13, Figure 4.18a). Highest mean was recorded in June 2002 which made up of 3% of the total population (Figure 4.18 a). Preflexion stage made up the most by station and month (Figure 4.19). Postflexion blenniid larvae were highest in October 2002 in the Station 4 with density of 5.8 ± 7.3 N.100m^{-3} (Figure 4.20 d).

Table 4.11. Mean density of Ambassidae from May 2002 to October 2003 in relation to their developmental stages.

Month	Preflexion			Flexion			Postflexion			Total	
	Mean	±SD	%	Mean	±SD	%	Mean	±SD	%	Mean	±SD
May 02	0.9	3	42.9	0.6	1.8	29	0.7	1.9	33.3	2.1	3.6
June	0	0	0	0.4	0.9	6.3	5.9	16.2	93.7	6.3	16.2
July	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0.1	0.2	100	0.1	0.2
September	0	0	0	0	0	0	0.1	0.2	100	0.1	0.2
October	0.6	1.6	15	0	0	0	3.4	7.9	85	4	9.4
November	0	0	0	0	0	0	1.7	4.5	100	1.7	4.5
December	0.2	0.6	100	0	0	0	0	0	0	0.2	0.6
January 03	0.7	2.5	35	0	0	0	1.3	2.9	65	2	3.6
February	0	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	4.4	16.1	100	4.4	16.1
April	0.3	0.7	13.6	0.1	0.4	4.5	1.9	2.4	86.4	2.2	3
May	0.3	0.8	33.3	0.1	0.3	11	0.5	1.2	55.6	0.9	1.5
June	0	0	0	0	0	0	8	16	100	8	16
July	0	0	0	0	0	0	0.3	1.1	100	0.3	1.1
August	0	0	0	0	0	0	1	2.4	100	1	2.4
September	0	0	0	0	0	0	2.8	8.3	100	2.8	8.3
October	0	0	0	0	0	0	1.4	4.3	100	1.4	4.3
Total mean	**0.2**	**1**		**0.1**	**0.5**		**1.9**	**7.5**		**2.1**	**7.7**

Table 4.12. Mean density of Ambassidae at seven stations (1-5: mangrove estuary, 6-7: offshore waters) and *P* value of one-way ANOVA among the stations in relation to their developmental stages.

Developmental Stages		Station 1	2	3	4	5	6	7	*P*-level
Preflexion	Mean	0.4	0.0	0.0	0.0	0.3	0.3	0.3	<0.05*
	±SD	2.0	0.0	0.0	0.0	1.7	1.0	0.7	
Flexion	Mean	0.0	0.2	0.0	0.0	0.0	0.0	0.2	0.099
	±SD	0.0	1.0	0.0	0.0	0.0	0.0	0.7	
Postflexion	Mean	0.2	0.0	1.8	0.4	0.8	7.5	1.9	<0.01**
	±SD	0.9	0.2	9.5	1.7	1.9	15.1	3.3	
Total	Mean	0.6	0.2	1.8	0.4	1.1	7.8	2.4	<0.01**
	±SD	2.1	1.0	9.5	1.7	2.5	15.3	3.4	

*significance at $P < 0.05$, ** significance at $P < 0.01$

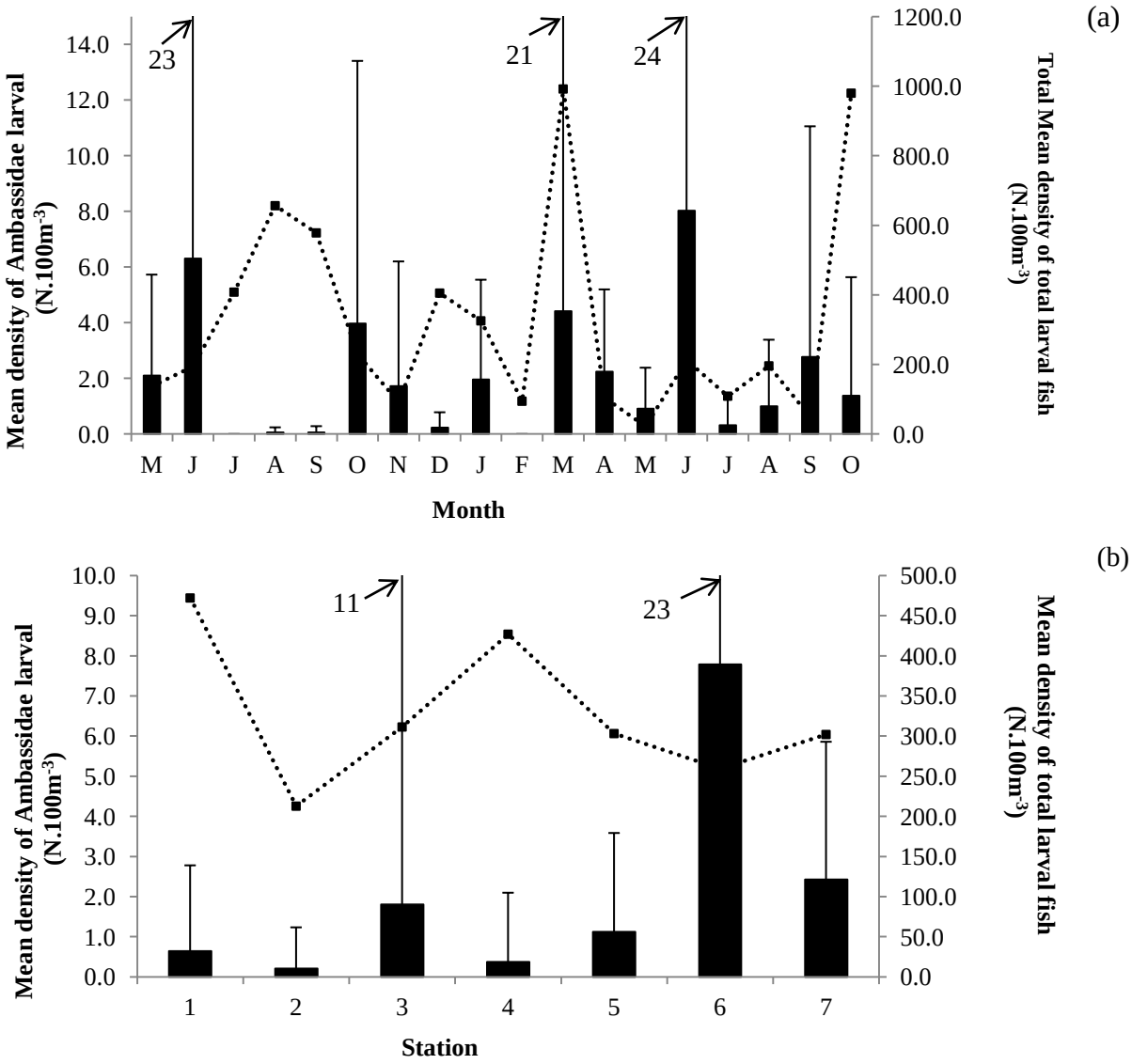

Figure 4.15. Temporal (a) and spatial (b) variations of mean abundances (±SD) of the total fish larvae (right vertical axis, dotted line) and larval ambassids (N.100 m^{-3}) (left vertical axis, bar graph) in Matang Mangrove estuary and offshore waters.

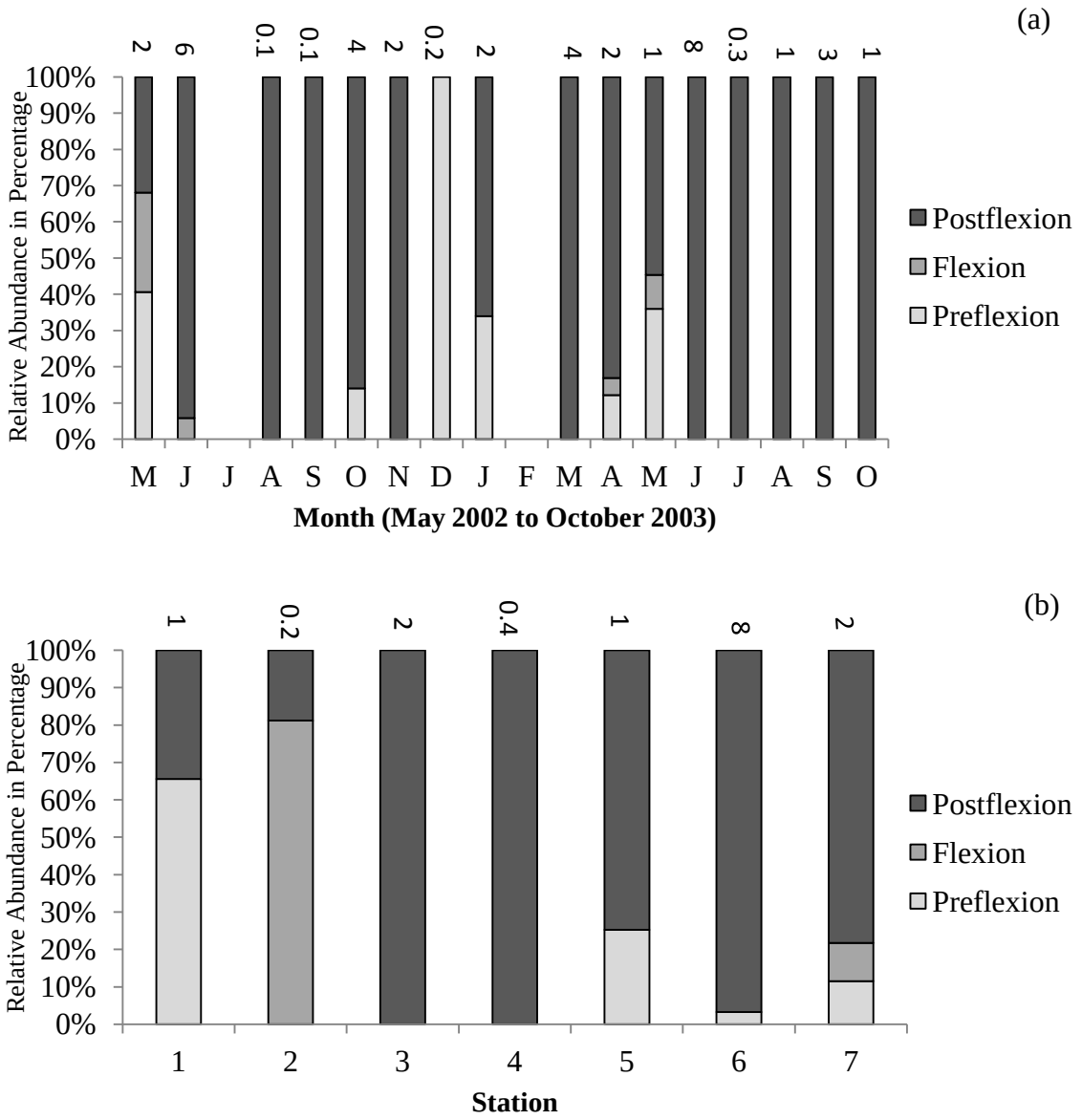

Figure 4.16. Temporal (a) and spatial (b) variations of the relative abundances of larval Ambassidae by developmental stages in Matang Mangrove estuary and offshore waters. Mean abundance (N.100m^{-3}) at each month and station is indicated.

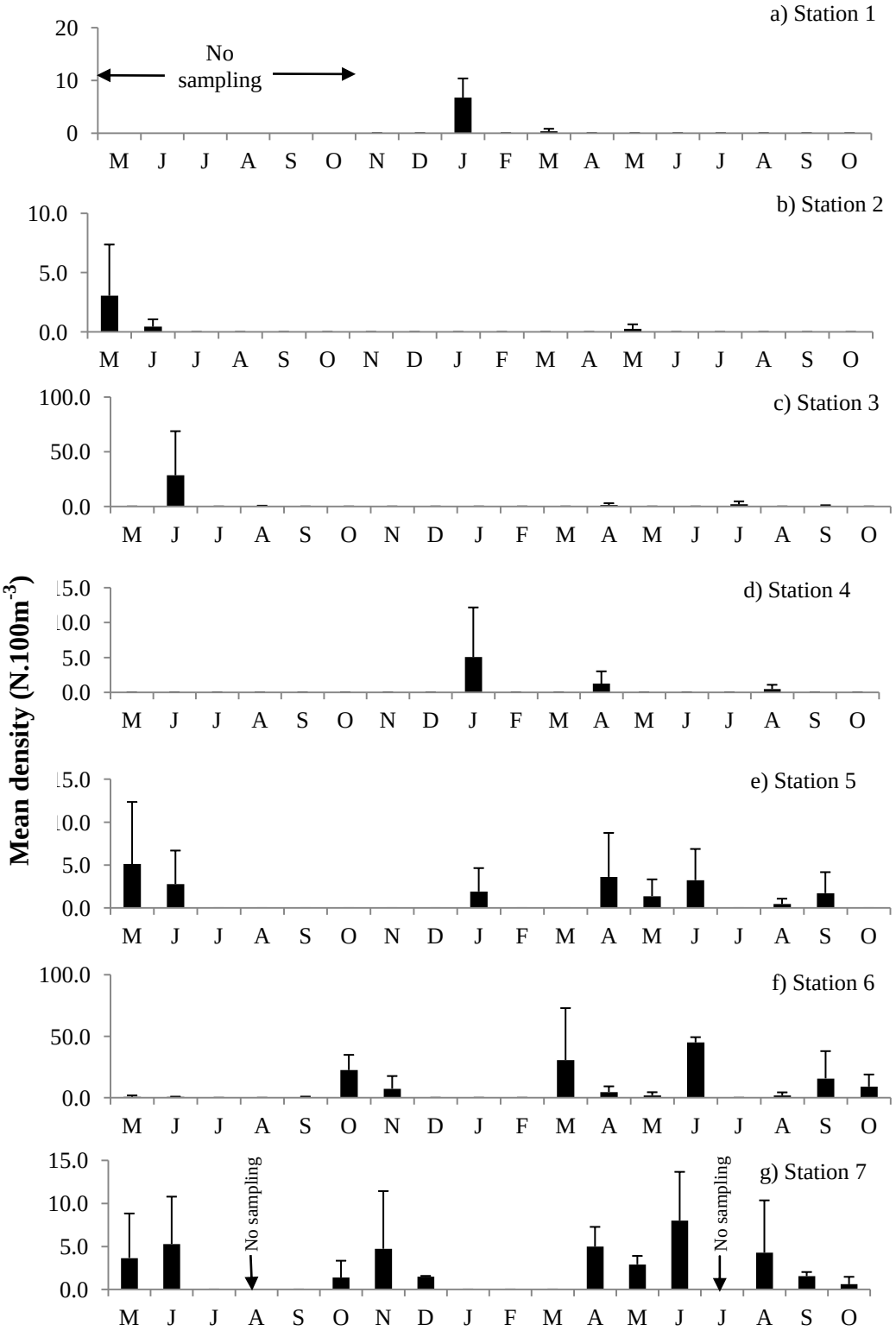

Figure 4.17. Mean density (N.100m^{-3}) of Ambassidae at different stations from May 2002 to October 2003. (Note different scale bar)

Table 4.13. Mean density of Blenniidae from May 2002 to October 2003 in relation to their developmental stages.

Month	Preflexion			Flexion			Postflexion			Total Mean	
	Mean	±SD	%	Mean	±SD	%	Mean	±SD	%	Mean	±SD
May 02	1.7	3	70.8	0.4	0.9	16.7	0.2	0.8	8.3	2.4	3.8
June	5.2	12.7	88.1	0.2	0.6	3.39	0.4	0.9	6.8	5.9	14
July	0.1	0.2	100.0	0	0	0	0	0	0	0.1	0.2
August	2.3	3	92.0	0.1	0.4	4	0.1	0.2	4	2.5	3.2
September	0.8	2.4	100.0	0	0	0	0	0	0	0.8	2.4
October	1.3	1.6	52.0	0	0	0	1.2	3.2	48	2.5	4.6
November	0.9	1.7	90.0	0	0.2	0	0	0.2	0	1	1.7
December	0.3	0.8	100.0	0	0	0	0	0	0	0.3	0.8
January 03	0	0	0.0	0	0	0	0	0	0	0	0
February	0.1	0.3	16.7	0	0	0	0.5	1.2	83	0.6	1.2
March	0	0	0.0	0	0	0	0	0	0	0	0
April	2.2	3.5	81.5	0	0	0	0.5	1.6	19	2.7	3.7
May	0.9	1.8	100.0	0	0	0	0	0	0	0.9	1.8
June	1.2	2.2	92.3	0	0	0	0.1	0.3	7.7	1.3	2.3
July	3.5	7.3	100.0	0	0	0	0.1	0.3	2.9	3.5	7.5
August	3.7	7.8	77.1	0.4	1.2	8.33	0.7	1.9	15	4.8	10.7
September	2.3	3.9	92.0	0	0	0	0.3	0.4	12	2.5	4
October	5.4	17	94.7	0.4	1.1	7.02	0	0	0	5.7	18.1
Total mean	**1.8**	**6**		**0.1**	**0.5**		**0.2**	**1**		**2.1**	**6.7**

Table 4.14. Mean density of Blenniidae at seven stations (1-5: mangrove estuary, 6-7: offshore waters) and *P* value of one-way ANOVA among the stations in relation to their developmental stages.

Developmental		Station							
Stages		1	2	3	4	5	6	7	*P*-level
Preflexion	Mean	0.0	0.8	2.1	2.2	2.9	3.3	0.1	0.17
	±SD	0.2	1.4	4.8	5.2	7.7	10.8	0.4	
Flexion	Mean	0.0	0.0	0.0	0.1	0.1	0.3	0.0	0.19
	±SD	0.0	0.0	0.2	0.7	0.4	0.9	0.1	
Postflexion	Mean	0.0	0.0	0.1	0.7	0.3	0.4	0.0	0.1
	±SD	0.0	0.2	0.3	2.2	0.7	1.2	0.0	
Total	Mean	0.0	0.8	2.3	3.0	3.2	4.0	0.2	0.1
	±SD	0.2	1.4	5.0	7.3	8.5	11.5	0.5	

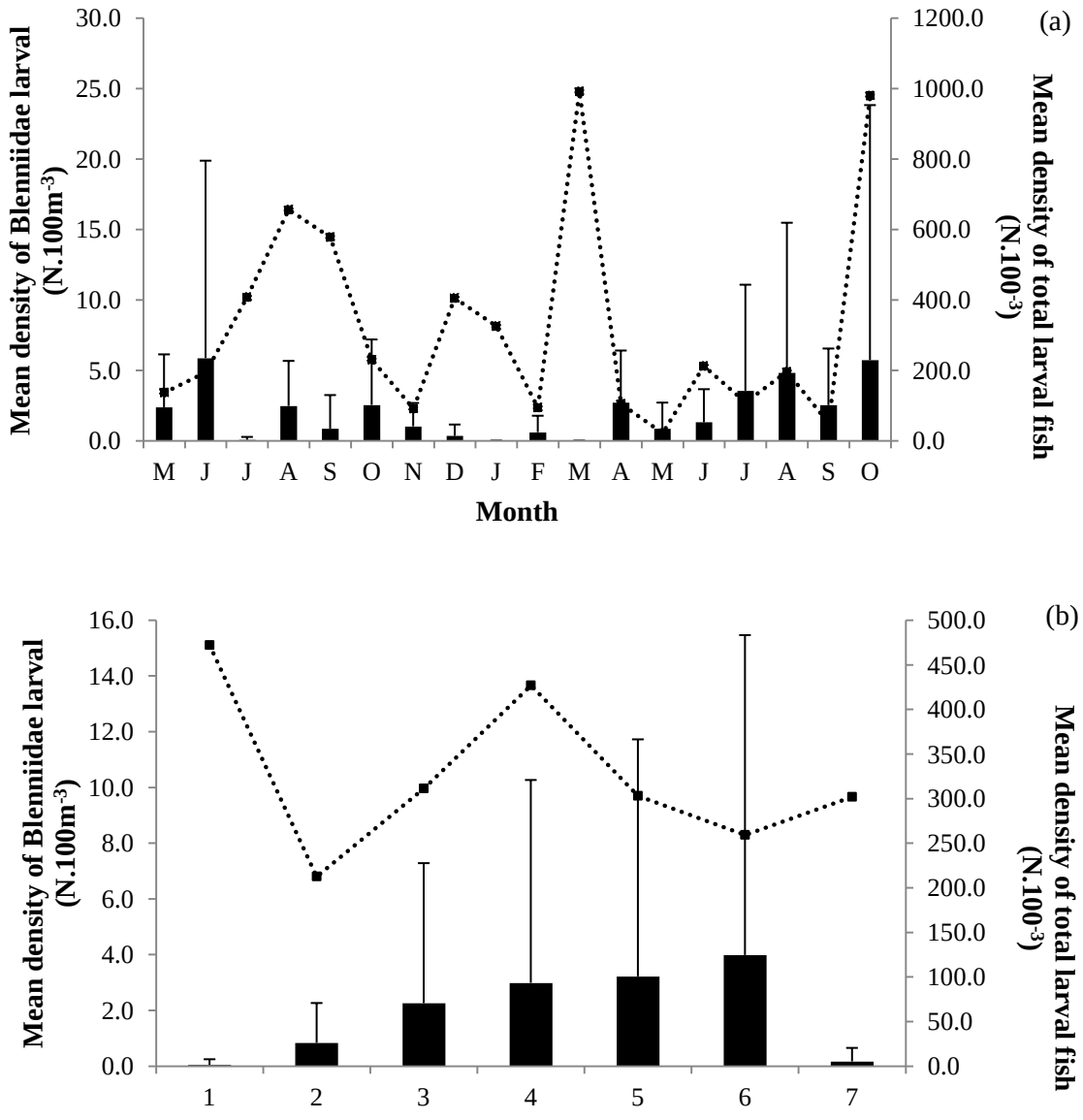

Figure 4.18. Temporal (a) and spatial (b)variations of mean abundances (±SD) of total fish larvae (right vertical axis, dotted line) and larval blenniids (N.100 m^{-3}) (left vertical axis, bar graph) in Matang Mangrove estuary and offshore waters.

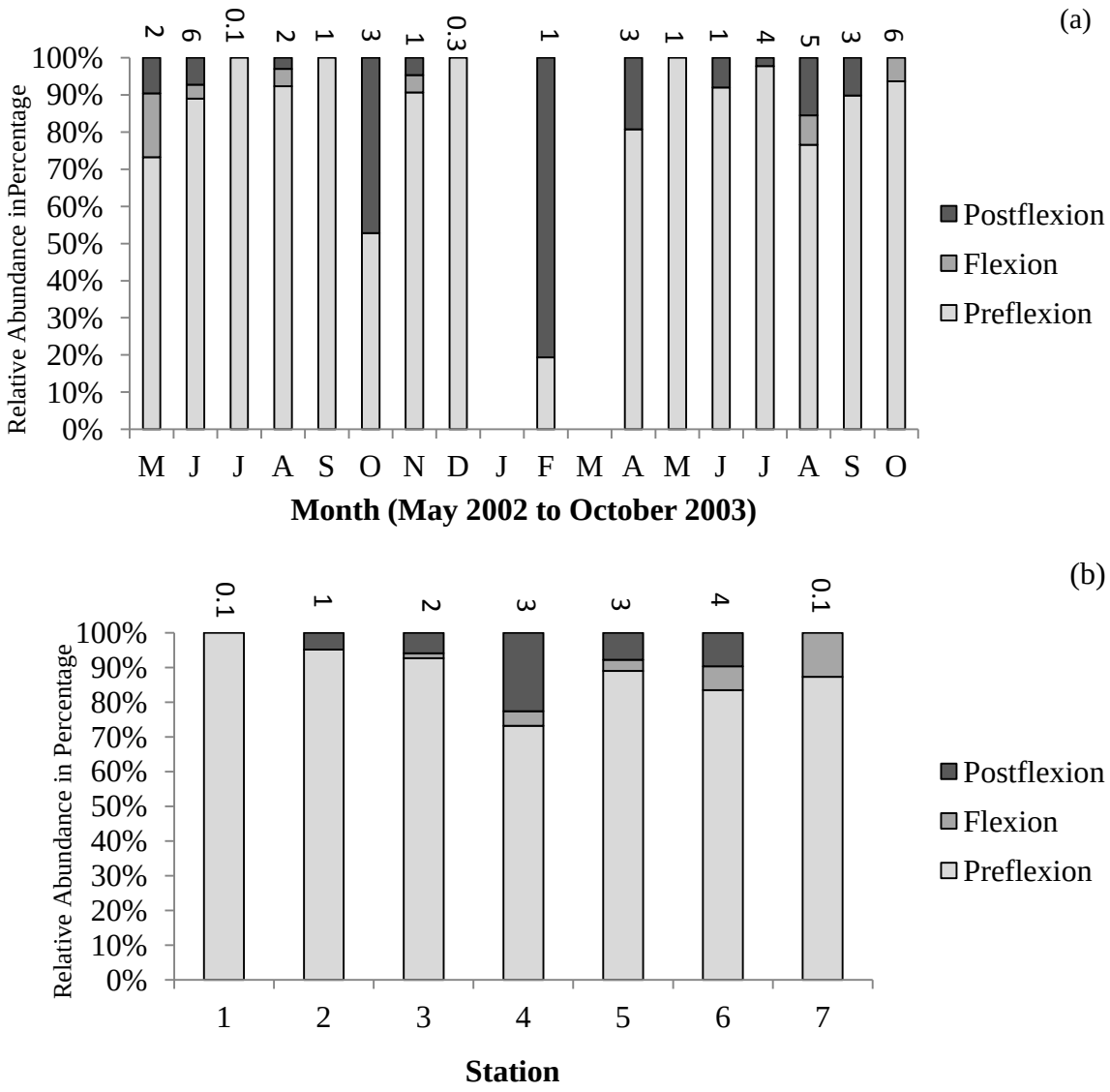

Figure 4.19. Temporal (a) and spatial (b) variations of the relative abundance of Blenniidae by developmental stages in Matang Mangrove estuary and offshore waters. Mean abundance (N.100m^{-3}) at each month and station is indicated.

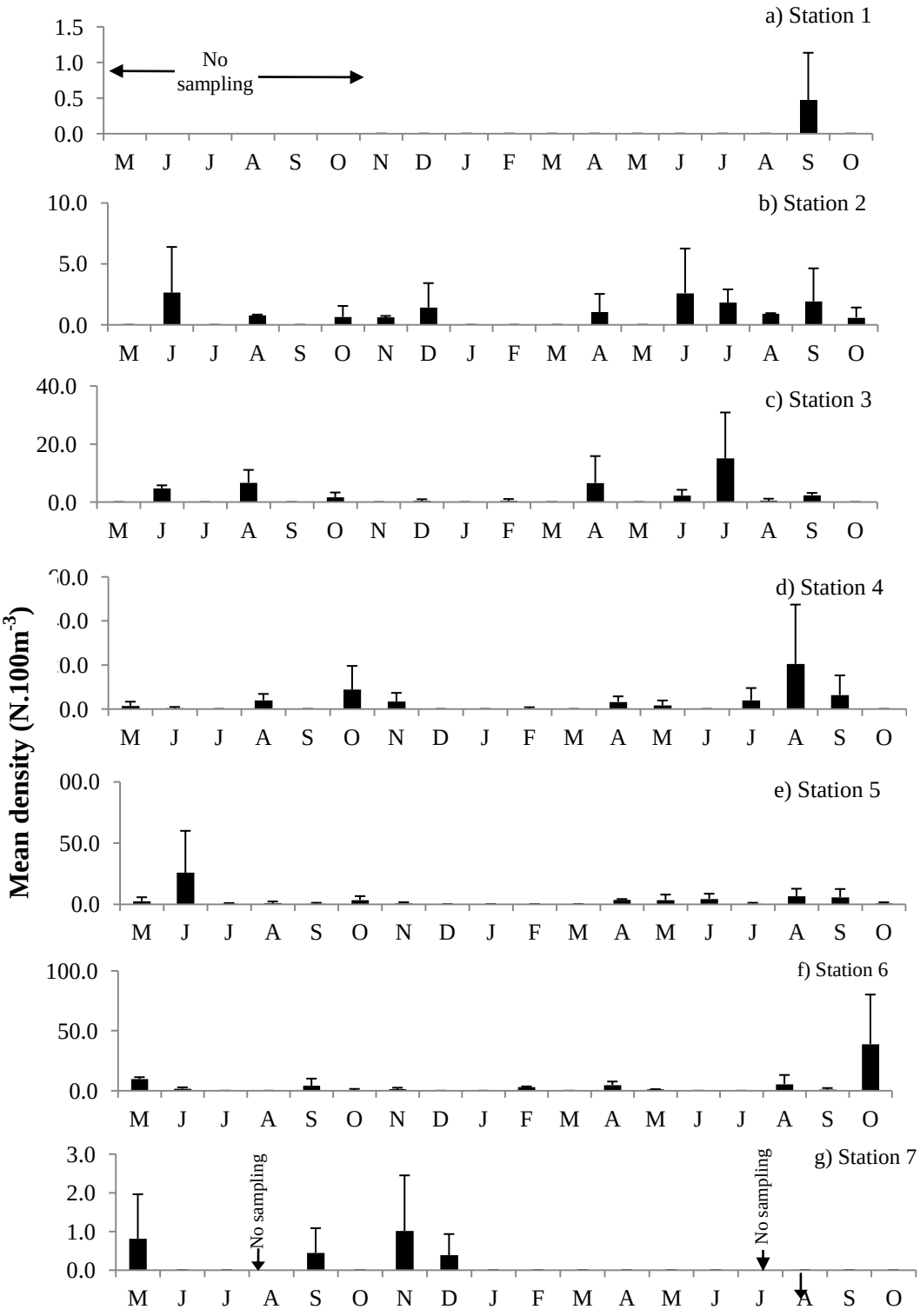

Figure 4.20. Mean density (N.100m^{-3}) of larval Blenniidae at different stations from May 2002 to October 2003. (Note different scale bar)

Blenniids were present at all stations in low numbers but most were encountered from Station 3 to Station 6, with mean density that ranged from 2.3± 5.0 N.100 m^{-3} to 4 ± 11.5 N.100m^{-3} (Figure 4.18b & 4.20). Most larvae were preflexion larvae with percentage more than 70%. The abundance of blenniid increased from Station 1 (inside the mangrove waters) to Station 6 (offshore waters) but it dropped drastically at Station 7 (mean 0.2 ± 0.5 N.100m^{-3}). Abundance of all developmental stages of Blenniidae was not significantly different between the stations ($P > 0.05$).

4.2.3.7 Cynoglossidae

Cynoglossidae larvae were abundant in September 2002 (49.4 ± 47.6 N.100m^{-3}) and October 2003 (43.1 ± 78.4 N.100m^{-3}) at the offshore waters (see Table 4.15, Figure 4.21a). All cynoglossids caught were at the preflexion stage. Cynoglossidae were recorded at all stations except Station 1 and were abundant at the offshore waters, mainly at Station 6 (4.7 ± 20.4N.100m^{-3}) and 7 (10.3 ± 29.3 N.100m^{-3}).

4.2.3.8 Scorpaenidae

Scorpaenidae larvae were found in 6 out of 18 months sampling at the offshore waters, where most were preflexion or yolk-sac stages (Figure 4.21b). It was usually observed in September to December 2002, August and October 2003. Highest density was in October 2003 (7.6 ± 15.2 N.100m^{-3}). In the mangrove estuary, only postflexion stage of Scorpaenidae larvae were found in March 2003 (0.1 ± 0.2 N.100m^{-3}) (Table 4.15).

Table 4.15. Monthly mean density of other fish larval families from May 2002 to October 2003 in Matang mangrove estuary and offshore waters.

Month	Platycephalidae				Scatophagidae				Leiognathidae				Bregmacerotidae			
	Mangrove		Offshore		Mangrove		Offshore		Mangrove		Offshore		Mangrove		Offshore	
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
May 2002	0.00	0.00	0.00	0.00	0.64	1.50	0.20	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
June	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.42
July	0.00	0.00	0.17	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.34
August	0.00	0.00	0.00	0.00	0.07	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
September	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
October	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
November	0.00	0.00	0.00	0.00	0.07	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
December	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
January 2003	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.23	0.00	0.00	0.00	0.00	0.00	0.00
February	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
March	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.39	0.00	0.00	0.06	0.19	0.00	0.00
April	0.00	0.00	0.00	0.00	0.07	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
June	0.00	0.00	0.20	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
July	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
August	0.00	0.00	6.03	9.79	0.00	0.00	0.23	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.51
September	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
October	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.65	0.00	0.00	0.00	0.00	0.00	0.00
All Groups	**0.00**	**0.00**	**0.37**	**2.49**	**0.04**	**0.35**	**0.02**	**0.15**	**0.02**	**0.19**	**0.00**	**0.00**	**0.004**	**0.05**	**0.05**	**0.19**

Table 4.15 (Continued)

Month	Cynoglossidae				Scorpaenidae				Syngnathidae				Carangidae			
	Mangrove		Offshore		Mangrove		Offshore		Mangrove		Offshore		Mangrove		Offshore	
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
May 2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.64	0.78	0.19	0.39	0.00	0.00	0.00	0.00
June	0.00	0.00	1.67	1.47	0.00	0.00	0.00	0.00	0.18	0.34	0.00	0.00	0.28	0.39	6.91	10.48
July	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.76	0.00	0.00	0.00	0.00	0.00	0.00
August	0.17	0.32	0.45	0.63	0.00	0.00	0.00	0.00	0.38	0.71	0.00	0.00	0.00	0.00	0.50	0.71
September	1.43	2.79	49.39	47.59	0.00	0.00	3.60	5.18	0.55	1.03	0.00	0.00	0.32	0.91	0.00	0.00
October	0.35	0.99	4.19	4.67	0.00	0.00	1.04	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
November	0.00	0.00	0.32	0.37	0.00	0.00	0.18	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
December	0.00	0.00	2.40	3.52	0.00	0.00	0.30	0.41	0.25	0.71	0.00	0.00	0.00	0.00	0.00	0.00
January 2003	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.27	0.00	0.00	0.00	0.00	0.00	0.00
February	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.22	0.00	0.00	0.00	0.00	0.00	0.00
March	0.00	0.00	2.56	1.59	0.06	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
April	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
June	0.00	0.00	0.17	0.34	0.00	0.00	0.00	0.00	0.08	0.26	0.00	0.00	0.00	0.00	0.40	0.80
July	0.18	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.60	0.00	0.00	0.00	0.00	0.00	0.00
August	0.10	0.33	19.01	19.19	0.00	0.00	3.75	6.44	0.33	0.70	0.23	0.45	0.00	0.00	0.00	0.00
September	0.09	0.27	1.15	2.30	0.00	0.00	0.00	0.00	0.08	0.24	0.00	0.00	0.00	0.00	0.00	0.00
October	0.15	0.46	43.15	78.43	0.00	0.00	7.60	15.20	0.88	1.43	0.00	0.00	0.00	0.00	0.00	0.00
All Groups	**0.13**	**0.71**	**7.20**	**24.80**	**0.004**	**0.05**	**0.96**	**4.17**	**0.23**	**0.62**	**0.02**	**0.14**	**0.03**	**0.22**	**0.44**	**2.74**

Table 4.15 (Continued)

Month	Mullidae				Terapontidae				Triacanthidae				Trichonotidae			
	Mangrove		Offshore		Mangrove		Offshore		Mangrove		Offshore		Mangrove		Offshore	
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
May 2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
June	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
July	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
August	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
September	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
October	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
November	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
December	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
January 2003	0.00	0.00	0.00	0.00	0.16	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
February	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
March	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
April	0.07	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.37
May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
June	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
July	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
August	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.45	0.00	0.00	0.00	0.00
September	0.00	0.00	0.23	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
October	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
All Groups	**0.004**	**0.06**	**0.01**	**0.11**	**0.01**	**0.12**	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**	**0.11**	**0.00**	**0.00**	**0.01**	**0.09**

Table 4.15 (Continued)

Month	Mugilidae				Unidentified				Total			
	Mangrove		Offshore		Mangrove		Offshore		Mangrove		Offshore	
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
May 2002	0.00	0.00	0.00	0.00	0.11	0.30	4.14	4.85	156.71	120.08	96.46	82.67
June	0.00	0.00	0.00	0.00	0.08	0.22	4.68	8.38	203.11	202.95	176.89	83.22
July	0.00	0.00	0.00	0.00	1.39	2.38	1.70	2.96	574.58	284.27	74.53	42.41
August	0.00	0.00	0.00	0.00	3.73	9.16	1.00	1.41	638.74	502.95	726.27	317.17
September	0.00	0.00	0.00	0.00	0.11	0.32	3.68	3.95	592.52	393.94	549.21	327.28
October	0.00	0.00	0.00	0.00	0.31	0.88	0.54	1.08	224.48	390.64	239.92	149.19
November	0.00	0.00	0.15	0.30	0.00	0.00	0.66	0.96	92.24	126.75	89.15	108.10
December	0.00	0.00	0.00	0.00	0.50	1.42	4.70	6.68	314.13	394.85	550.06	403.74
January 2003	0.00	0.00	0.00	0.00	0.11	0.34	0.00	0.00	439.23	514.64	40.65	57.91
February	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	131.26	333.53	11.13	6.84
March	0.00	0.00	0.00	0.00	0.80	1.08	18.40	23.91	1247.08	1053.22	353.37	349.91
April	0.00	0.00	0.00	0.00	0.08	0.26	0.47	0.59	67.63	49.39	197.77	116.82
May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	21.72	31.55	22.45	19.43
June	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.36	41.00	76.10	639.48	779.12
July	0.00	0.00	0.00	0.00	0.73	2.30	2.33	3.30	86.36	104.29	221.44	200.97
August	0.00	0.00	0.00	0.00	0.00	0.00	1.80	1.56	107.11	103.17	417.82	253.29
September	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.62	39.41	47.10	74.90	61.64
October	0.00	0.00	0.00	0.00	0.67	2.13	3.69	6.49	1054.19	1539.27	793.32	1346.68
All Groups	**0.00**	**0.00**	**0.009**	**0.07**	**0.45**	**2.29**	**2.78**	**7.32**	**331.97**	**616.59**	**286.29**	**443.09**

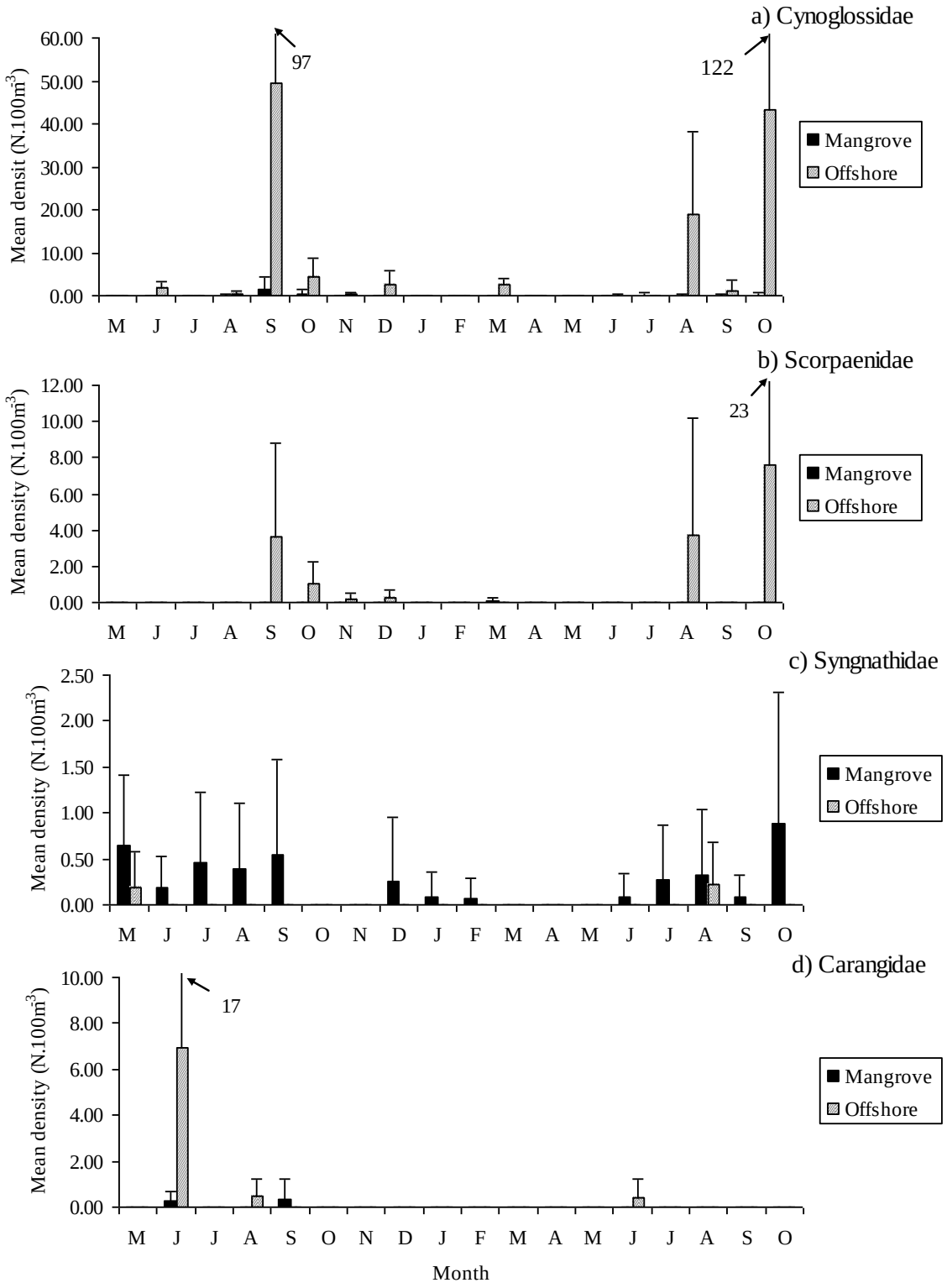

Figure 4.21. Monthly mean density of larval a) Cynoglossidae, b) Scorpaenidae, c) Syngnathidae and d) Carangidae in Matang mangrove estuary and adjacent offshore waters.

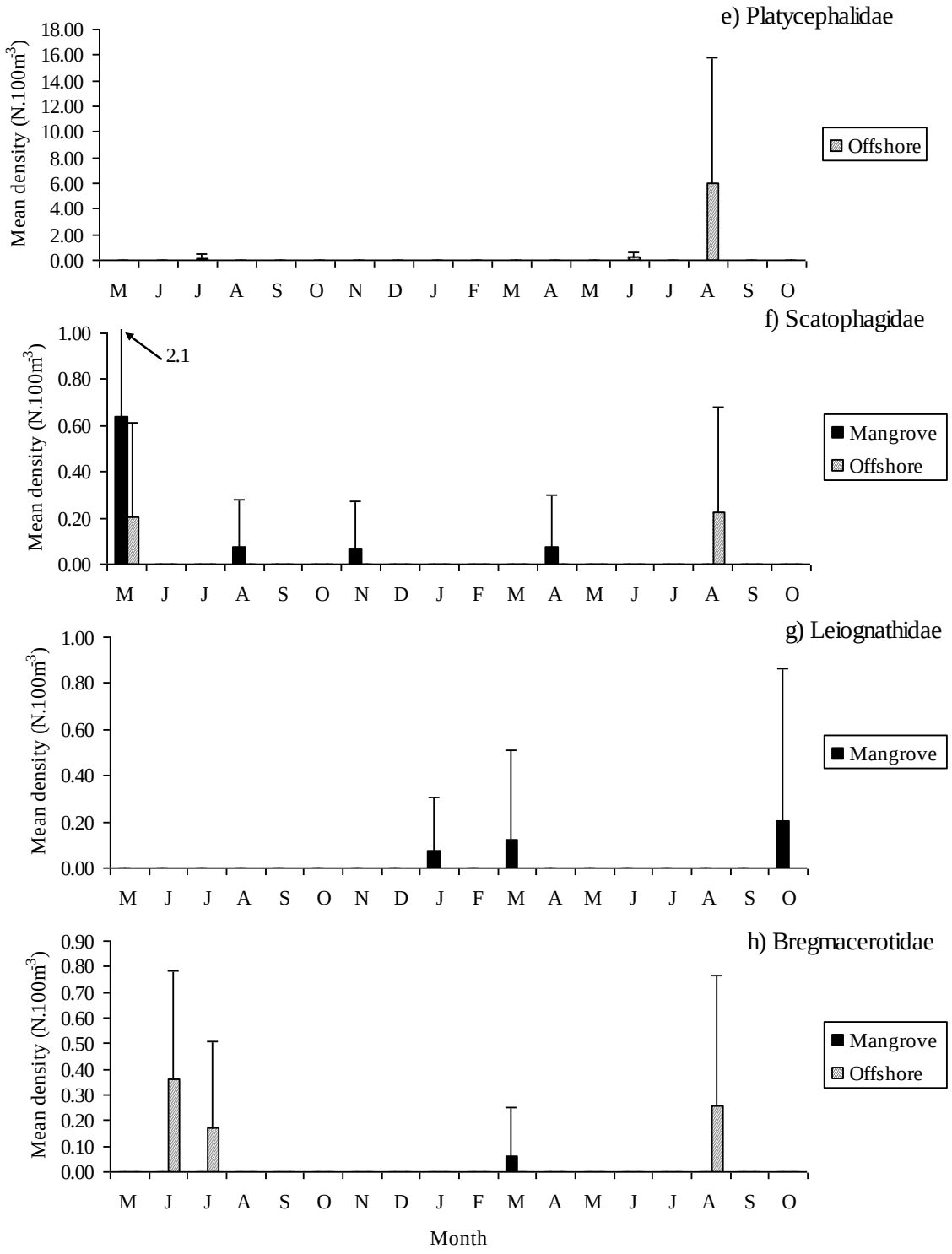

Figure 4.21. **(continued)**. Monthly mean density of larval e) Platycephalidae, f) Scatophagidae, g) Leiognathidae and h) Bregmacerotidae in Matang mangrove estuary and adjacent offshore waters.

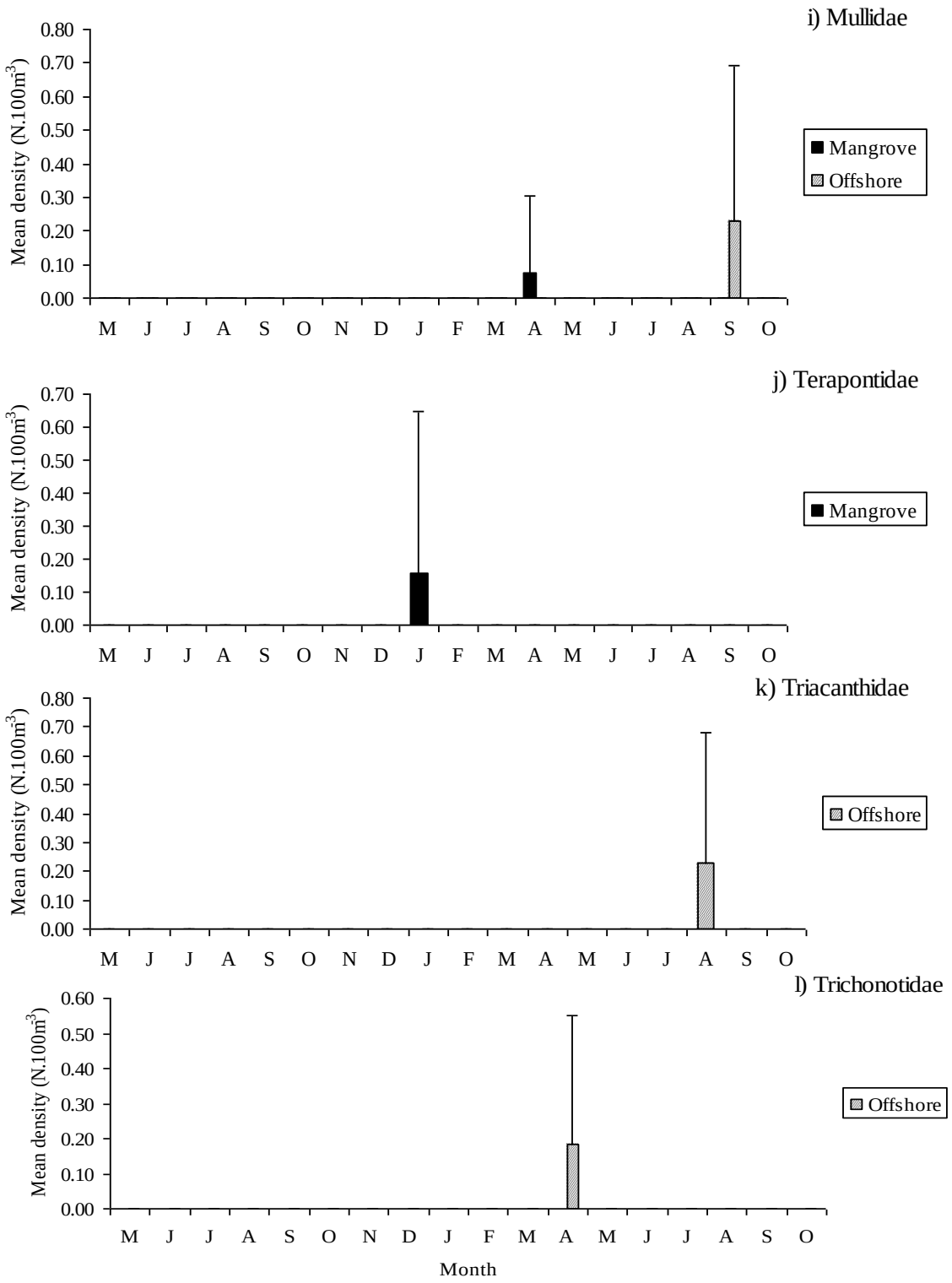

Figure 4.21. **(continued)**. Monthly mean density of i) Mullidae, j) Terapontidae, k) Triacanthidae and l) Trichonotidae in Matang mangrove estuary and adjacent offshore waters.

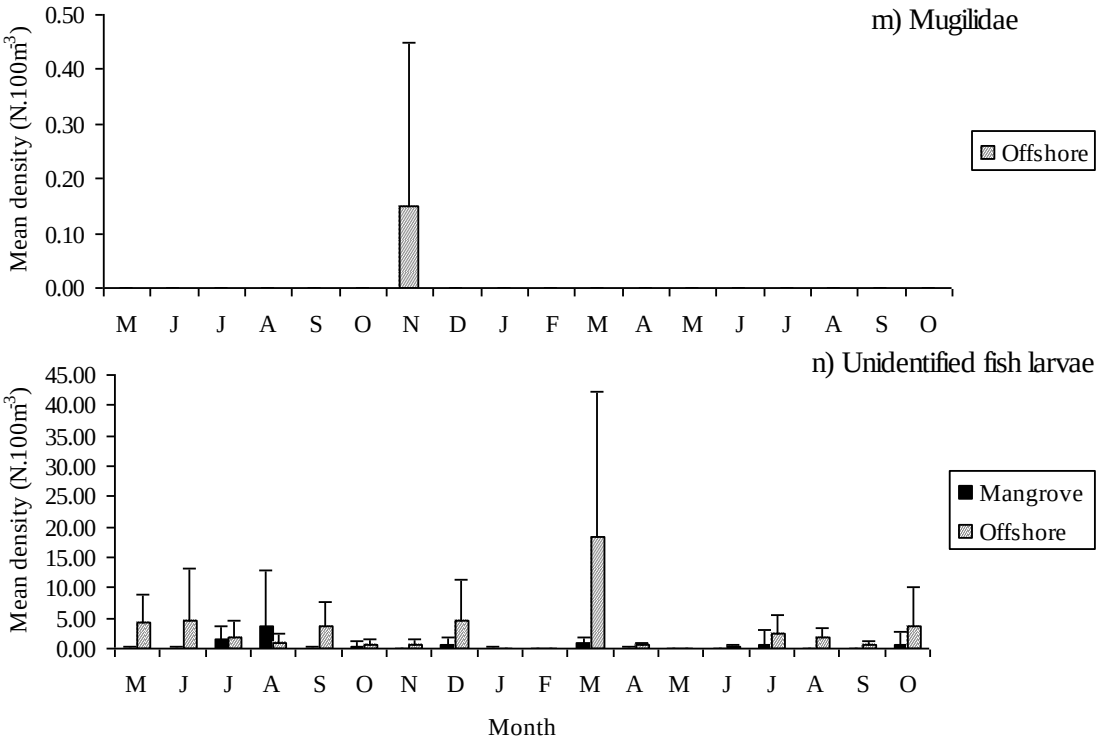

Figure 4.21. **(continued)**. Monthly mean density of larval m) Mugilidae and n) unidentified fish larvae in Matang mangrove estuary and adjacent offshore waters.

4.2.3.9 Syngnathidae

Highest density of larval Syngnathidae was in October 2003 (0.9 ± 1.4 N.100m^{-3}), occurring mainly in the mangrove estuary (Table 4.15, Figure 4.21c). They usually consisted of posflexion and juvenile stages. Around 85% of Syngnathidae caught were pipefishes (probably *Ichthyocampus carce*). The remaining were seahorses (*Hippocampus trimaculatus*). In the offshore waters, only juvenile Syngnathidae were recorded in May 2002 and August 2003.

4.2.3.10 Carangidae

Juveniles of Carangidae were only recorded at June and September 2002, with densities of 0.3 ± 0.4 N.100m^{-3} and 0.3 ± 0.9 N.100m^{-3} respectively, in the mangrove estuary (Figure 4.21d). Carangids were found at all stations except Station 1. In the offshore waters, carangids were caught in June, August 2002 and June 2003. Most of the Carangidae were preflexion stage in offshore areas except in June 2002 (6.9 ± 10.5 N.100^{-3}) where juveniles were found.

4.2.3.11 Platycephalidae

Platycephalidae larvae were only found in offshore waters in July 2002, June and August 2003 (Figure 4.21e). Preflexion platycephalid were found in June and August 2003, with highest density recorded in June 2003 (6.0 ± 9.8 N.100^{-3}). In July 2002, only postflexion larvae were recorded (0.17 ± 0.34 N.100^{-3}).

4.2.3.12 Scatophagidae

Scatophagidae larvae (*Scatophagus argus*) were found in the mangrove waters in May, August, November 2002 and April 2003. In the offshore waters, Scatophagidae was

only recorded in May 2002 and August 2003 (Figure 4.21f). All scatophagid found in this study were at postflexion stage.

4.2.3.13 Leiognathidae

Leiognathidae larvae were recorded inside the mangrove waters, only in Station 3 and 4. They were only caught in January, March and October 2003 which mainly consists of postflexion larva. Highest density was recorded in October 2003, 0.2 ± 0.7 $N.100^{-3}$ (Figure 4.21g).

4.2.3.14 Bregmacerotidae

Bregmacerotidae larvae were caught in the offshore waters in June, July 2002 and August 2003, which mostly consisted of preflexion larvae (Figure 4.21h). In the mangrove waters in Station 1, preflexion Bregmacerotidae were also recorded with density of 0.06 ± 0.19 $N.100m^{-3}$ in March 2003.

4.2.3.15 Mullidae

Flexion stages of Mullidae were found in Station 1 in April 2003. At the offshore waters, preflexion mullids were caught in September 2003 in Station 6 (Figure 4.21i).

4.2.3.16 Terapontidae

Two juveniles of *Terapon theraps* were caught in January 2003 inside mangrove estuary at Station 4 (Figure 4.21j).

4.2.3.17 Triacanthidae

Only one Triacanthidae larva was found during this study, at offshore waters (Station 6) in August 2003 (Figure 4.21k).

4.2.3.18 Trichonotidae

Trichonotidae larva was only found in April 2003 at Station 7 in this study, with density of 0.18 ± 0.37 N.100m^{-3} (Figure 4.21l).

4.2.3.19 Mugilidae

Preflexion mugilids (*Liza* spp.) was found in offshore waters (Station 7) in November 2003. Their mean density recorded was 0.15 ± 0.30 N.100m^{-3} (Figure 4.21m).

4.2.3.20 Unidentified fish

Mean density of unidentified fish larvae in the mangrove estuary ranged from 0.08 ± 0.22 N.100m^{-3}to 3.7 ± 9.2 N.100m^{-3}. In the offshore waters, mean density of unidentified fish larvae ranged from 0.18 ± 0.36 N.100m^{-3}to 18.4 ± 23.9 N.100m^{-3}. Most of the unidentified fishes could be those from marine species as higher density was from the offshore waters (Figure 4.21n).

4.3 DISCUSSION

4.3.1 Larval Fish Assemblages

The number of ichthyoplankton families in the Matang mangrove system was 19 but four families, Gobiidae, Engraulidae, Clupeidae and Sciaenidae, cumulatively made up 97.5% of the total larval abundance. This indicated that species diversity was uneven. Some rarely caught families accounted for less than 1% of the total larvae. No fresh water fish larvae were collected in this study as the lowest mean salinity encountered was 15‰ which was likely to be too high for freshwater species. Most freshwater fish species are not capable of osmoregulating in salt water and tend to be found in estuaries only when salinities decline to very low levels during periods of heavy freshwater discharge (Potter & Hyndes, 1999). The low diversity of ichthyoplankton has been

similarly reported in other estuarine larval fish populations around the world. For example, 25 families (54 taxa) were identified in North Brazilian mangrove creeks (Barletta-Bergan et al., 2002a, b), 26 families (56 taxa) in Sabah and Sarawak estuaries, Malaysia (Blaber et al., 1997) and 25 families in the mangrovecreeks of East Africa (Little et al., 1988).

The mean total fish densities of 22 to 1,247 N.100m^{-3} in Matang estuary obtained from the present study was comparable to those reported in the estuaries of Sabah and Sarawak which ranged from 3 to 920 N.100m^{-3} (Blaber et al., 1997). In an east African mangrove creek, the mean total fish larvae ranged from 120 to 200 N.100m^{-3} (Little et al., 1988), while in the St. Lucia estuary of KwaZulu, Natal (South Africa), the fish larvae density ranged from 15 to 1,003 N.100m^{-3} (Harris & Cyrus, 1995). In an estuary in Lima, Portugal, mean abundance was 8 N.100m^{-3} (Ramos et al., 2006). In general, the number of larval fish taxa and their densities between these studies at different system varied greatly. This may be due to differences in sampling methods, sampling gear, sampling time, habitat heterogeneity and the level of positive larval identification. Furthermore, each estuarine system may have a different abiotic environment (Blaber, 1997) which contributed to the different densities.

The present study showed that the spatial rather than temporal factor had contributed more to the differences in larval fish assemblage structure as was also reported by Kuo et al. (1999) and Robertson and Duke (1990a). The ANOVA results indicated that 60% of the total variability in families was due to spatial differences while the temporal (month) differences accounted for 25%. Although the distance between the river mouth and the nearest offshore station was short (8 km), fish assemblages and their ontogenetic stages were quite distinct between the mangrove

estuary and offshore waters. The variations in larval tolerance to different physical, chemical and biological factors, as well as their nursery habitat requirements (Kuo et al., 1999; Peters et al., 1998) could have resulted in the observed spatial differences. Seasonality was the most general feature observed among the different parameters used to study larval fish assemblage as reported in other studies (e.g. Whitefield, 1989; Loneragan & Potter, 1990; Barletta-Bergan et al., 2002a; Young & Potter, 2003). In general, differences between seasons are more pronounced than between years. The seasonal variations in water characteristics in the spawning area have an important influence on the spawning activity (Lam, 1983).

Number of larval fish species of the Matang mangrove estuary was lower as compared to the adjacent coastal waters, whereas larval abundance was generally higher inside the estuary (see Appendix 4.1). The larval fish assemblage was more diverse in the coastal waters due to presence of marine species. The higher larval abundance was attributable to the consistently abundant Gobiidae which are typical estuarine residents that include the familiar mudskippers. Gobiid larvae are likely to dominate estuarine waters because they form the most speciose family of estuarine and marine fishes (Nelson, 2006) and have a relatively long larval phase of approximately 40 days (Thresher, 1984). Gobiids were also well correlated to the morphological and physiological adaptations in inter-tidal habitats (Barletta et al., 2000). Their reproductive strategy by producing demersal eggs could reduce mortality risk which is associated with uncontrolled dispersal of eggs and early larvae out of the estuary. Some oxudercine gobies like *Periophthalmodon schlosseri* constructs burrows in the substrata of high intertidal zone and transport air for storage in its burrow (Ishimatsu et al., 1998). This adaptation enables reproduction of gobiid in the hypoxic mudflat substratum. Gobiid larvae also known to have high dispersal potential where they remain adrift in

ocean currents for about 3 weeks (Taylor & Hellberg, 2003). In the present study, gobiid larvae of all ontogenetic stages were found throughout the mangrove estuary, indicating their use of the mangrove estuary as feeding, spawning as well as nursery ground. Other larval studies have recorded similar findings, for examples, Little et al. (1988) recorded 69% gobiids in an East African mangrove creek, while in the Lupar and Lassa estuaries of Sarawak (Malaysia), gobiids constituted 38% and 34% respectively (Blaber et al., 1997). Kuo et al. (1999) reported 18 species of Gobiidae which was identified as the most diverse family in the mangrove creeks of the western coast of Taiwan. Ikejima et al. (2003) recorded 18 species of juvenile Gobiidaein a mangrove creek with high mud-component in Trang Province, Thailand. In Matang waters, 13 species of juvenile and adult gobies have so far been recorded (Chong, 2005; Then, 2008).

4.3.2 Recruitment

Recruitment into the nursery ground is generally species specific. The present study showed different peak abundances from different fish larval families.Then (2008) recorded three major recruitment fish periods into the MMFR estuarine habitats where certain marine species enter and utilize the estuary as feeding and nursery grounds. Highest peak of young juvenile fishes were recorded between January-February during Northeast monsoon period. The next highest abundance occurred between April-May while a minor peak of young fishes was between July-August. However, there was a time lapse between first entry into the estuary and point of capture (Then, 2008). Hence, the nursery recruitment seasons in Matang estuaries are likely to occur a few months prior to the observed peaks when the fishes enter as larvae or young juveniles.

In this study, two abundance peaks were observed in Gobiidae; in March and October. They were mainly consisted of preflexion larvae. Peak abundance of residual yolk-sac and preflexion gobiid was also observed during the diel study in November 2003, at the river mouth (refer Chapter 5). In MMFR, these months fall in the Northeast Monsoon period which typically brings the highest rainfall. Pauly & Navaluna (1983) suggested that reproduction and spawning seasons for many of these estuarine-dependant and resident fishes appear to be related to monsoonal events. Peaks in larval abundance also seemed to correlate with peaks in phytoplankton production and biomass (Garcia et al. 2003). During the peak abundance of gobiid in March, phytoplankton production and zooplankton biomass were observed to increase. Gobiidae was found to be ubiquitous atall stations inside the estuary up to theoffshore station (8km from the river mouth). This observation therefore, suggestsspawning season of gobiids occurs in the vicinity of mangrove estuary and nearshore waters during these two months. Recruitment of larvae of this family might have taken place at the same time. Eventhough two significant peaks were observed, their abundance was relatively high in other months, suggesting a long spawning season. Coastal and estuarine teleosts in the tropics are mainly serial spawners with a long spawning season (Longhurst & Pauly, 1987).

The Engraulidae was observed to have greater abundance between May-July and September-November at the furthest station in offshore waters (16 km from river mouth). These periods might be their spawning period. When larvae are near ages of 60-90 days, they started to accumulate in the nearshore zone before taking advantage of the tidal flux to penetrate into the estuary. This observation was well explained by the study carried out by Sarpedonti (2000). Sarpedonti (2000) reported two periods of recruitment of juvenile engraulids (three months after spawning): main one between

July-October and secondary period around February-March. Higher preflexion larvae between June to December would suggest higher postflexion larvaein October-January in the mangrove estuary (see Figure 4.7), suggesting recruitment and retainment of them in the mangrove estuary. *Stolephorus baganensis*, a common Engraulidae species found in MMFR spawns in clear, deeper coastal waters and moves towards shallower, more turbid waters at approximately 1.0 cm SL. *Thryssa kammalensis* spawns in shallow turbid waters in the estuary and remains there before migrating seawards to their maturation ground (Sarpedonti, 2000). Residency periods of these marine species within the estuaries could be a year or more (Robertson & Blaber, 1992). Clupeids have a coastal spawning pattern (Ré et al. 1990) and arelargely restricted to the mouth portion of estuaries as a result of tidal transport of coastal water from adjacent coastal areas. In this study, clupeid was not restricted to offshore waters but observed along the estuary. Nevertheless, highest abundance was caught at the furthest offshore station. This area might be their spawning area as most larvae were at the preflexion stage.

Some species of euryhaline fishes such as Sciaenidae may spawn inside the estuary and adjacent coastal waters. Their larvae are exported outside to the adjacent coastal waters or into the estuary irrespective of their developmental stage. This explained the presence of preflexion larvae in both the estuary and adjacent coastal waters. Based on field observation, juvenile sciaenids are also found abundant in the coastal mudflats of the MMFR. The overall high salinity of the estuary (> 20 ‰) could be the possible explanation to this observation. Yap (1995) reported that *Johnius carouna* and *J. weberi* spawned only once between July and September in Matang mangrove estuary. This observation was consistent with this study where greatest abundance of sciaenids was recorded in September 2002. This peak could be those of *Johnius carouna* and *J. weberi*. Out of the 14 species of sciaenids recorded from

Matang mangrove estuary, 11 species have also been found in offshore waters (Chong, 2005; Then, 2008). Their year-round presence could be due to their dietary flexibility for which Yap et al. (1994) had recorded monthly dietary changes involving 12 prey taxa for seven major sciaenid species occurring in Matang estuary waters.

In a tropical estuary environment, factors that stimulate reproductive activity are less understood. This could be due to the great variety of abiotic and biotic influences of marine, estuarine and freshwater origins that merged in this environment. The type of adult spawning seems to influence fish larva location. As a general pattern, larvae hatched from demersal eggs are located nearer to the adult habitat than those hatched from pelagic eggs (Brogan, 1994; Borgers et al., 2007). The results from the present study agree with this general observation. Preflexion larvae of pelagic spawners (i.e. Engraulidae, Sciaenidae) were found to be dispersed along the coastal waters. However, the Gobiidae was found inside the estuary, being a resident there. Blaber (2000) suggested that the resident species usually consist of small species and exhibit a wide variety of reproductive strategies. Ramos et al. (2006) found that some resident species of Gobidae and Ammodytidae produced demersal eggs in the upper reaches of the estuary that could adapt to an estuarine environment.

Although some fish recruitment periods are related to monsoonal seasons, the actual regulatory factors responsible for fish recruitment process are still not well understood (Boehlert & Mundy, 1988). The recruitment process of offshore spawners is a two-stage process which firstly depends upon factors regulating offshore planktonic environment and secondly, upon estuarine factors related to tidal fluxes, that may act as a zeitgeber (Boehlert & Mundy, 1988). Spawning and recruitment seasons in other estuaries have been related to input of freshwater (Staunton-Smith et al., 2004), algal

bloom (Warlen et al., 1998), synergistic influence of both water temperature and salinity gradients (Allen & Barker, 1990) and upwelling effects (Ben-Tzvi et al., 2007).

A study has hypothesized on the ontogenetical control of fish behavior and distribution (Sarpedonti & Chong, 2008). Segregation of fish larvae in relation to their biological and morphological characteristics is explained by sudden changes in body segments and organ growth (Sarpedonti, 2000) that govern individual ecological preference (Simonovic et al., 1999).

Then (2008) found that the nursery recruitment for many species is continuous over a few months or even year round. In this study, few peaks were observed for different fish larval families. Thus, the ongoing production and continuous arrival of larvae and young juveniles into estuaries is thought to be a survival strategy to reduce competition for resources among taxa (Allen & Barker, 1990) and at the same time also act as buffer to possible short term adverse fluctuations in the abundance of suitable planktonic larval foods. Spawnings usually occurs at a time when environmental conditions are most favourable for larval survival (Blaber, 2000).

4.3.3 Mangrove Estuary as Nursery Area

Sasekumar et al. (1994a) however, reported that 87% of the fishes in Matang mangrove waterways and 83% in adjacent mudflats were sexually immature or juveniles; from this, they suggested that the mangrove estuary plays a bigger role as nursery ground than as a spawning ground. The present study showed the importance of the mangrove estuary as nursery site for marine migrants especially the Engraulidae, Clupeidae and Ambassidae that enter the estuary at predominantly the postflexion and postlarval stages. The engraulid *Stolephorus baganensis* is a multiple spawner, spawning all year

round in clearer and relatively deep coastal waters (Sarpedonti & Chong, 2008). Their postflexion larvae (ca. 10 mm SL) then move towards the shallower and more turbid waters where they remain until the juvenile stage (three month old). Sasekumar et al. (1994) also observed a similar migration pattern for another engraulid species, *Thryssa kammalensis,* which move into Matang estuary as early juveniles. Their upstream migration and their residency in the estuary had been viewed as a migratory behaviour that enhances juvenile survival (Blaber, 1997).

The present study substantiates the importance of the mangrove estuaries as nursery area for marine euryhaline species (76% of estuarine fish population) which seek mangroves mainly at the juvenile stage (Chong, 2005). Blaber (2000) reported very few marine euryhaline that migrate into estuaries to spawn. Few exceptions include certain species of Mugilidae, Ariidae, Sciaenidae, Ambassidae and Dasyatidae (Chong, 1977; Singh, 2003; Yap, 1995). Nonetheless, larval absence in the water despite actual spawning may be due to post-spawning behavior as displayed by most ariids whereby male practices oral or buccal incubation of spawned eggs until a time when the young are released once capable of active feeding (Rimmer & Merrick, 1982). Adult ovoviviparous stingrays (*Himantura walga*) caught in the mangrove estuary have been observed to bear young in their uterus (personal observation). On the other hand, while larval Blenniidae were caught during the present study, previous studies in the mangrove estuary had never reported any juvenile or adult blennies. Adult blennies were not caught perhaps due to their burrowing or benthic nature and/or their close association with reefs, pilings or tidal pools. Inside the mangrove forest floor, some species of *Omobranchus* hide in the crevices of dead branches and logs and among mangrove roots (H. Larson, personal communication). Adult Cynoglossidae are benthic and are found mostly on the continental shelf over sandy and muddy bottoms. In this

study, their larvae were generally found more abundant in the offshore waters. Nevertheless, some study reported that the common flatfishes in Guaratuba Bay in Brazil spawn in mangrove areas and complete their life cycle within the estuarine area (Chaves & Vendel, 1997). All carangid found in this study were juveniles. This is consistent with the findings of Blaber & Cyrus (1983), where almost all carangids found in tropical estuarine waters are juveniles or sub-adults. The adults are usually marine and the spawning of most species takes place in deeper water. Sarpedonti et al. (2008) reported seven species of carangids in a mangrove creek in Brazil. The highest diversity of carangids however, contrasted with their low abundance. It is suggested that larva scarcity might be the result of high larval mortality rate and dispersal during driftingof larvae from offshore spawning group to coastal estuarine nursery ground.

In this study, 89% occurrences of Syngnathidae were recorded in mangrove estuary. This shows that some species of pipefish and seahorse (Syngnathidae) are utilizing the mangrove estuary as nursery area. Interestingly, there was no adult syngnathid recorded in previous studies in MMFR. This could be due to the lack of seagrasses and marine algae distributed in mangrove estuary. Adult sygnathids might be found at offshore waters beyond 16 km from the river mouth. The seahorses and pipefishes larvae were not abundant in MMFR. They were probably introduced into mangrove estuary by drifting vegetation driven by currents or coming from river upstream.

Most of Bregmacerotidae larvae observed in this study were from offshore waters, where the larvae might be utilizing planktonic crustacean as food sources especially copepods whichfound high in abundance at nearshore waters (Chew & Chong, 2011). Only one species from this family was identified in the offshore waters

of MMFR which is *Bregmaceros mcclellandi* (Then, 2008). Some fish larvae that were scarce (<1%), for example Terapontidae, Trichonotidae, Triacanthidae, Mullidae, Mugilidae, Platycephalidae were probably brought inside the mangrove estuary by offshore currents and tidal flux. This might suggest that these fish larvae used the Matang mangrove estuary as a temporary habitat.

4.3.4 Disconnection between Juvenile Fish Assemblage and Existing Larval Fish Populations

Various studies of juvenile and adult fish fauna in the Matang estuary have so far yielded 53 families (Table 4.16), while the present larval study recorded only 19 families. A more recent study of juvenile fishes conducted over a period of 4 years from 2006 to 2010 in the Matang coastal mudflats has yielded 77 identified species and 20 unidentified species (Chong et al., 2012). This big discrepancy in numbers clearly shows that the juvenile fish assemblage is quite disconnected from the existing larval fish populations in the mangrove estuary as well as nearshore waters. The study suggests that except for those species that spawn in upstream waters and those with non-planktonic larvae, many of the euryhaline species that visit the mangrove estuaries and nearshore waters are likely to spawn farther offshore (i.e. beyond 16 km) in marine waters. Quinn and Kojis (1985) recorded a similarly low number of species from the Labu estuary, Papua New Guinea (PNG), and suggested that the diversity of the mangrove ichthyofauna is not directly related to the diversity of the coastal waters in spite of the fact that PNG lies within the Indo-Malayan region which supports the highest diversity of reef fishes. Larval assemblages in an island mangrove habitat in the Carribean were significantly different from continental mangrove habitats which substantially had more estuarine species (Dennis, 1992). Most island habitats predominantly consists of coral fish species.

A study carried out during an expedition in the Straits of Malacca vis-a-vis in the waters of Jarak Island, Sembilan Island and Perak Island revealed more families of fish larvae in just 5 days of sampling (personal observation). A total of 24 fish larval families were recorded where the most abundant families were from Carangidae, Engraulidae, Gobiidae and Siganidae. However, the waters around the islands were not as rich in fish larvae (23-32 N.100m^{-3}), as compared to the more open waters along the Straits of Malacca. In a sampling along a transect from Pangkor Island toPerak Island, fish larval density ranged from 38 – 274 N.100m^{-3}. This observation suggests that even though the offshore areas comprised of higher diversity of fish larvae as compared to the mangrove estuary but in terms of abundance, mangrove estuary yielded more fish larvae than the open sea.

In offshore waters, Liew (1992) found that even though mangroves, estuaries and coral reefs are often documented as important nursery and spawning grounds for certain fishes, a large proportion of the commercially important fishes in Malaysian waters use the offshore habitats extensively. This included the commercially important groups like carangid and nemipterid larvae. In another survey conducted in the Exclusive Economic Zone (West Coast of Peninsular Malaysia) for six days in March 1998, 31 fish larval families were identified. The most dominant families were Gobiidae, Bregmacerotidae, Leiognathidae, Engraulidae and Bothidae (Rosdi et al., 2001). Another survey carried out from Pulau Langkawi to Port Klang along the Straits of Malacca concluded that Engraulidae, Bregmacerotidae, Gobiidae, Carangidae and Scombridae were the dominant fish larval families (Abdul Haris & Muhammd Faisal, 2006). They also observed that the density of fish larvae was higher near shore compared to offshore waters.

Table 4.16. Life history stages of fish families in estuaries of Matang Mangrove Forest Reserve, and adjacent coastal waters, Malaysia.

No.	Family	Mangrove estuary			Offshore (<16km)		
		[*]Larvae	[b]Juvenile	[a,b]Adult	[*]Larvae	[b]Juvenile	[b]Adult
1	Ambassidae	•	•	•	•	•	•
2	Apistidae			•			
3	Ariidae		•	•		•	•
4	Bagridae		•	•			
5	Batrachoididae		•	•			
6	Belonidae	•		•	•		
7	Blenniidae	•			•		
8	Bregmacerotidae	•			•	•	•
9	Callionymidae		•	•			
10	Carangidae	•	•	•	•	•	•
11	Centropomidae		•	•			
12	Chanidae			•			
13	Cichlidae		•				
14	Chirocentridae			•			
15	Clupeidae	•	•	•	•	•	•
16	Cynoglossidae	•	•	•	•	•	•
17	Cyprinodontidae			•			
18	Dasyatidae		•	•		•	•
19	Drepanidae		•	•		•	•
20	Eleotridae		•	•		•	•
21	Elopidae			•			
22	Engraulidae	•	•	•	•	•	•
23	Ephippidae					•	•
24	Gerreidae		•	•			
25	Gobiidae	•	•	•	•	•	•
26	Haemulidae		•	•		•	•
27	Hemiramphidae	•		•			
28	Hemiscylliidae					•	•
29	Latidae		•	•			
30	Leiognathidae	•	•	•		•	•
31	Lobotidae					•	•
32	Lutjanidae		•	•		•	•
33	Megalopidae		•	•			
34	Mugilidae		•	•	•	•	•
35	Mullidae	•	•	•	•	•	•
36	Muraenesocidae		•	•		•	•
37	Ophichthidae					•	•
38	Paralichthyidae		•				
39	Platycephalidae		•	•	•	•	•
40	Plotosidae		•	•		•	•
41	Polynemidae		•	•		•	•
42	Pristigasteridae		•	•		•	•
43	Scatophagidae	•	•	•	•	•	•
44	Sciaenidae	•	•	•	•	•	•
45	Scombridae		•			•	•
46	Scorpaenidae	•	•	•	•	•	•
47	Serranidae		•	•		•	•
48	Sillaginidae		•	•			
49	Siganidae		•	•		•	•

Table 4.16(continued)

50	Soleidae			•			
51	Sphyraenidae		•	•		•	•
52	Stegostomatidae		•	•		•	•
53	Stromateidae			•		•	•
54	Syngnathidae	•			•		
55	Synodontidae		•	•		•	•
56	Terapontidae	•	•	•		•	•
57	Tetradontidae	•	•	•		•	•
58	Toxotidae			•			
59	Triacanthidae		•	•	•	•	•
60	Trichiuridae			•			•
61	Trichonotidae				•		

*This study, [a]Chong (2005) and [b]Then (2008).

The absence of larvae in the water despite the occurrence of actual spawning may be due to post-spawning behavior as displayed by most ariids. The male practices oral or buccal incubation of spawned eggs until such time when the young are capable of active feeding (Rimmer & Merrick, 1982). Some families of fishes not recorded in this study were recruited into the estuary at a larger size. For example, Kiso & Mahyam (2003) reported that *Lutjanus johnii* was continuously recruited into the estuary in Matang mostly at 10-15 cm (SL) and remained there for a year before migrating back to the ocean at 25 cm SL. With increased size, juvenile fish switch to mudflat habitats as their foraging success in mangroves is reduced and the fish become less vulnerable to predators and are able to forage in the relative safety of open mudflats (Laegdsgaard & Johnson, 2001). Larval Blenniidae were caught during the present study, however, previous studies in the mangrove estuary had never reported any juvenile or adult blennies. Adult blennies were not caught perhaps due to their burrowing or benthic nature and/or their close association with reefs, pilings or tidal pools. Some species of *Omobranchus* hide in the crevices of dead branches and logs and among mangrove roots inside the mangrove forest floor (H. Larson, personal communication).

4.4 CONCLUSIONS

The larval fish assemblage in the Matang estuary is generally similar to those found in adjacent offshore waters except for two families. This is due to larval flux between estuary and coastal waters, whereby postflexion larvae or young juvenile of euryhaline migrant species are imported into the estuary, while yolk and preflexion larvae of resident species are exported out of the estuary. Although larval advection into or off the estuary is tidal, the final result of advection appears to be modulated by salinity and turbidity gradients, larval food availability, as well as larval stage and possibly larval behavior. It should be emphasized that there is a very gradual shift between the estuarine and marine conditions in the Matang mangrove estuary, hence rigid categorization is quite difficult. Based on their larval presence, Matang fishes could be classified as follows: (1) Estuarine group, those that utilize the mangrove estuary (including nearshore water) as spawning and nursery ground, e.g. Gobiidae, Syngnathidae and Ambassidae; (2) Marine euryhaline group, those that spawn in the sea but their larvae utilize the estuary and adjacent coastal waters as nursery ground; there are two types, those that (a) enter as larvae, e.g. Engraulidae, Clupeidae and Leiognathidae, Scatophagidae, Terapontidae, Scorpaenidae, Sciaenidae, Blenniidae, Platycephalidae, Carangidae, Mullidae, and (b) enter as juveniles, e.g. Lutjanidae, Serranidae; and (3) Stenohaline group which spawn only in the offshore waters and their larvae may enter the estuary during the dry season, e.g. Cynoglossidae, Bregmacerotidae, Trichonotidae, Triacanthidae.

It is hypothesized that there is a gradient of food abundance from offshore to nearshore that leads to immigrating fish larvae and juvenile in tropical waters. Chew and Chong (2011) found that the copepod abundance in MMFR was higher in near

shore waters compare to offshore waters. Therefore, this could explain the higher density of fish larvae in the mangrove estuary compared to the offshore waters.

CHAPTER 5

DIEL AND LUNAR STUDY

Summary of Important Findings

Fish larval populations occurring at the mangrove estuary's mouth are influenced by rainfall and other environmental parameters. Temperature ($P < 0.01$) and dissolved oxygen ($P < 0.05$) were significantly higher in the wet season, whereas salinity ($P < 0.01$) and pH values ($P < 0.01$) were significantly higher in the dry season. The difference betweenthe surface and bottom water for temperature, salinity, DO and pH during spring tide was not significant as the water was well mixed. During the dry season, Gobiidae, Engraulidae and Sciaenidae were abundant making up 95.1% of the total abundance, while the wet season was dominated by Gobiidae and Engraulidae (97.7%). Density of fish larvae at the river mouth showed no significant difference between top and bottom due to the shallow depth (5.75 ± 0.56 m). Gobiidae were abundant at new moon (NM = 190.3N.100m^{-3}) in wet season. Their high abundance was mainly contributed by the yolk-sac larvae stage indicating the most suitable period for spawning at lower salinity and when tidal inundation was highest at night. High numbers of gobiids were also observed particularly at the end of ebb or flood tide suggesting a strategy adopted at reduced water movement to maintain their position in the estuary. Engraulidae, however, were more abundant at neap tide when the preflexion larvae tended to aggregate at surface water during flood tide. This indicates that engraulid larvae may adopt a strategy for upstream penetration using the tidal current flow. They apparently first gather at near shore waters before migrating into the estuary. Basically most of the larval move in and out the estuary following the flood and ebb tides. At ebb tide, they accumulate at the river mouth staying near the bottom before penetrating the estuary during flood tide. Clupeidae was only recorded in the wet season, while preflexion larvae of Sciaenidae and Leiognathidae were only observed at

neap tide. Such behavioural divergences in larval stages among the families could explain the variability in their abundance during day and night, as well as tidal movement for both drier and wetter period. The results suggest that tidal phase (ebb/flood), dissolved oxygen, diel movement of copepod prey influence the upstream transport of fish larvae into the estuary.

5.1 INTRODUCTION

Successful recruitment and retention of fish larvae in estuaries which function as nursery areas are strategies adopted by the early life stages of many fish species. The ways fish larvae respond to the different hydrographic features (water quality, current velocity, light and wind direction) of an estuary are rather complex. Very few studies were carried out to examine the distribution of fish larvae as influenced by the lunar cycle (e.g. Krumme et al., 2004), tidal cycle (e.g. Joyeux, 1999; Bonecker et al., 2009) and diel cycle (e.g. Garrido et al., 2009). In Malaysia, very few fish larval studies have been carried out concerning any of these factors.

One of the hydrographic features that are important for recruitment of fish larvae into estuary is tidal stream. Larvae use selective tidal stream transport as a mechanism to aid their movement into estuaries. Hence, tidal movement plays a very important role in influencing the position and migration of larvae and juveniles in and out of the estuaries. The tidal movement may also lead to the accumulation of larvae at nearshore waters, before the larvae penetrate into the estuary. Flood tides are known to assist the onshore transport of larvae, while ebb tides have the opposite effect of exporting larvae out of the estuary. Hence, the position of the larva would be the result of the net effect between the two currents (Iles & Sinclair, 1982). Blaber (1987) noted that this ‘saltatory’ mechanism requires the larvae to swim most strongly during the ebbing tide

or in some other way, to try to maintain their position. Then, they rely on the flood tide to move them further upstream. Some estuarine fishes like gobiids, use selective tidal stream transport to export their larvae from the estuary (Ekau et al., 1997).

Most diel studies carried out in the mangrove estuary involves adult fishes (e.g. Ley et al. 2007; Lin & Shao, 1999) but hardly any on fish larvae. The vertical migration of the larvae in the water column has been proposed as a possible mechanism whereby fish larvae are retained in their nursery ground (Fortier & Leggett, 1983; Ré, 1987). Different fish species (e.g. Ahlstrom, 1959) and their ontogenetic stages (Brewer & Kleppel, 1986; Heath et al., 1991) display different vertical distribution ranges and migration patterns. The most common distribution pattern is for fish larvae to remain close to the surface at night (Röpke, 1993).

Apart from seasonal, tidal and diel effects, other physical factors such as salinity, temperature, dissolved oxygen, chemical substances, current velocity are also crucial to the distribution of fish larvae. The magnitude of water parameters such as dissolved oxygen, salinity and turbidity are highly dependent on freshwater inputs as well as the tides. The close link between larval fish abundance and physical environmental variables reflects the ability of the larva to position itself in the water column where conditions are optimal for its growth and survival (Lee et al., 2005).

In the present study, the river mouth was chosen as a sampling station to investigate the movements of larval and juvenile fishes in and out of the estuary. As had been reported by some studies (e.g. Govoni & Pietrafesa, 1994), sampling in a fixed station implies that water with different "vertical structure" may pass through the location which may influence the vertical movement of larvae within the water column.

Several important questions need to be addressed; firstly, to know how drier and wetter season, lunar cycle, tidal phase and the diel cycle would affect the distribution of fish larvae in the estuary (the river mouth). Answers to these questions will further benefit interpretation of strategies adopted by fish larvae in their utilization of estuarine resources. One of the major reasons why the diel study is carried out is the high variability and perhaps rapid recruitment of fish larval into the estuary which could not be detected by using monthly samplings. Therefore, the diel and weekly (lunar phase) samplings are carried out to allow this although only for two months. This is because weekly samplings require a lot of resources, including effort and time, both for field samplings and lab work. Thus, the 24 hour and lunar phase samplings during wet and dry season give more detailed study of what could happen daily and weekly.

The specific objectives of this study are:

1) To determine the diel, lunar and seasonal changes of environmental parameters in the estuary.

2) To determine the effects of season (dry and wet) (see Chapter 2, Section 2.3.4), lunar phase (first quarter, full moon, third quarter, and new moon), depth (surface and bottom), tides (flood and ebb) and light (day and night) on larval abundance.

5.2 RESULTS

5.2.1 Environmental Parameters and Plankton

Eight 24-hour studies following the lunar cycle were carried out in July (dry season) and November 2003 (wet season) at Station 5 which was at the river mouth of Sangga Kecil (see Chapter 2, Figure 2.1). Both dry and wet seasons were determined based on the average rainfall volume. Therefore, July 2003 represented the drier Southwest monsoon season (mean total rainfall 255.5 mm, from May-Oct 2003) and November

2003 represented the wetter Northeast monsoon season (mean total rainfall 531.7 mm, from Nov-Apr 2003), respectively (see Chapter 2, Figure 2.3).

5.2.1.1 Dry Season

Table 5.1 shows the results of a 4-way ANOVA conducted on the water parameters during the dry season as affected by lunar phase [first quarter (1Q), full moon (FM), third quarter (3Q) and new moon (NM)], tide (ebb, flood), depth (surface, bottom) and light (day, night). All water parameters at the different lunar phases differed significantly. Salinity, dissolved oxygen and turbidity were significantly different ($P < 0.01$) between surface and bottom water. Salinity and pH values were significantly different ($P < 0.01$) between ebb and flood tides, as well as day and night.

Temperature in the dry season ranged from 28.5ºC to 31.4ºC and was significantly higher in 3Q ($P < 0.01$). The surface water temperature decreased when night time approached and was lowest at high water slack in the morning (≈ 9 a.m.) (Figure 5.1 a & c). It then increased during daytime where surface temperature was higher than the bottom. Not much difference between surface and bottom temperature was observed during spring tide as the water was well mixed. Post-hoc Newman Keuls test shows that interactions between lunar phase, tide and light were significant. The temperature was significantly higher ($P < 0.01$) during 3Q at night ebb (7.30p.m.-1.30a.m.) (see Appendix 5.1). Mean salinity increased from 1Q to NM. Salinity at the bottom was significantly higher than the surface water during neap tide ($P< 0.01$) (Figure 5.2 a & c). This stratification suggests the occurrence of a temporary 'salt wedge'. In spring tide, minimum (less than 25‰) and maximum (above 30‰) salinities were recorded at low water and high water slack, respectively (Figure 5.2 b & d).

Table 5.1. Mean readings of water parameters (±SD) and summary of 4-way ANOVA in dry season (July 2003) in relation to lunar phase, depth, tidal phase and light.

	Temperature (°C) Mean ±SD	**Salinity (‰) Mean ±SD**	**Dissolved Oxygen (mgL^{-1}) Mean ±SD**	**Turbidity (NTU) Mean±SD**	**pH Mean ±SD**
1.Lunar phase					
First Quarter	29.72 ± 0.68[a]	26.85 ± 0.7[a]	4.67 ± 0.54[a]	102.14 ± 121.09[a]	7.69 ± 0.08[a]
Full Moon	29.72 ± 0.10[a]	27.53 ± 1.18[b]	3.26 ± 0.33[b]	110.63 ± 109.35[a]	7.72 ± 0.18[a]
Third Quarter	30.52 ± 0.72[b]	27.95 ± 0.75[c]	5.16 ± 0.62[c]	24.83 ± 17[b]	7.75 ± 0.08[a]
New Moon	29.88 ± 0.34[a]	29.21 ± 0.61[d]	3.75 ± 0.58[d]	121.5 ± 165.24[a]	7.59 ± 0.09[b]
P-level	< 0.01**	< 0.01**	< 0.01**	< 0.01**	< 0.01**
2. Depth					
Surface	30.03 ± 0.67	27.62 ± 1.23	4.41 ± 1.03	42.37 ± 42.68	7.68 ± 0.13
Bottom	29.91 ± 0.55	28.16 ± 1.1	4 ± 0.73	137.18 ± 151.94	7.7 ± 0.12
P-level	NS	< 0.01**	< 0.01**	< 0.01**	NS
3. Tide					
Ebb	29.92 ± 0.55	28.13 ± 1.05	4.30 ± 0.86	76.95 ± 137.19	7.72 ± 0.12
Flood	30.00 ± 0.68	27.64 ± 1.28	4.12 ± 0.96	102.60 ± 101.69	7.67 ± 0.13
P-level	NS	< 0.01**	NS	< 0.01**	< 0.05*
4. Light					
Night	30.01 ± 0.56	27.63 ± 1.33	4.08 ± 0.9	78.5 ± 94.52	7.65 ± 0.1
Day	29.92 ± 0.66	28.1 ± 1.03	4.32 ± 0.92	99.32 ± 139.46	7.72 ± 0.14
P-level	NS	< 0.01**	NS	< 0.01**	< 0.01**
Interactions					
Lunar x Depth	NS	< 0.05*	< 0.05*	NS	NS
Lunar phase x Tide	NS	NS	NS	NS	NS
Depth x Tide	NS	NS	NS	NS	NS
Lunar phase x Light	< 0.05*	NS	NS	< 0.01**	NS
Depth x Light	NS	NS	NS	NS	NS
Tide x Light	NS	< 0.01**	NS	NS	< 0.05*
Lunar phase x Depth x Tide	NS	NS	NS	NS	NS
Lunar phase x Depth x Light	NS	NS	NS	NS	NS
Lunar phase x Tide x Light	< 0.01**	NS	NS	NS	NS
Depth x Tide x Light	NS	NS	NS	NS	NS
1x 2 x 3 x 4	NS	NS	NS	NS	NS

*Significance at *P*< 0.05, ** significance at *P*< 0.01, NS - no significance; homogenous groups indicated by superscripts a, b, c and d

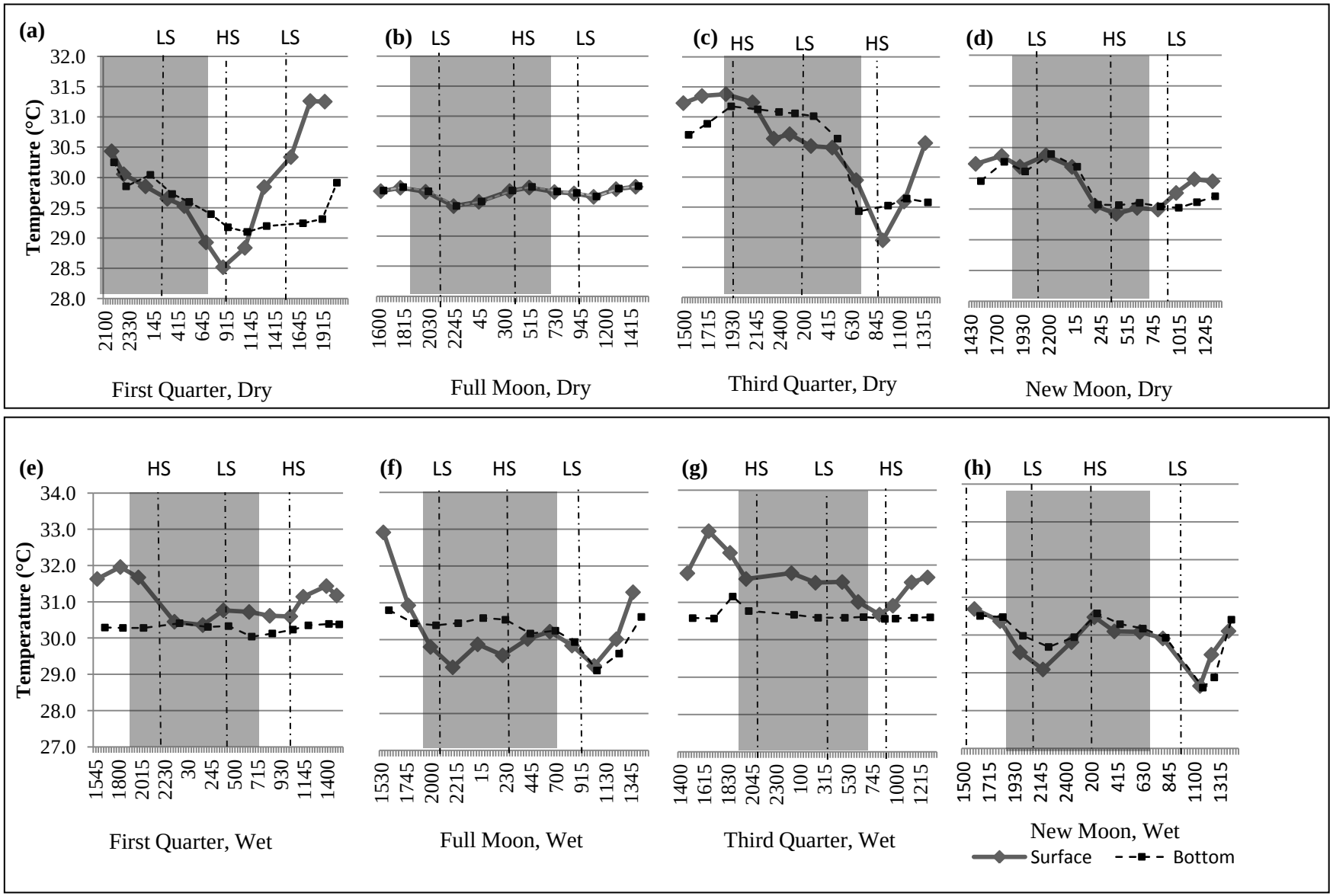

Figure 5.1. Surface and bottom temperature by lunar phase during dry (a-d) and wet (e-h) seasons. LS - low slack; HS - high slack

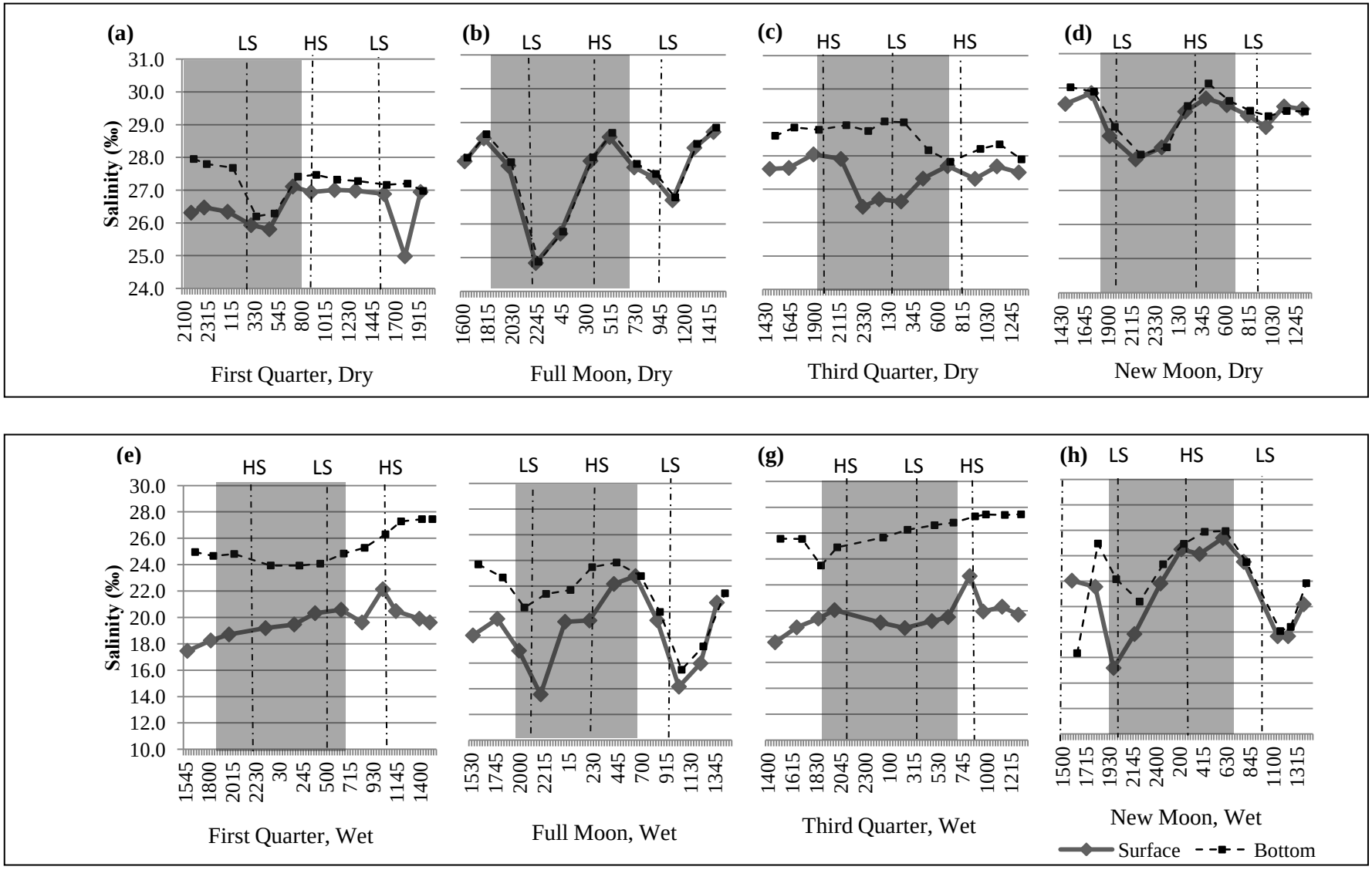

Figure 5.2. Surface and bottom salinity by lunar phase during dry (a-d) and wet (e-h) seasons.LS - low slack; HS - high slack

The mean dissolved oxygen values were recorded with a minimum of 2.5 mgL^{-1} and maximum of 6.3 mgL^{-1} occurring at slack tides, except in 1Q. In 1Q, reverse trend was observed with higher surface DO value (5.7 mgL^{-1}) and lower bottom DO value (3.7 mgL^{-1}) at low water slack in the evening (Figure 5.3a). The phytoplankton density was high at this time (Figure 5.6a). Turbidity was always much higher at the bottom than the surface water, except at 6 p.m. in 1Q, when higher reading was recorded at the surface water (Figure 5.4a). Turbidity reading was observed to be high just before the slack waters. Although no significant difference of turbidity values was recorded between ebb and flood tides, higher values was recorded in flood tides. Both the surface and bottom pH value at all lunar phases except 1Q followed a similar trend as salinity and DO, with higher value during high water slack and lower value at low water slack. During the 1Q, higher surface pH value was observed at low water slack between 1 p.m. to 6 p.m (Figure 5.5a).

As expected, chlorophyll *a* concentration was lower at night time compared to day time. Peak phytoplankton activity was usually in the late afternoon. Higher zooplankton was observed at night time ($P < 0.05$) and bottom water ($P < 0.05$). Total zooplankton biomass was significantly lower in new moon (Table 5.2). At FM, zooplankton biomass at the bottom water was observed to be very high (3.62 gm^{-3}) (Figure 5.6 b), contributing to the observed high turbidity at that time.

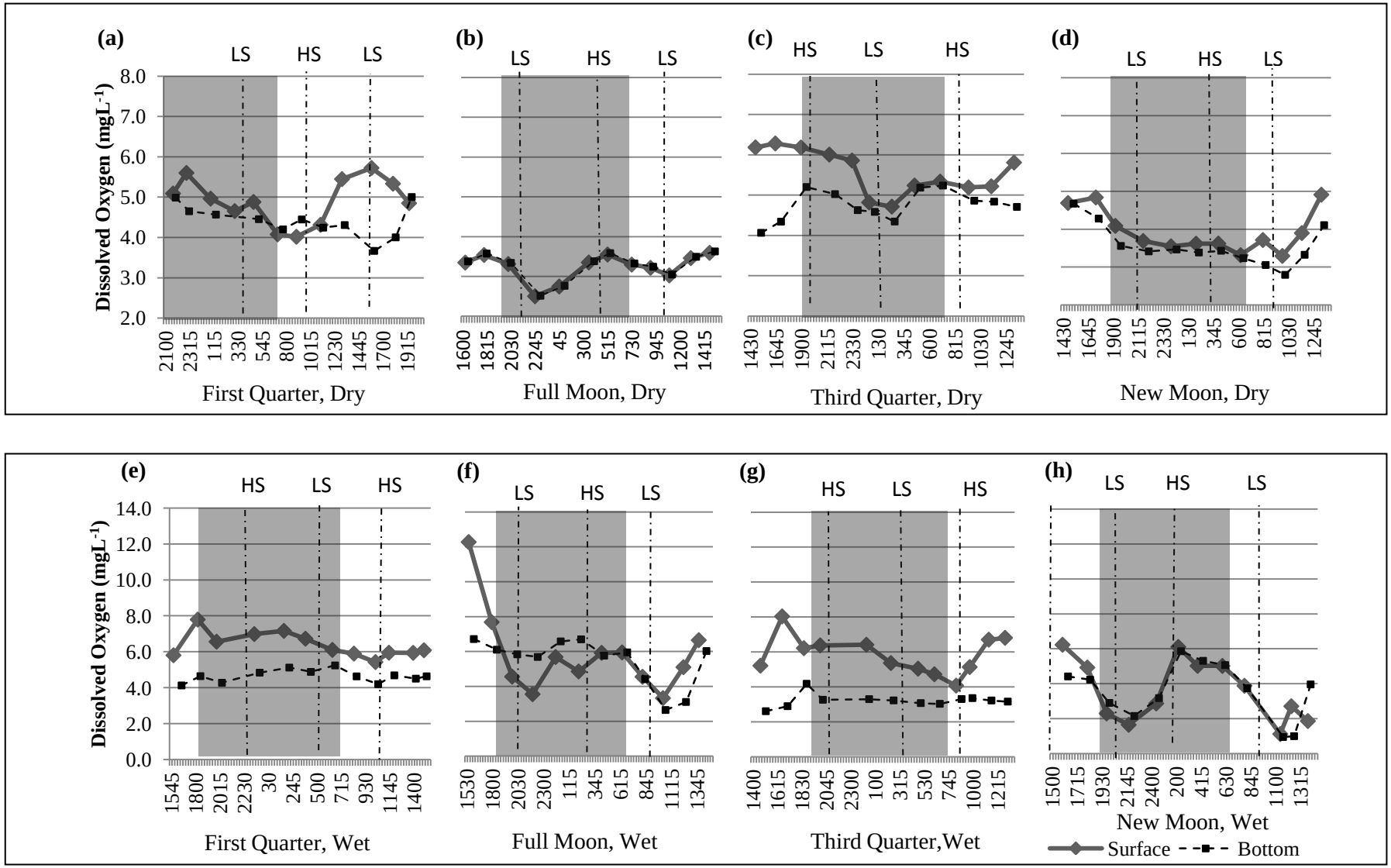

Figure 5.3. Surface and bottom dissolved oxygen by lunar phase during dry (a-d) and wet (e-h) season. LS - low slack; HS - high slack

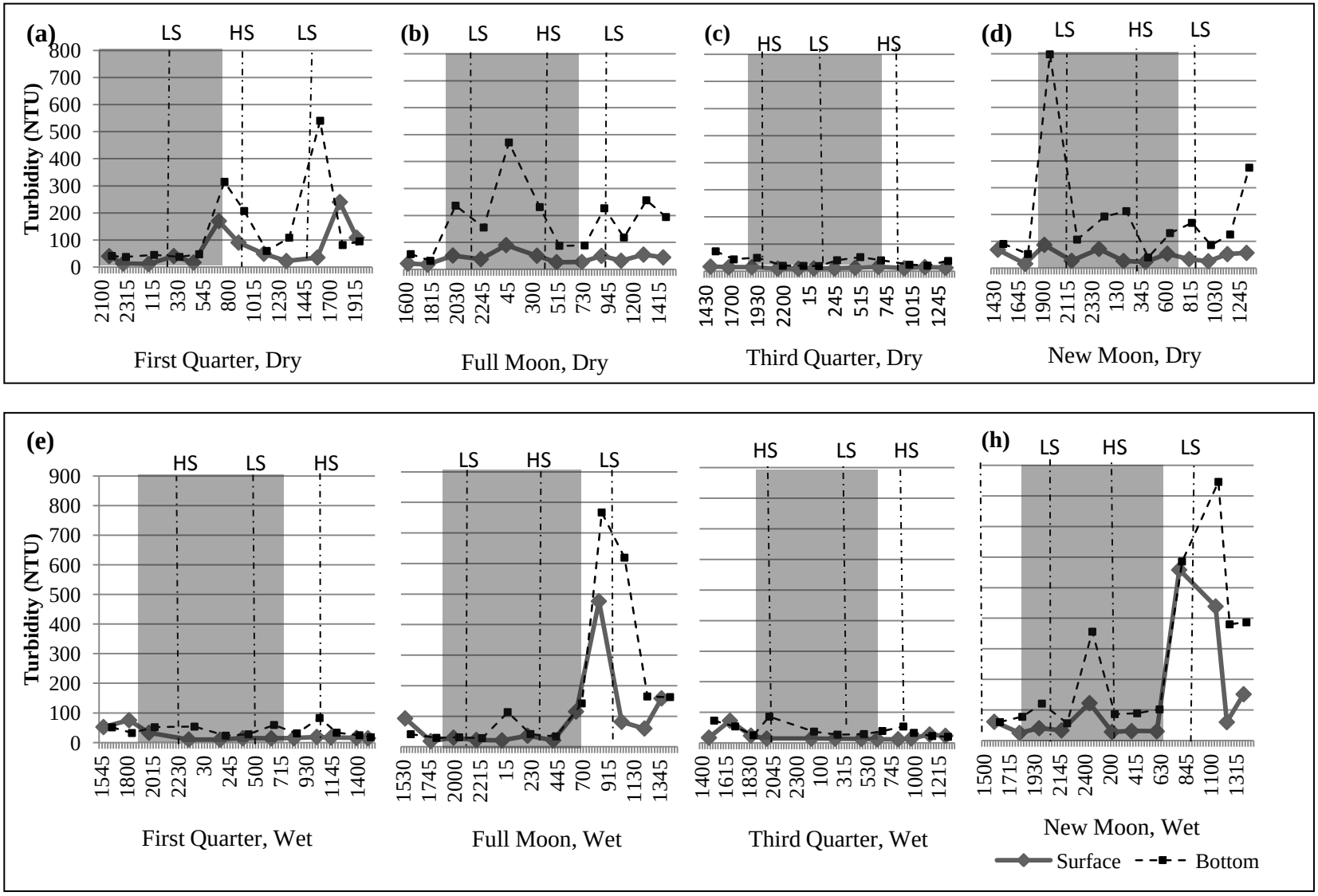

Figure 5.4. Surface and bottom turbidity by lunar phase during dry (a-d) and wet (e-h) season. LS - low slack; HS - high slack

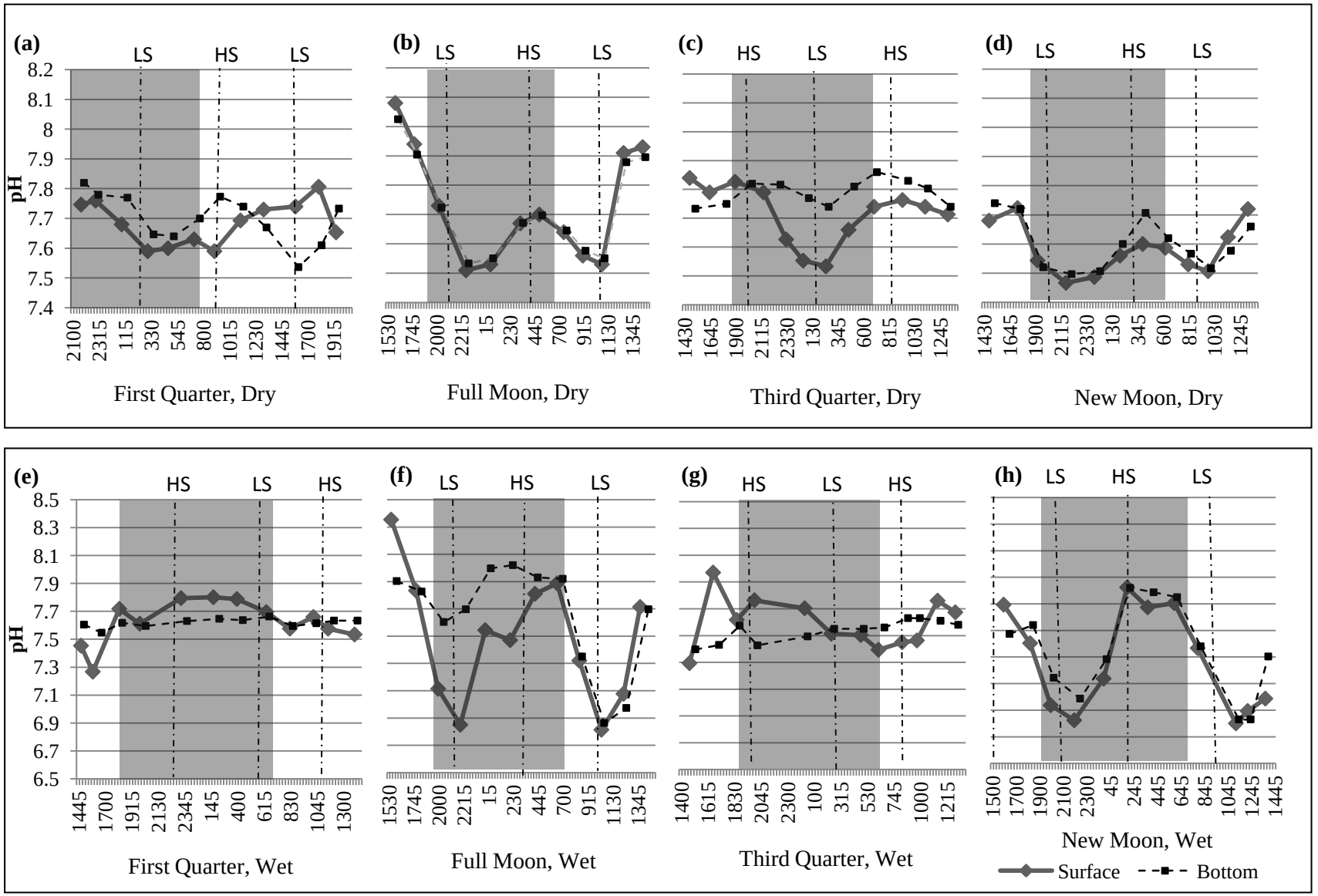

Figure 5.5. Surface and bottom pH by lunar phase during dry (a-d) and wet (e-h) season. LS - low slack; HS - high slack

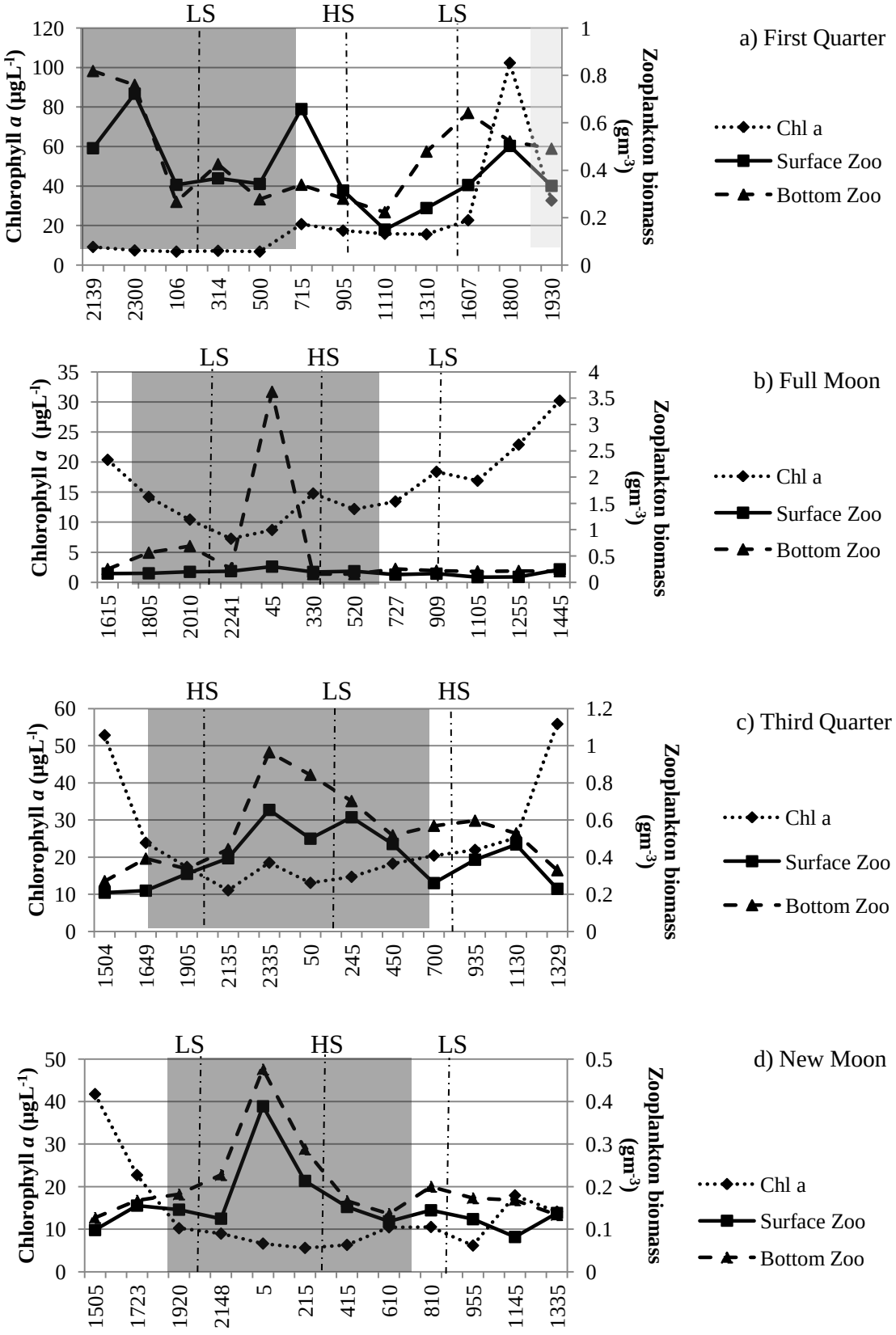

Figure 5.6. Fluctuations of surface chlorophyll *a* and zooplankton biomass (surface and bottom) at different lunar phase during dry season.LS - low slack; HS - high slack

Table 5.2. Mean values of chlorophyll *a* and zooplankton biomass recorded in dry season for each effect (lunar phase, depth, tidal phase and light). Summary of 3-way ANOVA results on chlorophyll *a* and 4-way ANOVA on zooplankton biomass of different fractions are shown.

	Chlorophyll *a* (μgL^{-1})	**Zooplankton Biomass (gm^{-3})**			
		>500 µm	**250-500 µm**	**125-250 µm**	**Total**
	Mean ±SD	**Mean ±SD**	**Mean ±SD**	**Mean±SD**	**Mean ±SD**
Overall mean	18.93 ± 16.41	0.1559 ± 0.2581	0.1163 ± 0.1019	0.0911± 0.0908	0.3632 ± 0.3890
1. Lunar phase					
First Quarter	22.06 ± 26.51[a]	0.0783 ± 0.0599[a]	0.1554 ± 0.0916[a]	0.1964 ± 0.0839[a]	0.4300 ± 0.1812[a]
Full Moon	15.81 ± 6.48[a]	0.1734 ± 0.4544[a,b]	0.1182 ± 0.1620[a,b]	0.0839 ± 0.0948[b]	0.3755 ± 0.7035[a]
Third Quarter	24.42 ± 14.60[a]	0.2854 ± 0.1777[b]	0.1265 ± 0.0589[a,b]	0.0551 ± 0.0267[b,c]	0.4670 ± 0.1957[a]
New Moon	13.44 ± 10.31[b]	0.0864 ± 0.0660[a]	0.0650 ± 0.0188[b]	0.0291 ± 0.0173[c]	0.1804 ± 0.0899[b]
P-level	< 0.01**	< 0.01**	< 0.05*	< 0.01**	< 0.05*
2. Depth					
Surface	18.93 ± 16.41	0.1128 ± 0.1137	0.0910 ± 0.0565	0.0797 ± 0.0797	0.2835 ± 0.1650
Bottom	—	0.1989 ± 0.3434	0.1415 ± 0.1284	0.1026 ± 0.1001	0.4330 ± 0.5154
P-level	—	NS	< 0.05*	NS	< 0.05*
3. Tide					
Ebb	17.26 ± 11.30	0.1351 ± 0.1579	0.1202 ± 0.0793	0.0945 ± 0.0882	0.3498 ± 0.2307
Flood	20.61 ± 20.42	0.1767 ± 0.3299	0.1123 ± 0.1212	0.0877 ± 0.0940	0.3767 ± 0.5022
P-level	NS	NS	NS	NS	NS
4. Light					
Night	10.21 ± 3.91	0.2600 ± 0.3707	0.1266 ± 0.1365	0.0935 ± 0.1037	0.4801 ± 0.5577
Day	25.16 ± 19.01	0.0815 ± 0.0638	0.1089 ± 0.0678	0.0894 ± 0.0813	0.2798 ± 0.1542
P-level	< 0.01**	< 0.01**	NS	NS	< 0.05*
Interactions					
Lunar x Depth	—	NS	NS	NS	NS
Lunar phase x Tide	NS	NS	NS	NS	NS
Depth x Tide	—	NS	NS	NS	NS
Lunar phase x Light	NS	NS	NS	NS	NS
Depth x Light		NS	NS	NS	NS
Tide x Light	NS	NS	NS	NS	NS
Lunar phase x Depth x Tide	—	NS	NS	NS	NS
Lunar phase x Depth x Light	—	NS	NS	NS	NS
Lunar phase x Tide x Light	NS	NS	< 0.05 *	< 0.05 *	NS
Depth x Tide x Light	—	NS	NS	NS	NS
1x 2 x 3 x 4	—	NS	NS	NS	NS

*Significance at *P*< 0.05, ** significance at *P*< 0.01, NS - no significance; homogenous groups indicated by superscripts a, b and c

5.2.1.2 Wet Season

Table 5.3 presents the results of a 4-way ANOVA of water parameters during wet season as influenced by depth (surface, bottom), tide (ebb, flood), light (day, night) and lunar phase (first quarter, full moon, third quarter and new moon). All water parameters were significantly different among the lunar phases. All water parameters except pH were significantly different ($P < 0.05$) between surface and bottom water. The tidal phase had no significant effect on turbidity. The time of day had significant effect on salinity, turbidity and pH ($P < 0.05$).

Surface temperature, DO and pH were lower at night flood during spring tide (Figure 5.1, 5.3 & 5.5 f & h). The flood tide brought in cooler water mass from the offshore. As expected, salinity was lower during wet season due to the depressive effect of rainfall. Differences between the surface and bottom salinity was larger during neap tide due to less mixing. At spring tide the surface and bottom temperature, salinity, DO and pH had similar trend. Higher measurements of temperature, salinity, DO and pH were observed during high water slack and lower value at low water slack. Turbidity was below 100 NTU during the neap tide. However, high turbidity (above 400 NTU) was observed in the surface and bottom water during spring tide at the end of low water slack and the start of flooding (Figure 5.4 f & h).

Surface and bottom zooplankton was also observed to peak at this time when the turbidity was high (Figure 5.7 c & d). Mean chlorophyll *a* concentration was significantly lower at 1Q moon in wet season (8.3 ± 2.7 μgL^{-1}) (see Table 5.4). Post-hoc Newman-Keuls test indicated that the mean concentration of chlorophyll *a* at day time during spring tide (3Q) was significantly higher than night time.

Table 5.3. Mean readings of water parameters (±SD) and summary of 4-way ANOVA in wet season (November 2003) in relation to lunar phase, depth, tidal phase and light.

	Temperature (ºC) **Mean ±SD**	**Salinity (‰)** **Mean ±SD**	**Dissolved Oxygen (mgL^{-1})** **Mean ±SD**	**Turbidity (NTU)** **Mean±SD**	**pH** **Mean ±SD**
1. Lunar phase					
First Quarter	30.66 ± 0.54[a]	22.53 ± 3.2[a]	5.51 ± 1.03[a]	32.52 ± 20.9[a]	7.62 ± 0.11[a]
Full Moon	30.25 ± 0.78[b]	19.83 ± 3.01[b]	5.65 ± 1.90[a]	137.74 ± 197.56[b]	7.57 ± 0.43[a]
Third Quarter	31.13 ± 0.65[c]	22.88 ± 3.6[a]	4.52 ± 1.56[b]	31.5 ± 21.22[a]	7.56 ± 0.15[a]
New Moon	29.91 ± 0.60[d]	21.55 ± 3.23[a]	3.61 ± 1.66[c]	197.17 ± 224.35[b]	7.31 ± 0.36[b]
P-level	< 0.01**	< 0.01**	< 0.01**	< 0.01**	< 0.01**
2. Depth					
Surface	30.69 ± 0.98	19.66 ± 2.43	5.42 ± 1.89	67.99 ± 116.91	7.49 ± 0.35
Bottom	30.29 ± 0.47	23.73 ± 3.06	4.11 ± 1.38	131.47 ± 196.75	7.54 ± 0.28
P-level	< 0.01**	< 0.01**	< 0.01**	< 0.01 **	NS
3. Tide(F/E)					
Ebb	30.59 ± 0.63	22.35 ± 3.24	5.26 ± 1.64	87.01 ± 161.57	7.62 ± 0.24
Flood	30.39 ± 0.92	21.05 ± 3.52	4.38 ± 1.77	112.45 ± 167.33	7.41 ± 0.35
P-level	NS	< 0.01**	< 0.01**	< 0.05*	< 0.01**
4. Diel					
Night	30.39 ± 0.6	21.94 ± 3.16	4.91 ± 1.45	52.64 ± 58.78	7.57 ± 0.3
Day	30.58 ± 0.91	21.49 ± 3.65	4.75 ± 1.99	139.57 ± 209.09	7.47 ± 0.32
P-level	NS	NS	NS	< 0.01**	NS
Interactions					
Lunar x Depth	< 0.01**	< 0.01**	< 0.01**	NS	NS
Lunar phase x Tide	NS	NS	NS	NS	NS
Depth x Tide	NS	NS	NS	NS	NS
Lunar phase x Light	NS	< 0.05*	NS	NS	NS
Depth x Light	< 0.05*	NS	NS	NS	NS
Tide x Light	NS	NS	NS	NS	NS
Lunar phase x Depth x Tide	NS	NS	NS	NS	NS
Lunar phase x Depth x Light	NS	NS	NS	NS	NS
Lunar phase x Tide x Light	NS	NS	NS	NS	NS
Depth x Tide x Light	NS	NS	NS	NS	NS
1x 2 x 3 x 4	NS	NS	NS	NS	NS

*Significance at *P*< 0.05, ** significance at *P*< 0.01, NS - no significance; homogenous groups indicated by superscripts a, b, c and d

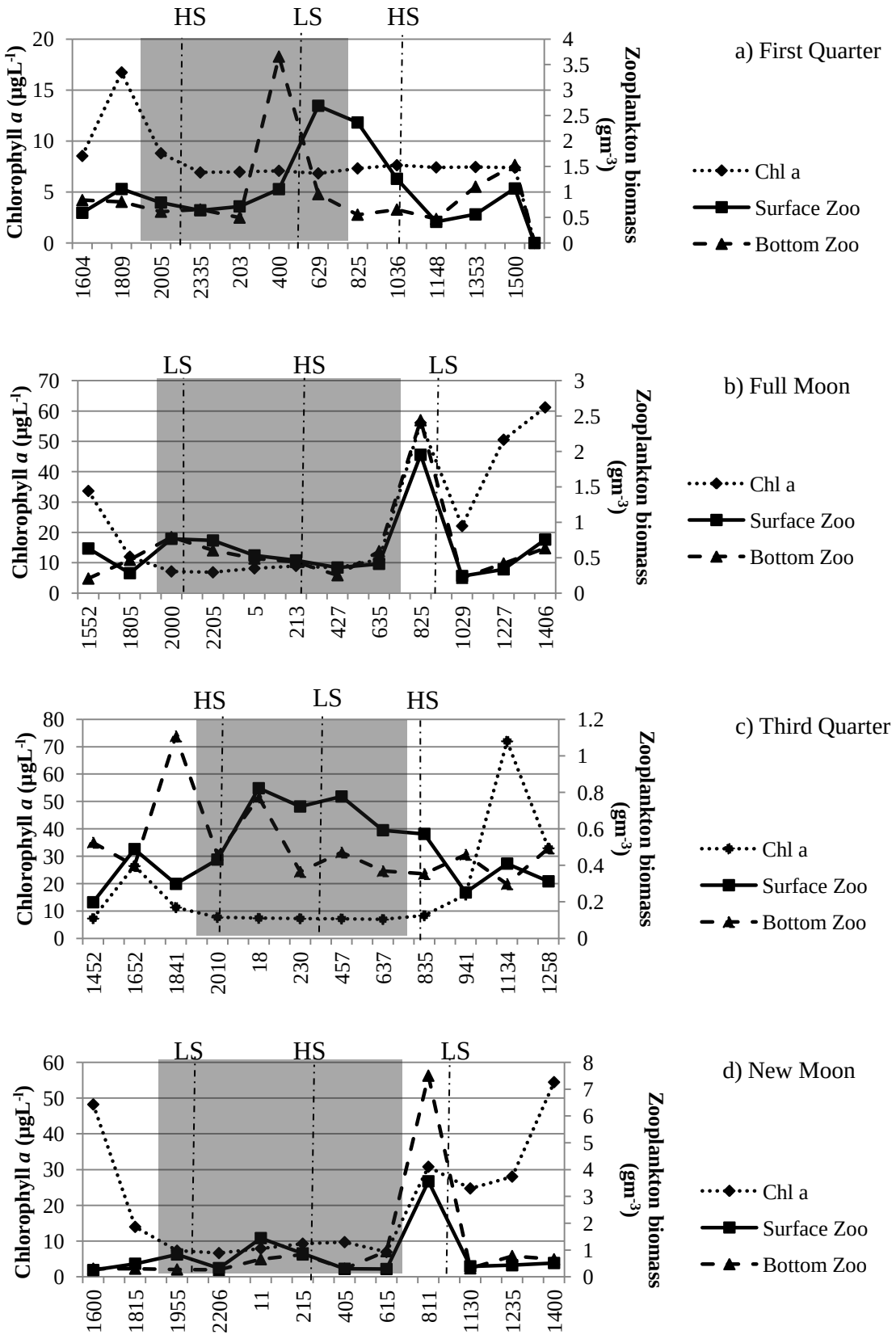

Figure 5.7. Fluctuations of surface chlorophyll *a* and zooplankton biomass (surface and bottom) at different lunar phase during wet season. LS - low slack; HS - high slack

Table 5.4. Mean values of chlorophyll *a* and zooplankton biomass recorded during wet season for each effect (lunar phase, depth, tidal phase and light). Summary of 3-way ANOVA results on chlorophyll *a* and 4-way ANOVA on zooplankton biomass of different fractions are shown.

	Chlorophyll *a* (μgL^{-1}) Mean ±SD	**Zooplankton Biomass (gm^{-3})**			
		>500µm Mean ±SD	**250-500µm Mean ±SD**	**125-250µm Mean±SD**	**Total Mean ±SD**
Overall mean	17.58 ± 17.06	0.5473 ± 0.6081	0.1611 ± 0.2974	0.0769 ± 0.1493	0.7854 ± 0.9297
1. Lunar phase					
First Quarter	8.25 ± 2.74[a]	0.8244 ± 0.8009[a]	0.1779 ± 0.0930	0.0620 ± 0.0282	1.0642 ± 0.7854
Full Moon	23.83 ± 20.95[b]	0.3818 ± 0.2434[b]	0.1544 ± 0.2059	0.0894 ± 0.1426	0.6256 ± 0.5210
Third Quarter	17.57 ± 19.17[b]	0.3811 ± 0.2113[b]	0.0831 ± 0.0294	0.0335 ± 0.0124	0.4978 ± 0.2129
New Moon	20.67 ± 16.77[b]	0.6019 ± 0.8008[a,b]	0.2292 ± 0.5495	0.1227 ± 0.2573	0.9538 ± 1.5533
P-level	<0.01**	< 0.05*	NS	NS	NS
2. Depth					
Surface	17.58 ± 17.06	0.5392 ± 0.4765	0.1479 ± 0.2126	0.0689 ± 0.1298	0.7599 ± 0.6608
Bottom	—	0.5555 ± 0.7212	0.1744 ± 0.3651	0.0850 ± 0.1675	0.8148 ± 1.1440
P-level	—	NS	NS	NS	NS
3. Tide					
Ebb	17.98 ± 18.15	0.5654 ± 0.7365	0.2165 ± 0.4064	0.1078 ± 0.2052	0.8897 ± 1.2251
Flood	17.18 ± 16.28	0.5293 ± 0.4519	0.1057 ± 0.0862	0.0460 ± 0.0311	0.6811 ± 0.4733
P-level	NS	NS	NS	NS	NS
4. Light					
Night	7.79 ± 1.14	0.5634 ± 0.6019	0.1059 ± 0.0644	0.0551 ± 0.0396	0.7244 ± 0.6041
Day	25.86 ± 19.75	0.5337 ± 0.6187	0.2079 ± 0.3955	0.0954 ± 0.1985	0.8370 ± 1.1386
P-level	< 0.01**	NS	NS	NS	NS
Interactions					
Lunar x Depth	—	NS	NS	NS	NS
Lunar phase x Tide	NS	NS	NS	NS	NS
Depth x Tide	—	NS	NS	NS	NS
Lunar phase x Light	< 0.05*	NS	NS	NS	NS
Depth x Light	NS	NS	NS	NS	NS
Tide x Light	NS	NS	NS	NS	NS
Lunar phase x Depth x Tide	—	NS	NS	NS	NS
Lunar phase x Depth x Light	—	NS	NS	NS	NS
Lunar phase x Tide x Light	NS	NS	NS	NS	NS
Depth x Tide x Light	—	NS	NS	NS	NS
1x 2 x 3 x 4	—	NS	NS	NS	NS

*Significance at *P*< 0.05, ** significance at *P*< 0.01, NS - no significance; homogenous groups indicated by superscripts a and b

5.2.1.3 Seasonal Effects of Dry and Wet Season

T-test results showed that season significantly affected temperature ($P < 0.01$), salinity ($P < 0.01$), dissolved oxygen ($P < 0.05$) and pH values ($P < 0.01$) (Table 5.5). The temperature was significantly higher in the wet season than dry season ($P < 0.01$) with mean reading of 30.5 ± 0.8ºC and 29.9 ± 0.6ºC, respectively. Salinity was 27.9 ± 1.2 ‰ in dry season compared to 21.7 ± 3.4‰ in wet season. Dissolved oxygen concentration was significantly higher ($P < 0.05$) in wet season (4.8 ± 1.8 mgL^{-1}) than dry season (4.2 ± 0.9 mgL^{-1}). The pH value was significantly higher in dry season (7.7 ± 0.1) than at wet season (7.5 ± 0.3). The turbidity values were not significantly different ($P > 0.05$) between the two seasons. Mean chlorophyll *a* concentrations in dry season (18.9 ± 16.4 μgL^{-1}) was not significantly different ($P > 0.05$) from wet season (17.6 ± 17.1 μgL^{-1}). Nevertheless, chlorophyll *a* was observed to be higher during neap tide in dry season but during spring tide, in wet season. Total zooplankton biomass was significantly higher in wet season than the dry season ($P < 0.01$).

Table 5.5. Mean values of environmental parameters (±SD) and summary of one-way ANOVA results between dry and wet season. Min = minimum, Max = maximum.

Environmental parameter		**Season**		
		Dry	**Wet**	***P*-level**
Temperature	Mean ±SD	29.96 ± 0.61	30.48 ± 0.79	<0.01**
(ºC)	Min	28.52	28.61	
	Max	31.38	32.91	
Salinity	Mean ±SD	27.88 ± 1.19	21.70 ± 3.43	< 0.01**
(‰)	Min	24.84	13.56	
	Max	30.13	27.45	
Dissolved Oxygen	Mean ±SD	4.20 ± 0.91	4.82 ± 1.75	< 0.05*
(mgL^{-1})	Min	2.50	0.95	
	Max	6.28	12.28	
Turbidity	Mean ±SD	89.78 ± 120.81	99.73 ± 164.1	NS
(NTU)	Min	9.37	9.77	
	Max	798.30	846.43	
pH	Mean ±SD	7.69 ± 0.13	7.51 ± 0.32	< 0.01**
	Min	7.47	6.80	
	Max	8.08	8.35	
Chlorophyll *a*	Mean ±SD	18.97 ± 16.40	17.59 ± 17.05	NS
(μgL^{-1})	Min	5.59	6.67	
	Max	102.35	72.03	
Total zooplankton biomass	Mean ±SD	0.3632 ± 0.3890	0.7854 ± 0.9297	< 0.01**
(gm^{-3})	Min	0.0816	0.1977	
	Max	3.6206	7.5011	

*Significance at $P< 0.05$, ** significance at $P< 0.01$, NS - no significance

5.2.2 Fish Larval Assemblages in Diel Study

A total of 16,707 fish larvae representing 15 families were collected during the dry season (N = 3,155) and wet season (N = 13,552). Mean density for total larvae were significantly lower ($P < 0.01$) in dry season (34.78 ± 38.98 $N.100m^{-3}$) compared to wet season (156.04 ± 232.86 $N.100m^{-3}$) (Table 5.6). Total number of fish larval families recorded was 12 for both dry and wet season.

The larval assemblages in the dry season (N = 3,155) were numerically dominated by three families that made up 95.1% of the total abundance (Table 5.6). Gobiidae was the most abundance family comprising 52% of the catch, with mean of 17.8 ± 31.4 N.100m^{-3}, followed by Engraulidae, 13.7 ± 20.8 N.100m^{-3} (39.9%), Sciaenidae, 2.0 ± 6.8 N.100m^{-3} (5.8%) and Blenniidae, 0.4 ± 1.2 N.100m^{-3} (1.2%). Other families that were less represented and contributed less than 1% were Cynoglossidae, Syngnathidae, Ambassidae, Platycephalidae, Leiognathidae, Scorpaenidae, Belonidae and Hemiramphidae.

In the wet season, larval assemblages (N = 13,552) were dominated by two families which constituted 98.8% of the total abundance (Table 5.6). Gobiidae was the most abundant family comprising 51.9% of the catch, with mean of 80.92 ± 217.6 N.100m^{-3}, followed by Engraulidae, 73.2 ± 123.5 N.100m^{-3} (46.9%). Other families that were less represented and contributed less than 1% were Sciaenidae, Blenniidae, Clupeidae, Cynoglossidae, Ambassidae, Syngnathidae, Mugilidae, Leiognathidae, Scorpaenidae and Tetraodontidae.

Table 5.6. Mean density (±SD) of fish larval families and non-parametric Kruskal-Wallis ANOVA in dry (July 2003) and wet season (November 2003).

Family	Season		*P*-level
	Dry	Wet	
Gobiidae	17.84 ± 31.42	80.92 ± 217.61	<0.01**
Engraulidae	13.68 ± 20.76	73.17 ± 123.47	<0.01**
Sciaenidae	1.98 ± 6.80	0.43 ± 1.46	NS
Blenniidae	0.41 ± 1.18	0.39 ± 1.64	NS
Clupeidae	0	0.36 ± 1.93	-
Cynoglossidae	0.21 ± 0.85	0.25 ± 1.06	NS
Syngnathidae	0.18 ± 0.59	0.12 ± 0.49	NS
Ambassidae	0.08 ± 0.50	0.17 ± 1.26	NS
Platycephalidae	0.02 ± 0.27	0	-
Leiognathidae	0.01 ± 0.18	0.02 ± 0.23	NS
Scorpaenidae	0.01 ± 0.13	0.01 ± 0.17	NS
Belonidae	0.01 ± 0.15	0	-
Hemiramphidae	0.01 ± 0.16	0	-
Tetraodontidae	0	0.01 ± 0.15	-
Mugilidae	0	0.04 ± 0.40	-
Unidentified	0.51 ± 2.04	0.15 ± 0.61	NS
Total	34.28 ± 33.6	156.04 ± 232.86	<0.01**

* Significance at $P < 0.01$, NS - no significance

Total larvae was significantly different between the lunar phase ($P < 0.01$) (Table 5.7) in dry season. Total larvae were significantly low in 1Q with mean 16.83 ± 23.56 N.100m^{-3}. Higher abundance was recorded in FM (43.59 ± 53.63 N.100m^{-3}) and 3Q (43.11 ± 37.81 N.100m^{-3}). Lowest mean total larvae were recorded in 3Q (71.8 ± 72.32 N.100m^{-3}) during the wet season. No significant difference of total mean fish larval abundance occurred between day and night, as well as tidal phase. However, interactions between light and tide showed that total fish larval density was significantly higher ($P < 0.05$) at day flood.

Table 5.7. Mean total density (±SD) and summary of non parametric Kruskal-Wallis ANOVA in relation to lunar phase, depth, tide and light during dry season and wet season.

Season	Dry Season	Wet Season
1. Lunar phase		
First Quarter	16.83 ± 23.56[a]	193.66 ± 190.08[a]
Full Moon	43.59 ± 53.63[b]	119.15 ± 128.23[a]
Third Quarter	43.11 ± 37.81[b]	71.80 ± 79.05[b]
New Moon	35.22 ± 28.39[b]	239.53 ± 379.92[a]
P-level	$P< 0.01$**	$P< 0.01$*
2. Depth		
Surface	31.15 ± 36.17	177.62 ± 266.93
Bottom	38.41 ± 41.48	134.45 ± 191.90
P-level	NS	NS
3. Tide		
Flood	34.72 ± 45.65	202.42 ± 302.01
Ebb	34.84 ± 31.17	109.65 ± 116.01
P-level	NS	NS
4. Light		
Day	33.42 ± 39.78	164.76 ± 266.35
Night	36.65 ± 38.03	145.72 ± 186.70
P-level	NS	NS
Tide-Light	NS	$P < 0.01$*

* Significance at $P< 0.01$, NS - no significance; homogenous groups indicated by superscripts a and b

5.2.3 Seasonal and Diel Pattern of Larval Fish in Relation to Water Parameters and Plankton Biomass

5.2.3.1 Gobiidae

Mean total density of Gobiidae was significantly higher in wet season than dry season ($P < 0.01$) (Dry =17.8 ± 31.4 N.100m^{-3}; Wet = 80.9 ± 217.6 N.100m^{-3}) (Table 5.6). A Kruskal-Wallis test indicates a significant lunar pattern ($P < 0.01$) in mean total abundance of gobiid in dry season (Table 5.8). Highest mean density was recorded in FM (34.8 ± 53.1 N.100m^{-3}) followed by NM, 16.8 ± 18.6 N.100m^{-3}; 3Q, 13.2 ± 16.8 N.100m^{-3} and 1Q, 6.4 ±10.2 N.100m^{-3}. Gobiidae larvae were active at night as all developmental stages were higher during night time ($P < 0.01$).

Preflexion and flexion larvae showed significant differences among lunar phases ($P < 0.01$). Higher number of preflexion gobiids was observed at full moon (33.0 ± 51.9 N.100m^{-3}). The tidal and diel effects also influenced the preflexion gobiids especially during night flood. During full moon, abundance of preflexion gobiids at the surface and bottom water peaked at or around low water slack at night (Figure 5.8 a). Another peak was observed at the bottom water around water slack at day time. These peaks were attributed by higher mean abundance of preflexion larvae at flood tide (16.2 ± 38.5 N.100m^{-3}). Nevertheless, a 3-way ANOVA showed no significant difference in relation to depth, tidal phase and light ($P > 0.05$).

Postflexion gobiid was abundant at flood tide at the bottom water in NM (Figure 5.8c). This occurred after low water slack at night time. Significant differences ($P < 0.05$) between tidal phase and light were observed for both flexion and postflexion stage of gobiids, being abundant at night flood.

In wet season, total mean densities of Gobiidae by lunar phase in decreasing order were as follows: NM = 225.4 ± 383.8 N.100m^{-3}; FM = 68.0 ± 118.5 N.100m^{-3}; 3Q = 17.5 ± 21.8 N.100m^{-3} and 1Q = 12.7 ± 15.0N.100m^{-3}) (Table 5.9). Kruskal-Wallis test results showed that the lunar phase ($P < 0.01$) significantly influenced larval abundance of preflexion and flexion stages. Yolk-sac (32.4 ± 152.4 N.100m^{-3}) and juvenile (0.2 ± 0.7 N.100m^{-3}) stages were only recorded in NM. Yolk-sac gobiids were found abundantly at the bottom water at night flood with mean of 601 N.100m^{-3} during flood tide (Figure 5.9a). During this time, the salinity was quite low (20.4 ‰) at the bottom (see Figure 5.2h).

Table 5.8. Mean density of Gobiidae (±SD) and summary of non-parametric Kruskal-Wallis ANOVA in relation to lunar phase, depth, tide and light during dry season.

	Preflexion	**Flexion**	**Postflexion**	**Total**
Dry Season	15.4 ± 30.4	0.4 ± 1.3	2.1 ± 5.9	17.8 ± 31.4
1. Lunar phase				
FirstQuarter	4.9 ± 8.2[a]	0.41 ± 1.2[a]	0.9 ± 2.1	6.4 ± 10.2[a]
Full Moon	33.02 ± 51.9[b]	0	1.7 ± 5.1	34.8 ± 53.1[b]
Third Quarter	11.39 ±14.7[c]	0.39 ± 1.8[a]	1.4 ± 3.5	13.2 ± 16.8[c]
New Moon	12.10 ± 17.5[c]	0.5 ± 0.9[a,c]	4.2 ± 9.7	16.8 ± 18.6[b,c]
P -level	*P*< 0.01**	*P*< 0.05*	NS	*P*< 0.01**
2. Depth				
Surface	14.5 ± 27.4	0.3 ± 1.1	1.7 ± 5.3	16.5 ± 27.7
Bottom	16.4 ± 33.3	0.4 ± 1.4	2.5 ± 6.6	19.2 ± 34.9
P -level	NS	NS	NS	NS
3. Tide				
Flood	16.2 ± 38.5	0.4 ± 1.1	3.2 ± 7.9	19.8 ± 39.6
Ebb	14.7 ± 19.5	0.3 ± 1.4	0.9 ± 2.5	15.9 ± 20.4
P -level	NS	NS	NS	NS
4. Light				
Day	12.6 ± 29.2	0.1 ± 0.5	0.28 ± 1.28	13.1 ± 29.2
Night	19.3 ± 31.7	0.7 ± 1.8	4.51 ± 7.03	24.5 ± 22.4
P -level	*P*< 0.01**	*P*< 0.01**	*P*< 0.01**	*P*< 0.01**
Tide- Light	*P*< 0.01**	NS	*P*< 0.01**	*P*< 0.01**

*Significance at *P*< 0.05, ** significance at *P*< 0.01, NS - no significance;
homogenous groups indicated by superscripts a, b and c

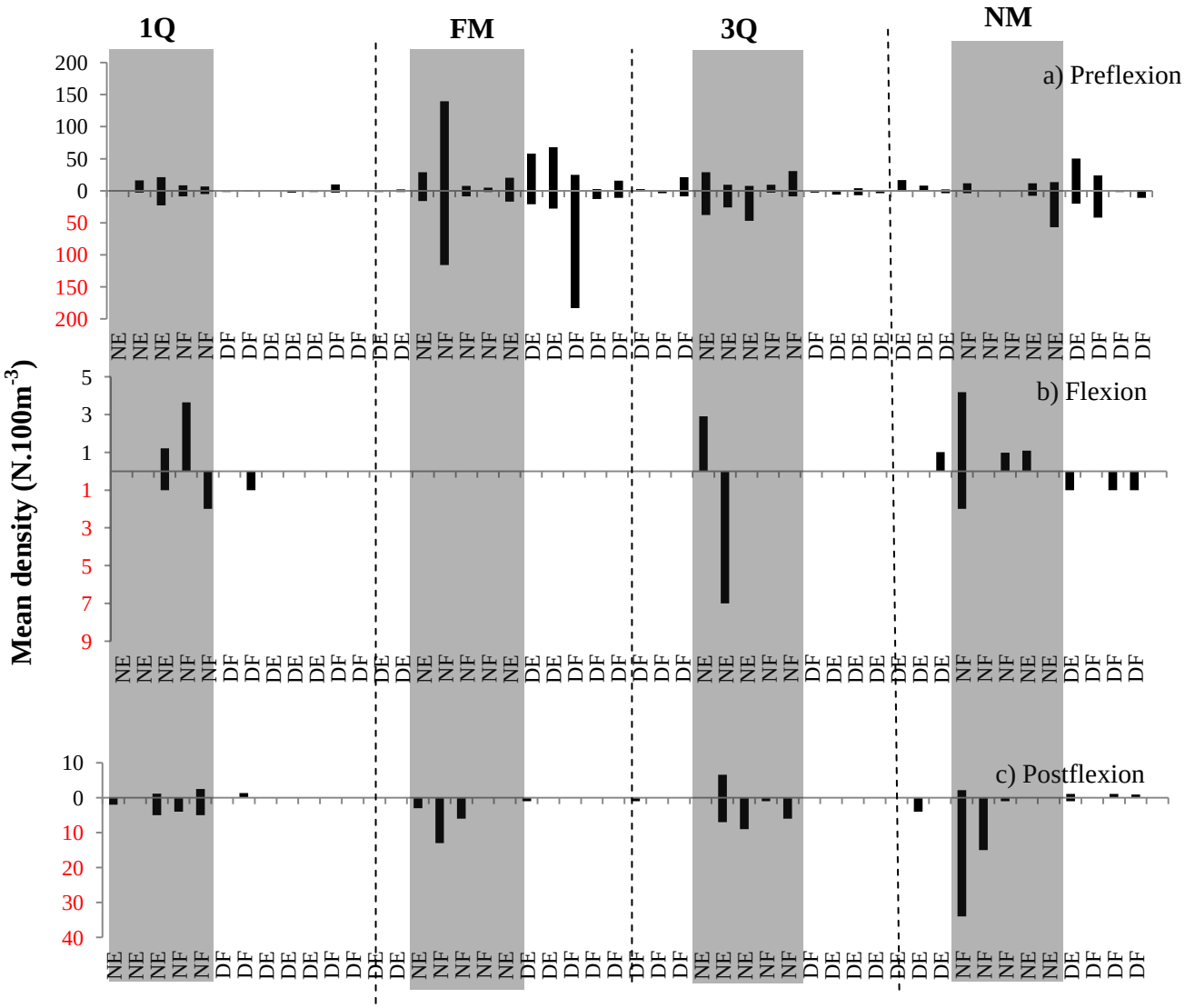

Figure 5.8. Surface (top bar) and bottom (bottom bar) distribution of Gobiidae at different developmental stages by lunar phase during dry season; (a) preflexion, (b) flexion and (c) postflexion. 1Q - First Quarter; FM - Full Moon; 3Q - Third Quarter; NM - New Moon; NE - night ebb; NF - night flood; DE - day ebb; DF - day flood. Shaded area represents night time. (Note different scale bar)

Mean density of preflexion gobiid was significantly abundant in NM (190.3 ± 357.2 N.100m^{-3}), followed by FM, 61.9 ± 114.0 N.100m^{-3}; 3Q, 7.1 ± 11.1 N.100m^{-3} and 1Q, 5.5 ± 7.1 N.100m^{-3}. Preflexion larvae peaked at day flood at the surface and bottom water during new moon with mean of 1582.2N.100m^{-3} and 724.6N.100m^{-3} respectively (Figure 5.9b). During full moon, preflexion larvae were observed to be abundant at or around low slack water during flood tide, at the surface water (365.16 N.100^{-3}) and bottom water (260 N.100m^{-3}) (Figure 5.9b). Mean flexion gobiid showed significantly higher density (P< 0.01) at 3Q (5.4 ± 8.6 N.100m^{-3}). Abundance of flexion larvae were significantly higher (P< 0.05) at day time during flood tide (Figure 5.9c).The postflexion larvae were observed to peak at the end or beginning of ebb and flood tides (Figure 5.9d), with significantly higher abundance at flood tide (P < 0.05). Juvenile gobiids were however only found in wet season in NM with lower density that ranged from 1 – 2 N.100m^{-3} (Figure 5.9e). They were only caught during day time at flood tide.

Table 5.9. Mean density of Gobiidae (±SD) and summary of non-parametric Kruskal-Wallis ANOVA in relation to lunar phase, depth, tide and light during wet season.

	Yolk-sac	Preflexion	Flexion	Postflexion	Juvenile	Total
Wet Season	8.09 ± 76.92	66.23 ± 200.80	2.22 ± 6.02	4.33 ± 6.93	0.05 ± 0.34	80.92 ± 217.61
1. Lunar phase						
First Quarter	0	5.5 ± 7.07[a]	1.91 ± 5.79[a]	5.30 ± 7.95	0	12.71 ± 15.00[a]
Full Moon	0	61.94 ± 114.02[b]	1.4 ± 4.91[a]	4.78 ± 6.89	0	68.04 ± 118.53[b]
Third Quarter	0	7.13 ± 11.05[a]	5.44 ± 8.58[b]	4.92 ± 7.68	0	17.50 ± 21.81[a]
New Moon	32.38 ± 152.44	190.33 ± 357.21[c]	0.14 ± 0.56[a]	2.32 ± 4.46	0.20 ± 0.66	225.41 ± 383.84[c]
P -level	-	*P*< 0.01**	*P*< 0.01**	NS	-	*P*< 0.01**
2. Depth						
Surface	2.38 ± 11.12	88.46 ± 251.26	1.89 ± 5.66	4.99 ± 8.04	0.07 ± 0.40	97.82 ± 254.18
Bottom	13.81 ± 108.19	43.99 ± 130.13	2.56 ± 6.38	3.67 ± 5.58	0.03 ± 0.26	64.02 ± 173.26
P -level	NS	NS	NS	*P*< 0.05*	-	NS
3. Tide						
Flood	13.94 ± 108.21	104.75 ± 275.38	3.33 ± 7.78	5.73 ± 7.98	0.10 ± 0.48	127.85 ± 296.88
Ebb	2.24 ± 10.76	27.71 ± 47.22	1.11 ± 3.15	2.93 ± 5.38	0.00	33.98 ± 51.15
P -level	NS	NS	NS	*P*< 0.05*	-	NS
4. Light						
Day	0.74 ± 7.51	95.27 ± 262.56	3.19 ± 7.66	3.24 ± 6.79	0.09 ± 0.39	102.53 ± 264.65
Night	16.79 ± 113.05	31.90 ± 68.56	1.08 ± 2.76	5.63 ± 6.91	0	55.37 ± 140.80
P -level	*P*< 0.01**	NS	NS	*P*< 0.01**	-	NS
Interactions						
Tide x Light	*P*< 0.05*	NS	*P*< 0.05*	*P*< 0.01**	-	*P*< 0.05*

*Significance at *P*< 0.05, ** significance at *P*< 0.01, NS - no significance; homogenous groups indicated by superscripts a, b and c

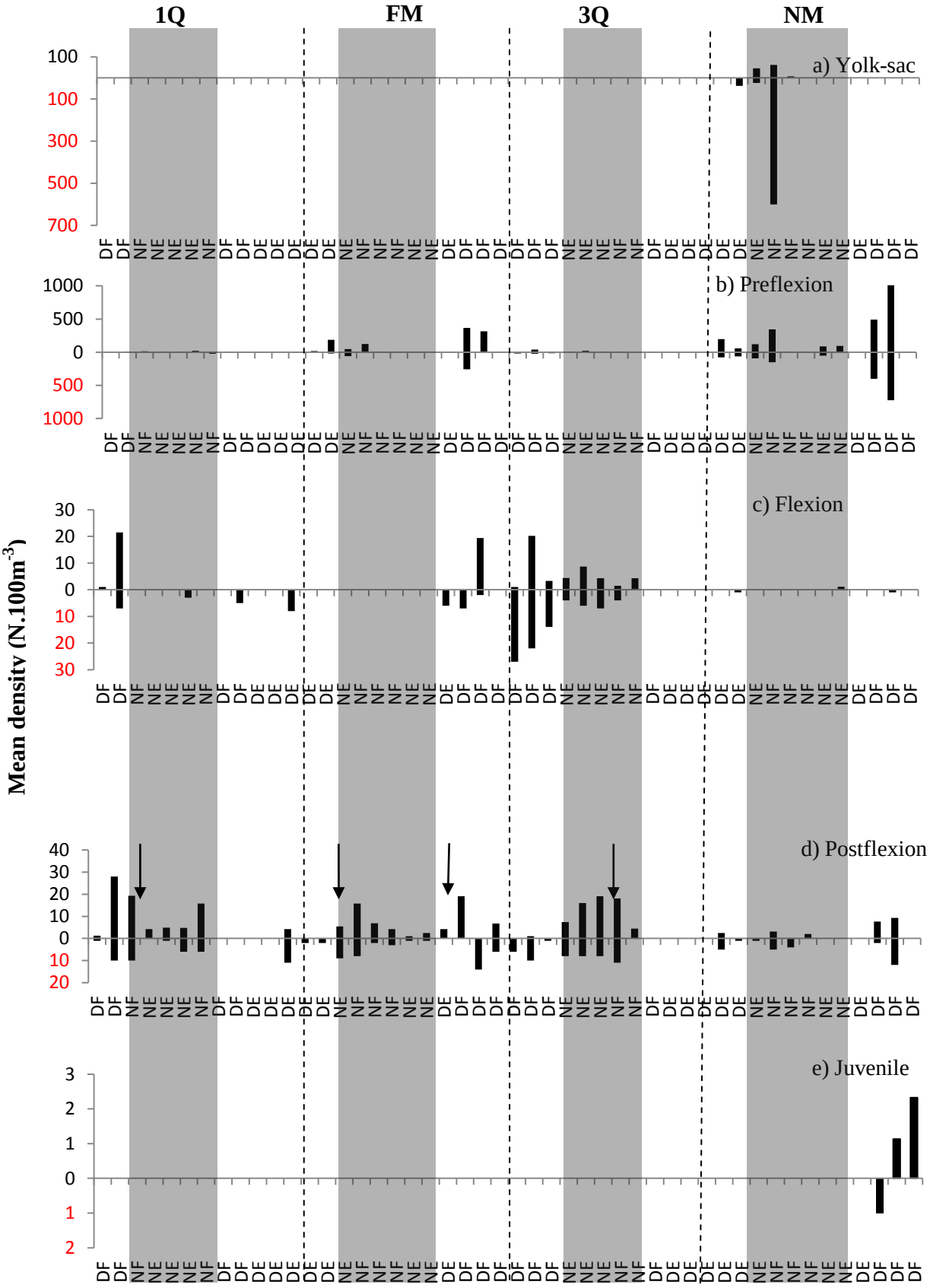

Figure 5.9. Surface (top bar) and bottom (bottom bar) distribution of Gobiidae at different developmental stages by lunar phase during wet season; (a) yolk-sac stage, (b) preflexion, (c) flexion, (d) postflexion and (e) juvenile. 1Q - First Quarter; FM - Full Moon; 3Q - Third Quarter; NM - New Moon; NE - night ebb; NF - night flood; DE - day ebb; DF - day flood. Shaded area represents night time. Arrow shows slack water. (Note different scale bar)

5.2.3.2 Engraulidae

Mean total density of Engraulidae in dry and wet season were 13.7 ± 20.8 N.100m^{-3} and 73.2 ± 123.5 N.100m^{-3}, respectively. Mean total density in the wet season was significantly higher ($P < 0.01$) than dry season (Table 5.7).

In dry season, total mean density of Engraulidae by lunar phase in descending order was as follows: 3Q = 20.6 ± 22.6 N.100m^{-3}; NM = 17.1 ± 20.0 N.100m^{-3}; 1Q = 8.7 ± 20.6 N.100m^{-3} and FM = 8.2 ± 17.3 N.100m^{-3} (Table 5.10). Preflexion and flexion stage were significantly affected by lunar phases.

Preflexion larvae were significantly higher ($P< 0.01$) in 3Q. Peak abundance of preflexion engraulids was observed just before or near high water slack at the surface and bottom water in 3Q (Figure 5.10a). Another peak abundance was observed just after high water slack, when the tide began to fall in the morning. Abundance of preflexion engraulid was significantly higher at day time ($P < 0.01$). Flexion larvae were observed to peak in high water slack in 3Q at the surface, and at the bottom water during the start of ebb tide (Figure 5.10b). Postflexion larvae were observed to remain at the bottom water during ebb tide especially in 1Q, FM and 3Q (Figure 5.10c). Abundance of postflexion larvae was significantly higher at night ($P < 0.01$) in dry season.

Total abundance of engraulids was significantly higher at 1Q (176.0 ± 182.6 N.100m^{-3}) in the wet season ($P < 0.01$) (Table 5.11). All developmental stages of engraulids were significantly different between lunar phases ($P < 0.01$).

Mean density of preflexion larvae were higher at neap tides (1Q > 3Q). Preflexion larvae were significantly higher during flood tide compared to ebb tide with

mean of 24.9 ± 78.3 N.100m^{-3} and 18.2 ± 28.4 N.100m^{-3}, respectively. Surface preflexion larvae increased during flood tide at night in 3Q (Figure 5.11a). They continued to increase after high water slack to 105.2 N.100m^{-3} before decreased to below 10 N.100m^{-3}. At day time, preflexion larvae at the surface and bottom were observed to peak at high water slack in 1Q and 3Q (Figure 5.11a).

Abundance of flexion larvae was highest in 1Q with mean of 109.4 ± 111.9 N.100m^{-3}. Both surface and bottom flexion stage engraulid were observed to be abundant during ebb tide, and was higher at night (Figure 5.11b). Nevertheless, surface abundance of flexion larvae was recorded the highest at night during flood tide (mean 418.7 N.100m^{-3}).

While postflexion larvae were recorded highest in FM (32.9 ± 51.7 N.100m^{-3}), juveniles of engraulid were only collected in 3Q and NM during the wet season. Mean density of postflexion was highest in FM, at day flood, at high slack waters (Figure 5.11c).

Table 5.10. Mean density of Engraulidae (±SD) and summary of non-parametric Kruskal-Wallis ANOVA in relation to lunar phase, depth, tide and light during dry season.

	Preflexion	**Flexion**	**Postflexion**	**Total**
Dry Season	6.91 ± 14.12	2.12 ± 6.24	5.31 ± 12.51	13.68 ± 20.76
1. Lunar phase				
First Quarter	2.83 ± 5.92[a]	2.03 ± 7.38[a]	6.71 ± 18.28	8.74 ± 20.60[a]
Full Moon	3.54 ± 7.10[a]	0.60 ± 2.31[a,b]	3.94 ± 13.67[a]	8.17 ± 17.27[a]
Third Quarter	11.60 ± 17.94[b]	2.79 ± 7.11[a,b,c]	6.17 ± 8.58	20.56 ± 22.60[b]
New Moon	9.60 ± 18.49[b]	3.08 ± 6.67[a,c]	4.45 ± 6.28	17.13 ± 20.04[b]
P -level	*P*< 0.01**	*P*< 0.05*	*P*< 0.01**	*P*< 0.01**
2. Depth				
Surface	6.11 ± 12.57	1.81 ± 5.68	4.69 ± 10.90	12.36 ± 8.78
Bottom	7.72 ± 15.56	2.44 ± 6.77	5.94 ± 13.98	15.00 ± 22.61
P -level	NS	NS	NS	NS
3. Tide				
Flood	6.28 ± 15.09	2.04 ± 6.19	4.84 ± 10.72	12.59 ± 21.10
Ebb	7.54 ± 13.15	2.21 ± 6.32	5.78 ± 14.09	14.75± 20.47
P -level	NS	NS	NS	NS
4. Light				
Day	10.22 ± 17.42	2.53 ± 7.00	4.47 ± 13.24	16.28 ± 24.12
Night	2.33 ± 4.52	1.56 ± 4.98	6.47 ± 11.40	10.06 ± 14.27
P -level	*P*< 0.01**	NS	*P*< 0.01**	NS
Interactions				
Tide-Light	*P*< 0.01**	NS	*P*< 0.01**	NS

*Significance at *P*< 0.05, ** significance at *P*< 0.01, NS - no significance; homogenous groups indicated by superscripts a, b, and c

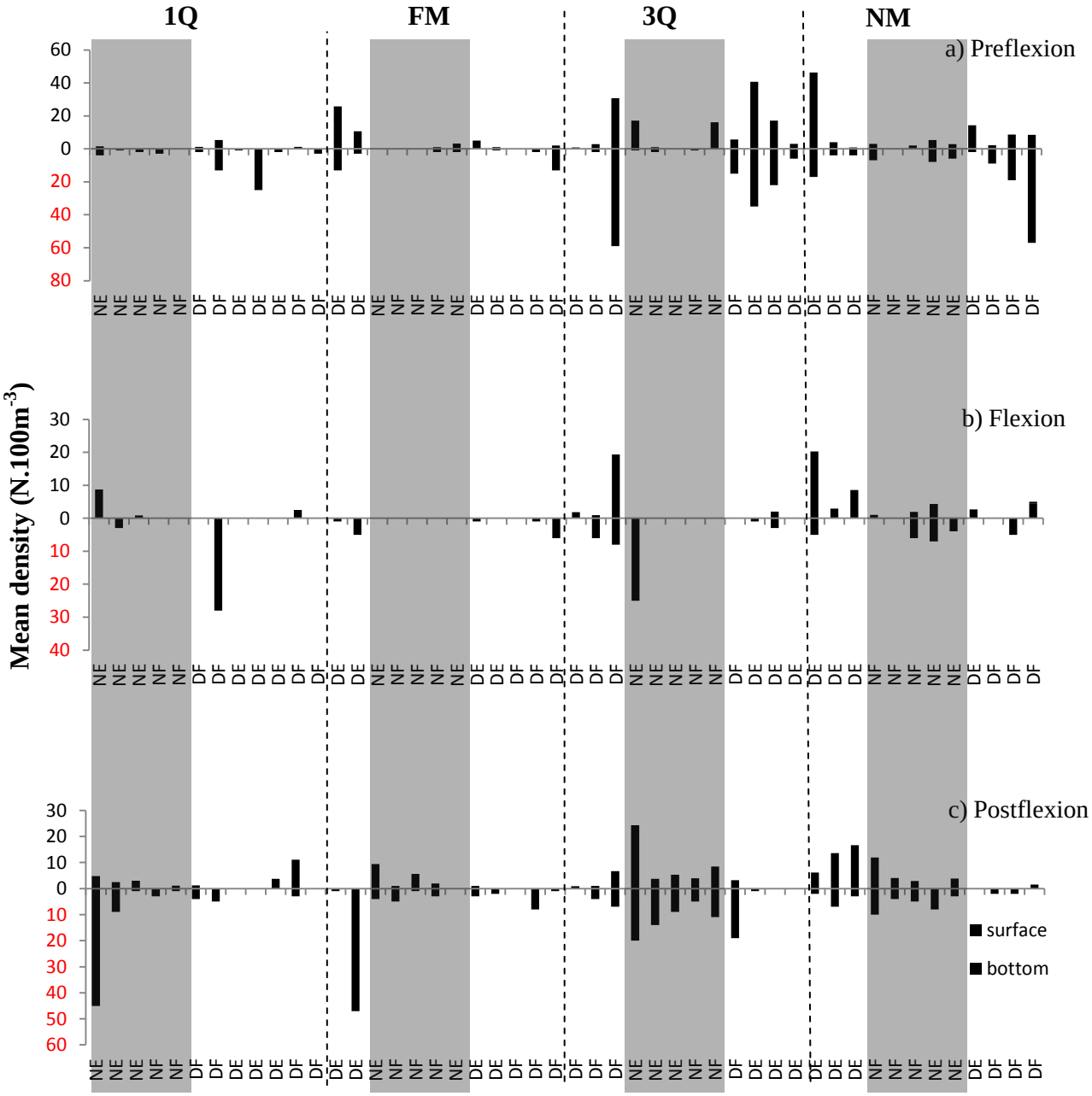

Figure 5.10. Surface (top bar) and bottom (bottom bar) distribution of Engraulidae at different developmental stages by lunar phase during dry season; (a) preflexion, (b) flexion and (c) postflexion. 1Q - First Quarter; FM - Full Moon; 3Q - Third Quarter; NM - New Moon; NE - night ebb; NF - night flood; DE - day ebb; DF - day flood. Shaded area represents night time. (Note different scale bar)

Table 5.11. Mean density of Engraulidae (±SD) and summary of non-parametric Kruskal-Wallis ANOVA in relation to lunar phase, depth, tide and light during wet season.

	Preflexion	**Flexion**	**Postflexion**	**Juvenile**	**Total**
Wet Season	21.55 ± 58.83	36.08 ± 82.27	15.48 ± 38.05	1.54 ± 6.81	73.17 ± 123.47
1. Lunar phase					
First Quarter	47.19 ± 96.57[a]	109.38 ± 136.32[a]	19.49 ± 24.87[a]	0	176.017 ± 182.63[a]
Full Moon	1.71 ± 4.79[b]	16.07 ± 31.42[b]	32.88 ± 67.14[a]	0	50.65 ± 87.17[b]
Third Quarter	32.14 ± 55.98[a]	15.34 ± 20.38[b]	4.85 ± 7.43[b]	0.09 ± 0.43	52.42 ± 70.41[b]
New Moon	5.13 ± 10.83[b]	3.55 ± 10.34[c]	4.73 ± 11.98[b]	6.08± 12.67	13.46 ± 24.70[c]
P -level	*P*< 0.01**	*P*< 0.01**	*P*< 0.01**	*P*< 0.01**	*P*< 0.01**
2. Depth					
Surface	20.17 ± 44.22	40.02 ± 95.02	17.27 ± 42.65	1.26 ± 4.54	77.56 ± 131.00
Bottom	22.92 ± 70.70	32.14 ± 67.45	13.70 ± 32.95	1.82 ± 8.52	68.79 ± 115.97
P -level	NS	NS	NS	NS	NS
3. Tide					
Flood	24.87 ± 78.27	30.49 ± 80.88	16.92 ± 47.40	0.60 ± 3.11	72.33 ± 135.08
Ebb	18.22 ± 28.43	41.67 ± 83.69	14.05 ± 25.69	2.48 ± 9.05	74.01 ± 113.36
P -level	*P*< 0.05*	NS	NS	*P*< 0.05*	NS
4. Light					
Day	22.70 ± 74.60	22.51 ± 38.54	16.26 ± 48.79	1.21 ± 7.82	61.02 ± 104.05
Night	20.77 ± 31.74	52.12 ± 112.35	14.57 ± 18.95	1.93 ± 5.41	87.54 ± 142.35
P -level	*P*< 0.01**	NS	*P*< 0.01**	*P*< 0.05*	NS
Tide -Light	NS	NS	*P*< 0.05*	*P*< 0.01**	NS

*Significance at *P*< 0.05, ** significance at *P*< 0.01, NS - no significance; homogenous groups indicated by superscripts a, b and c

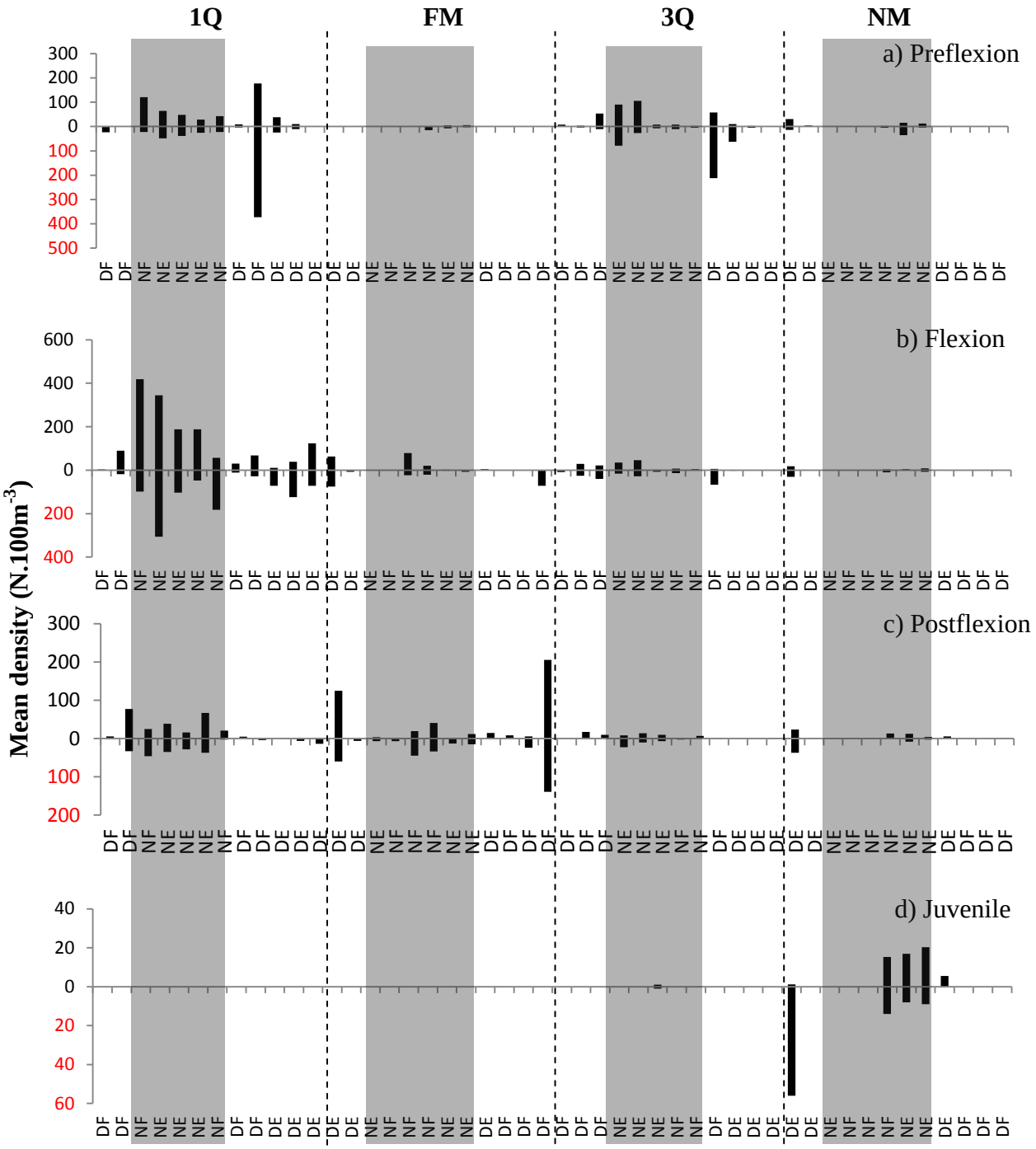

Figure 5.11. Surface (top bar) and bottom (bottom bar) distribution of Engraulidae at different developmental stages by lunar phase during wet season. (a) preflexion, (b) flexion, (c) postflexion and (d) juvenile. 1Q - First Quarter; FM - Full Moon; 3Q - Third Quarter; NM - New Moon; NE - night ebb; NF - night flood; DE - day ebb; DF - day flood. Shaded area represents night time. (Note different scale bar)

5.2.3.3 Sciaenidae

Mean total Sciaenidae was significantly higher ($P < 0.05$) in dry season than wet season with mean of 1.9 ± 6.8 N.100m^{-3} and 0.4 ± 1.5 N.100m^{-3}, respectively. In dry season, sciaenid larvae were highest in 3Q (7.3 ± 12.0 N.100m^{-3}) where 99.4% of total sciaenid consisted of preflexion larvae (Table 5.12). Preflexion larvae were only recorded in neap tides (1Q < 3Q). Preflexion sciaenids were higher in ebb tide (2.5 ± 7.6 N.100m^{-3}). They were also significantly higher at daytime (2.9 ± 7.4 N.100m^{-3}) ($P < 0.05$). The abundance of preflexion sciaenid was higher at 3Q during day ebb. This observation might be related to the high concentration of chlorophyll *a* during this time (see Figure 5.6c).

Table 5.12. Mean density of Sciaenidae (±SD) and summary of non-parametric Kruskal-Wallis ANOVA in relation to lunar phase, depth, tide and light during dry season.

	Preflexion	**Flexion**	**Postflexion**	**Total**
Dry Season	1.97 ± 6.80	0	0.01 ± 0.15	1.98 ± 6.80
1. Lunar phase				
First Quarter	0.53 ± 1.94	0	0	0.53 ± 1.94[a]
Full Moon	0.00	0	0.04 ± 0.30	0.04 ± 0.30[a]
Third Quarter	7.34 ± 11.99	0	0	7.34 ± 11.99[b]
New Moon	0.00	0	0	0.00
P -level	*P*< 0.01**	—	—	*P*< 0.01**
2. Depth				
Surface	1.38 ± 5.87	0	0.02 ± 0.21	1.41 ± 5.86
Bottom	2.54 ± 7.61	0	0	2.54 ± 7.61
P -level	NS	—	—	NS
3. Tide				
Flood	0.96 ± 4.34	0.00	0.02 ± 0.21	0.99 ± 4.34
Ebb	2.97 ± 8.47	0.00	0	2.97 ± 8.47
P -level	NS	—	—	NS
4. Light				
Day	2.89 ± 8.15	0.00	0	2.89 ± 8.15
Night	0.71 ± 3.98	0.00	0.03 ± 0.23	0.73 ± 3.98
P -level	*P*< 0.05*	—	—	NS

*Significance at *P*< 0.05, ** significance at *P*< 0.01, NS - no significance; homogenous groups indicated by superscripts a and b

Similar to dry season, sciaenids were only found in neap tides (1Q > 3Q) in wet season. Preflexion larvae collected in 1Q were significantly higher than 3Q (Table 5.13). Flexion and postflexion larvae were only recorded in 3Q with mean of 0.08 ± 0.6 N.100m^{-3} and 0.05 ± 0.3 N.100m^{-3}, respectively. No significant difference was observed between the depth, tide and light.

Table 5.13. Mean density of Sciaenidae (±SD) and summary of non-parametric Kruskal-Wallis ANOVA in relation to lunar phase, depth, tide and light during wet season.

	Preflexion	**Flexion**	**Postflexion**	**Total**
Wet Season	0.39 ± 1.40	0.02 ± 0.29	0.01 ± 0.17	0.43 ± 1.46
1. Lunar phase				
First Quarter	1.18 ± 2.23	0	0	1.18 ± 2.32
Full Moon	0.00	0	0	0.00
Third Quarter	0.37 ± 1.26	0.08 ± 0.59	0.05 ± 0.34	0.50 ± 1.52
New Moon	0	0	0	0
P -level	*P*< 0.01**	—	—	*P*< 0.01**
2. Depth				
Surface	0.35 ± 1.11	0.04 ± 0.42	0	0.39 ± 1.25
Bottom	0.43 ± 1.64	0	0.02 ± 0.24	0.48 ± 1.66
P -level	NS	—	—	NS
3. Tide				
Flood	0.58 ± 1.78	0.04 ± 0.04	0	0.65 ± 1.87
Ebb	0.19 ± 0.81	0	0.02 ± 0.24	0.22 ± 0.84
P -level	NS	—	—	NS
4. Light				
Day	0.44 ± 1.64	0.04 ± 0.40	0	0.48 ± 1.72
Night	0.32 ± 1.05	0	0.03 ± 0.25	0.37 ± 1.09
P -level	NS	—	—	NS

** Significance at *P*< 0.01, NS - no significance

5.2.3.4 Blenniidae

Total mean density during dry season was 0.40 ± 1.2 N.100m^{-3}. Total mean density was highest in new moon (0.6 ± 1.6 N.100m^{-3}) (Table 5.14). Postflexion blennid was only recorded in 1Q. Blenniid larvae found during the dry season had preference to more saline waters and higher concentration of phytoplankton.

Table 5.14. Mean density of Blenniidae (±SD) and summary of non-parametric Kruskal-Wallis ANOVA in relation to lunar phase, depth, tide and light during dry season.

	Preflexion	**Flexion**	**Postflexion**	**Total**
Dry Season	0.39 ± 1.14	0	0.01 ± 0.18	0.41 ± 1.18
1. Lunar phase				
First Quarter	0.41 ± 1.21	0	0.05 ± 0.37	0.47 ± 1.35
Full Moon	0.25 ± 0.79	0	0	0.25 ± 0.79
Third Quarter	0.27 ± 0.73	0	0	0.27 ± 0.73
New Moon	0.64 ± 1.60	0	0	0.64 ± 1.60
P -level	NS	—	—	NS
2. Depth				
Surface	0.45 ± 1.33	0	0.03 ± 0.26	0.48 ± 1.39
Bottom	0.33 ± 0.91	0	0	0.33 ± 0.91
P -level	NS	—	—	NS
3. Tide				
Flood	0.37 ± 1.16	0	0	0.37 ± 1.16
Ebb	0.42 ± 1.12	0	0.03 ± 0.26	0.44 ± 1.20
P -level	NS	—	—	NS
4. Light				
Day	0.33 ± 0.99	0	0.02 ± 0.24	0.36 ± 1.07
Night	0.48 ± 1.32	0	0	0.48 ± 1.32
P -level	NS	—	—	NS

NS - no significance

Total mean density in wet season showed significant difference in lunar phase, with highest density in 1Q (1.20 ± 3.0 N.100m^{-3}). Night catches were also significantly higher ($P < 0.01$) than day time. Blenniids were abundant at night in 1Q. Mean density of preflexion Blenniidae was significantly higher ($P < 0.01$) in 1Q. Meanwhile, postflexion larvae were only recorded in 1Q. Highest abundance of blenniid larvae were found in warmer and less turbid waters, with a preference for larger sized zooplankton (>500µm) (see Table 5.3 & 5.4). They were recorded at neap flood tide.

Table 5.15. Mean density of Blenniidae (±SD) and summary of non-parametric Kruskal-Wallis ANOVA in relation to lunar phase, depth, tide and light during wet season.

	Preflexion	**Flexion**	**Postflexion**	**Total**
Wet Season	0.24 ± 0.82	0.00	0.15 ± 1.10	0.39 ± 1.64
1. Lunar phase				
First Quarter	0.61 ± 1.34[a]	0.00	0.59 ± 2.16	1.20 ± 3.04[a]
Full Moon	0.04 ± 0.29[b]	0.00	0.00	0.04 ± 0.29[b]
Third Quarter	0.27 ± 0.72[a,b]	0.00	0.00	0.27 ± 0.72[b]
New Moon	0.04 ± 0.30[b]	0.00	0.00	0.04 ± 0.30[b]
P -level	*P*< 0.01**	—	—	*P*< 0.01**
2. Depth				
Surface	0.28 ± 0.92	0.00	0.20 ± 1.37	0.48 ± 2.01
Bottom	0.20 ± 0.70	0.00	0.09 ± 0.74	0.29 ± 1.16
P -level	NS	—	—	NS
3. Tide				
Flood	0.14 ± 0.62	0.00	0.25 ± 1.53	0.39 ± 2.04
Ebb	0.34 ± 0.97	0.00	0.04 ± 0.28	0.33 ± 1.10
P -level	NS	—	—	NS
4. Light				
Day	0.14 ± 0.62	0.00	0.25 ± 1.53	0.39 ± 2.04
Night	0.34 ± 0.97	0.00	0.04 ± 0.28	0.39 ± 1.10
P -level	NS	—	—	*P*< 0.05**

*Significance at *P*< 0.05, ** significance at *P*< 0.01, NS – no significance; homogenous groups indicated by superscripts a and b

5.2.3.5 Clupeidae

Clupeidae was exclusively collected during wet season. Total larvae in wet season were 0.4 ± 1.9 N.100m^{-3}. Total preflexion and postflexion larvae were 0.02 ± 0.31 N.100m^{-3} and 0.3 ± 1.8 N.100m^{-3}, respectively (Table 5.16). Preflexion larvae were only caught in 1Q (0.1 ± 0.6 N.100m^{-3}). However, postflexion stage was caught in all lunar phase. Postflexion larvae were significantly higher in 1Q ($P < 0.01$) (mean 1.1 ± 3.5 N.100m^{-3}). All clupeids were only found at night time. Higher abundance of clupeids was also observed during ebb tide. The larvae enter mangrove waters presumably to feed on the richer zooplankton resources found during night time. Higher abundance of clupeid caught during ebb tides may suggest their strategy to maintain in the estuary at this condition.

5.2.3.6 Cynoglossidae

Only preflexion Cynoglossidae were recorded in dry season with mean of 0.2 ± 0.8 N.100m^{-3} (Table 5.17). They were collected only at neap tides (1Q < 3Q) ($P< 0.01$). Total mean density Cynoglossidae found in wet season is 0.3 ± 1.1 N.100m^{-3} (Table 5.18). Similar to dry season, cynoglossids were only found in neap tide (1Q < 3Q) ($P< 0.01$). Preflexion larvae were higher at night time. Preflexion larvae were higher in 3Q at night time. In 1Q, preflexion larva was only collected during flood tide.

Table 5.16. Mean density of Clupeidae (±SD) and summary of non-parameteric Kruskal-Wallis ANOVA in relation to lunar phase, depth and tide during wet season.

	Preflexion	**Flexion**	**Postflexion**	**Total**
Season	0.02 ± 0.31	0.00	0.34 ± 1.83	0.36 ± 1.93
1. Lunar phase				
First Quarter	0.09 ± 0.62	0.00	1.13 ± 3.51[a]	1.22 ± 3.70[a]
Full Moon	0.00	0.00	0.08 ± 0.40[b]	0.08 ± 0.40[b]
Third Quarter	0.00	0.00	0.09 ± 0.43[b]	0.09 ± 0.43[b]
New Moon	0.00	0.00	0.05 ± 0.35[b]	0.05 ± 0.35[b]
P -level	—	—	*P*< 0.01**	*P*< 0.01**
2. Depth				
Surface	0.04 ± 0.44	0.00	0.44 ± 2.47	0.49 ± 2.61
Bottom	0.00	0.00	0.24 ± 0.80	0.24 ± 0.80
P -level	—	—	NS	NS
3. Tide				
Flood	0.04 ± 0.44	0.00	0.18 ± 0.88	0.23 ± 1.23
Ebb	0.00	0.00	0.50 ± 2.44	0.50 ± 2.44
P -level	—	—	NS	NS
4. Light				
Day	0.00	0.00	0.00	0.00
Night	0.05 ± 0.46	0.00	0.74 ± 2.66	0.79 ± 2.80
P -level	—	—	—	—

** Significance at *P*< 0.01, NS - no significance; homogenous groups indicated by superscripts a and b

Table 5.17. Mean density of Cynoglossidae (±SD) and summary of non-parametric Kruskal-Wallis ANOVA in relation to lunar phase, depth, tide and light during dry season.

	Preflexion	**Flexion**	**Postflexion**	**Total**
Dry Season	0.21 ± 0.85	0	0	0.21 ± 0.85
1. Lunar phase				
First Quarter	0.23 ± 0.79	0	0	0.23 ± 0.79
Full Moon	0.	0	0	0.00
Third Quarter	0.61 ± 1.43	0	0	0.61 ± 0.43
New Moon	0.	0.	0	0
P -level	*P*< 0.01**	—	—	*P*< 0.01**
2. Depth				
Surface	0.15 ± 0.73	0	0	0.15 ± 0.73
Bottom	0.27 ± 0.95	0	0	0.27 ± 0.95
P -level	NS	—	—	NS
3. Tide				
Flood	0.27 ± 1.04	0	0	0.27 ± 1.04
Ebb	0.15 ± 0.60	0	0	0.15 ± 0.60
P -level	NS	—	—	NS
4. Light				
Day	0.27 ± 1.01	0	0	0.27 ± 1.01
Night	0.12 ± 0.55	0	0	0.12 ± 0.55
P -level	NS	—	—	NS

** Significance at *P*< 0.01, NS - no significance

Table 5.18. Mean density of Cynoglossidae (±SD) and summary of non-parametric Kruskal-Wallis ANOVA in relation to lunar phase, depth, tide and light during wet season.

	Preflexion	**Flexion**	**Postflexion**	**Total**
Wet Season	0.23 ± 1.04	0.00	0.02 ± 0.22	0.25 ± 1.06
1. Lunar phase				
First Quarter	0.28 ± 1.21	0.00	0.09 ± 0.44	0.37 ± 1.26
Full Moon	0.00	0.00	0.00	0.00
Third Quarter	0.64 ± 1.63	0.00	0.00	0.64 ± 1.63
New Moon	0.00	0.00	0.00	0.00
P -level	*P*< 0.01**	—	—	*P*< 0.01**
2. Depth				
Surface	0.27 ± 1.00	0.00	0.02 ± 0.24	0.29 ± 1.02
Bottom	0.19 ± 1.08	0.00	0.02 ± 0.21	0.21 ± 1.09
P -level	NS	—	—	NS
3. Tide				
Flood	0.32 ± 1.36	0.00	0.02 ± 0.24	0.35 ± 1.38
Ebb	0.14 ± 0.54	0.00	0.02 ± 0.21	0.16 ± 0.57
P -level	NS	—	—	NS
4. Light				
Day	0.18 ± 1.19	0.00	0.00	0.18 ± 1,19
Night	0.29 ± 0.83	0.00	0.05 ± 0.33	0.34 ± 0.88
P -level	*P*< 0.05 *	—	—	*P*< 0.01**

*Significance at *P*< 0.05, ** significance at *P*< 0.01, NS - no significance

5.2.3.7 Ambassidae

Total mean density was 0.08 ± 0.50 N.100m^{-3} in dry season (Table 5.19). Ambassidae was not sampled in FM. Preflexion ambassid was only collected in NM 0.06 ± 0.44 N.100m^{-3}. Postflexion was observed to be higher in 1Q (0.2 ± 0.8 N.100m^{-3}) than 3Q (0.04 ± 0.28 N.100m^{-3}) and NM (0.11 ± 0.53 N.100m^{-3}). There was no significant difference between all the effects. Ambassid larvae collected in dry season had the affinity of greener waters.

Total mean density of ambassid was 0.17 ± 1.26 N.100m^{-3} (Table 5.20). Ambassidae was not collected in FM. Preflexion ambassid were only recorded in 3Q (0.09 ± 0.43 N.100m^{-3}). Postflexion ambassids were only collected in 1Q and NM. Postflexion ambassid recorded in 1Q was abundant at the surface of the water column (*P* < 0.05). On the other hand, ambassids were abundant at the bottom water during new moon. The abundance of ambassid larvae correlated well with higher zooplankton abundance (>500 µm). Highest abundance was recorded in wet season, at neap flood tide.

Table 5.19. Mean density of Ambassidae (±SD) and summary of non-parametric Kruskal-Wallis ANOVA in relation to lunar phase, depth, tide and light during dry season.

	Preflexion	**Flexion**	**Postflexion**	**Total**
Dry Season	0.02 ± 0.22	0.00	0.06 ± 0.46	0.08 ± 0.50
1. Lunar phase				
First Quarter	0.00	0.00	0.17 ± 0.82	0.17 ± 0.82
Full Moon	0	0.00	0.00	0.00
Third Quarter	0.00	0.00	0.04 ± 0.28	0.04 ± 0.28
New Moon	0.06 ± 0.44	0.00	0.04 ± 0.31	0.11 ± 0.53
P -level	—	—	NS	NS
2. Depth				
Surface	0.03 ± 0.31	0	0.06 ± 0.48	0.10 ± 0.56
Bottom	0.00	0.00	0.06 ± 0.44	0.06 ± 0.44
P -level	—	—	NS	NS
3. Tide				
Flood	0.03 ± 0.31	0.00	0.09 ± 0.53	0.12 ± 0.61
Ebb	0.00	0.00	0.04 ± 0.38	0.04 ± 0.38
P -level	—	—	NS	NS
4. Light				
Day	0.03 ± 0.29	0.00	0.06 ± 0.44	0.08 ± 0.53
Night	0.00	0.00	0.07 ± 0.48	0.07 ± 0.48
P -level	—	—	NS	NS

NS - no significance

Table 5.20. Mean density of Ambassidae (±SD) and summary of non-parametric Kruskal-Wallis ANOVA in relation to lunar phase, depth, tide and light during wet season.

	Preflexion	**Flexion**	**Postflexion**	**Total**
Wet Season	0.02 ± 0.22	0.00	0.15 ± 1.24	0.17 ± 1.26
1. Lunar phase				
First Quarter	0.00	0.00	0.37 ± 1.54	0.37 ± 2.19
Full Moon	0.00	0.00	0.00	0.00
Third Quarter	0.09 ± 0.43	0.00	0.00	0.09 ± 0.43
New Moon	0.00	0.00	0.21 ± 1.17	0.21 ± 1.17
P -level	—	—	NS	NS
2. Depth				
Surface	0.00	0.00	0.18 ± 1.55	0.18 ± 1.55
Bottom	0.04 ± 0.31	0.00	0.11 ± 0.83	0.15 ± 0.88
P -level	—	—	NS	NS
3. Tide				
Flood	0.02 ± 0.21	0.00	0.21 ± 1.57	0.23 ± 1.58
Ebb	0.02 ± 0.23	0.00	0.08 ± 0.80	0.10 ± 0.83
P -level	—	—	NS	NS
4. Light				
Day	0.02 ± 0.20	0.00	0.10 ± 0.80	0.12 ± 0.83
Night	0.03 ± 0.24	0.00	0.20 ± 1.62	0.22 ± 1.63
P -level	—	—	NS	NS

NS - no significance

5.2.3.8 Other families

In this study, Syngnathidae consistsed of *Ichthyocampus carce* and *Hippocampus trimaculatus* where most consisted of early juveniles. Mean density of Syngnathidae during dry and wet season were 0.18 ± 0.59 N.100m^{-3} and 0.12 ± 0.49 N.100m^{-3}, respectively (Table 5.21 and 5.22). There was no significant difference between lunar phase, depth, tide and light during both dry and wet season. Syngnathidae has a preference to more saline and greener waters. Syngnathids were more abundant in dry season.

Platycephalidae larva was only collected in dry season (N=1) during full moon. It was found at the surface tow during night flood tide (Table 5.21). Mean density was 0.08 ± 0.55 N.100m^{-3}. Platycephalid was collected in turbid waters and have a preference to phytoplankton.

Leiognathidae larva was recorded in 1Q during dry season (N=1) and in 3Q during wet season (N=2), with mean of 0.05 ± 0.36 N.100m^{-3} and 0.05 ± 0.33 N.100m^{-3}, respectively. In dry season, leiognathids were found at surface tow during day flood. In wet season, they were found at surface tow in night ebb and flood.

Scorpaenidae larvae were recorded in third quarter moon during night flood in both dry (N=1) and wet season (N=1). The difference was the depth where they were caught. Scorpaenidae larvae were recorded during surface tows in dry season while they were found at the bottom in wet season. Scorpaenidae had a preference to larger sized zooplankton in both dry and wet season.

Belonidae larva was only recorded in dry season with mean of 0.01 ± 0.15 N.100m^{-3}. It was recorded in 3Q at surface tow during day ebb. It was found in greener waters. Hemiramphidae larva was only found in dry season (N=1) in NM with density of 0.05 ± 0.15 N.100m^{-3}. It was recorded at the surface water during day flood. Tetraodontidae larva was only found in wet season (N=1). It was recorded in 1Q during day ebb at the bottom water. It preferred warmer water and larger-sized zooplankton.

Juvenile mugilids were only recorded in wet season (N=3). Mean density was 0.16 ± 0.79 N.100m^{-3}. They were recorded in NM, at surface tow during night flood. Mugilids preferred less saline waters. Mean abundance of unidentified fish larvae

Table 5.21. Mean density of other families (±SD) and summary of non-parametric Kruskal-Wallis ANOVA in relation to lunar phase, depth, tide and light during dry season**.**

	Syngnathidae	**Platycephalidae**	**Leiognathidae**	**Scorpaenidae**	**Hemiramphidae**	**Unidentified**
Dry Season	0.18 ± 0.59	0.02 ± 0.27	0.01 ± 0.18	0.01 ± 0.13	0.01 ± 0.11	0.51 ± 2.04
1. Lunar phase						
First Quarter	0.11 ± 0.51	0.00	0.05 ± 0.36	0.00	0	0.11 ± 0.55[a]
Full Moon	0.25 ± 0.68	0.08 ± 0.55	0.00	0.00	0	0.00[a,c]
Third Quarter	0.21 ± 0.63	0.00	0.00	0.04 ± 0.27	0	0.83 ± 2.47[a,b]
New Moon	0.16 ± 0.53	0.00	0.00	0.00	0.05 ± 0.32	1.12 ± 3.09[b]
P -level	NS	—	—	—	—	*P*< 0.01**
2. Depth						
Surface	0.14 ± 0.50	0.04 ± 0.39	0.03 ± 0.25	0.02 ± 0.19	0.02 ± 0.22	0.37 ± 1.43
Bottom	0.22 ± 0.67	0.00	0.00	0.00	0	0.65 ± 2.50
P -level	NS	—	—	—	—	NS
3. Tide						
Flood	0.22 ± 0.65	0.04 ± 0.39	0.03 ± 0.25	0.02 ± 0.19	0.02 ± 0.22	0.24 ± 0.94
Ebb	0.15 ± 0.52	0.00	0.00	0.00	0	0.79 ± 2.70
P -level	NS	—	—	—	—	NS
4. Light						
Day	0.20 ± 0.63	0.00	0.02 ± 0.23	0.00	0.02 ± 0.21	0.49 ± 1.78
Night	0.15 ± 0.53	0.05 ± 0.42	0.00	0.02 ± 0.21	0	0.54 ± 2.36
P -level	NS	—	—	—	—	NS

** Significance at *P*< 0.01, NS - no significance; homogenous groups indicated by superscripts a, b and c

Table 5.22. Mean density of other families (±SD) and summary of non-parametric Kruskal-Wallis ANOVA in relation to lunar phase, depth, tide andlight during wet season.

	Syngnathidae	**Leiognathidae**	**Scorpaenidae**	**Tetraodontidae**	**Mugilidae**	**Unidentified**
Wet Season	0.12 ± 0.49	0.02 ± 0.23	0.01 ± 0.17	0.01 ± 0.15	0.04 ± 0.40	0.15 ± 0.61
1. Lunar phase						
First Quarter	0.17 ± 0.57	0.00	0.00	0.04 ± 0.30	0.00	0.34 ± 0.87
Full Moon	0.17 ± 0.59	0.00	0.00	0.00	0.00	0.16 ± 0.64
Third Quarter	0.09 ± 0.44	0.09 ± 0.46	0.05 ± 0.33	0.00	0.00	0.06 ± 0.41
New Moon	0.05 ± 0.33	0.00	0.00	0.00	0.16 ± 0.79	0.05 ± 0.36
P -level	NS	—	—	—	—	NS
2. Depth						
Surface	0.15 ± 0.55	0.05 ± 0.33	0.00	0.00	0.08 ± 0.56	0.19 ± 0.63
Bottom	0.09 ± 0.43	0.00	0.02 ± 0.23	0.02 ± 0.21	0.00	0.12 ± 0.59
P -level	NS	—	—	—	—	NS
3. Tide						
Flood	0.09 ± 0.43	0.02 ± 0.23	0.02 ± 0.23	0.00	0.08 ± 0.56	0.18 ± 0.71
Ebb	0.15 ± 0.55	0.02 ± 0.23	0.00	0.02 ± 0.21	0.00	0.12 ± 0.49
P -level	NS	—	—	—	—	NS
4. Light						
Day	0.12 ± 0.50	0.00	0.00	0.02 ± 0.20	0.00	0.19 ± 0.70
Night	0.12 ± 0.48	0.05 ± 0.34	0.03 ± 0.25	0.00	0.09 ± 0.58	0.10 ± 0.48
P -level	NS	—	—	—	—	NS

NS - no significance

recorded during dry and wet season was 0.51 ± 2.04 N.100m^{-3}and 0.15 ± 0.61 N.100m^{-3}, respectively.

5.3 DISCUSSION

5.3.1 Seasonality and Tidal Effect

The different season, lunar phases, tidal conditions and day/night cycle are likely to affect distributions and compositions of fish larvae in mangrove habitats. In tropical mangrove waters, the rainfall has been considered as one of the most important variable affecting the seasonal patterns of fish abundance (Robertson & Duke, 1990; Rooker & Dennis, 1991). The correlation between larval fish abundance and rainfall (as observed in wet season) is usually associated with an increase in plankton availability at the onset of the rainy season (Cushing, 1990; Ikejima et al., 2003). The abundance of total fish larval density in the present study was significantly higher (nearly five times) during wet season than dry season at the river mouth of Sangga Kecil. Ikejima et al. (2003) also reported higher abundance of juvenile fishes in the wet season in a mangrove estuary in Thailand. This kind of seasonal changes in the abundance of fishes may be an indication of their breeding patterns (Robertson & Duke, 1990b) and changes in food availability in the estuary (Robertson & Duke, 1990a). Chew & Chong (2011) also observed greater abundance of zooplankton especially copepods, which is the main food to fish larvae, during the wet season in Matang mangrove estuary. This could explain the higher abundance of fish larvae during the wet season as food was abundant. In a tropical mangrove estuary in Australia, the wet season was observed to coincide with highest recruitment period of juvenile fishes and highest zooplankton abundance (Robertson et al. 1988; Robertson & Duke, 1990b). Studies in east Africa often associate spawning and recruitment activities with the monsoon seasons and rainfall patterns (Okera, 1974; Nzioka, 1983). The turbid waters which occur during wet season also reduce the

visibility in the water column and thus minimize the effectiveness of large visual fish predators to prey on smaller fishes (Blaber & Blaber, 1980). This could also explain the higher abundance of fish larvae captured during wet season as escapement of larvae was low due to lower visibility.

There were 15 fish larval families recorded for the eight 24-hr studies during the dry and wet season, out of which two families were dominant, Gobiidae and Engraulidae. Both families were also found in great numbers in the mangrove estuary and adjacent waters during the 18-month sampling where 19 fish larval families were found (see Chapter 4). The influx of fishes at the river mouth of Sangga Kecil did not differ significantly between seasons as both seasons recorded twelve fish larval families each. Generally, different seasons will show specific family variations in abundance due to different larval recruitment, survival rate, growth rate and reproduction rate (Robertson & Duke, 1990b). However, in this study, specific family variations of the fish larvae was not clearly shown between the two months representing the dry and wet season, but instead, higher abundance of total larvae of only a few fish families was observed. Total larva (N) caught in wet season was four times higher than the dry season. Mean total Gobiidae was 4.7 times higher in the wet season while the engraulid was 5.6 times higher. Nevertheless, the results obtained were partly comparable with other studies. Barletta-Bergan et al. (2002a, b) reported that estuary-spawning species showed highest abundance during the dry season while the coastal-spawning species during the rainy season. They also observed that the species richness, diversity and evenness in mangrove creeks were highest in the early rainy season.

Abundance of gobiid larvae was 4.7 times higher in November (wet season) than in July (dry season). The higher occurrence of gobiid larvae in wet season during new

moon suggests a spawning period as their life stages mainly consisted of yolk-sac and preflexion stages. The spring tide is the period of maximum inundation of the mangrove forest floor where most of the gobies reside. Therefore, chances of the larvae being transported into the near shore areas are high as they are more widely dispersed during inundation. The high abundance of yolk-sac stage recorded during night catches indicate that spawning of certain species of gobies probably took place in the vicinity of the river mouth. Higher abundance of gobiid larvae (mean density of 1,256 N.100m^{-3}) was also observed during the monthly sampling at the river mouth in October 2003 (see Chapter 4, Figure 4.4). This could suggest more spawnings during this period, which extended to the following month of November, as observed in the diel study. Higher rainfall during these months might trigger the spawning of some species of Gobiidae. Blaber (2000) noted that spawning in the estuary during the wet season would ensure that a sufficient portion of eggs and larvae can be transported out to the seas by river discharge and hence dispersed.

Strong current flow during spring tides might yield higher nekton catches (Hampel et al., 2003). Thus, higher-water level is an important condition for tidal migration of fish into the estuary. With higher abundance of gobiid remaining at the bottom during flood tide, they might be performing vertical migrations at certain tidal phases (in this case, flood tide) in order to remain in the estuary and for feeding. In Belgium, Cattrijsse et al. (1994) found that the common goby's stomach index increases with flood tide and decreases with ebb indicating that gobies begin to feed when they enter the marsh where maximum consumption is reached at the first hour of flood. In this study, it was observed that the gobies remained in the water column during the changing of the tides especially at low water slack. The early flood tide initiated a peak

as it carried along dense batch of gobies, especially during full moon (see Figures 5.8 & 5.9).

Different recruitment patterns were observed in gobies during the dry season. Night catches for all developmental stages of gobies were more frequent during neap and spring tides. Nevertheless, the difference was more obvious in neap tides between day and night catch. Higher food sources were obtained as higher zooplankton biomass was recorded at night (See Figure 5.7b). Larger sized zooplankton biomass was positively correlated with abundance of preflexion and postflexion gobiids in neap tide.This observation suggests that gobies prefer to feed at calmer and lower visibility waters. During night time, fish larvae are less vulnerable to predation by larger visual dependent fish that enter the mangrove estuary to feed at night. Although there is no significant difference in abundance of larvae between depths, gobies were observed to be more abundant at surface during night time in spring tide especially at full moon. The low level of DO observed between 10pm-1am close to the bottom of the river indicates anoxic conditions (see Figure 5.3b). In addition to that, the high turbidity (>100 NTU) would have also caused the low abundance of larvae (see Figure 5.4b). The anoxic conditions and turbid water could cause low concentration of plankton in bottom waters and thus, explaining the negative correlation between preflexion larvae and dissolved oxygen during dry season in spring tide. This might also be a reason why gobiid larvae stayed at the surface during night time. In contrast, higher abundance of larvae was observed at the bottom water during day time.

Dispersal of fish larvae from marine spawning grounds into the estuaries is influenced by coastal currents (Boehlert &Mundy, 1988). Most of the species of Engraulidae constituted mainly of preflexion larvae. Hence, they were found to be

greater during neap tide especially at ebb tide. This observation is also reported by Sarpedonti (2000) in Sungai Selangor estuary where higher larval abundance of *Stolephorus baganensis* was recorded at ebb tide during both neap and spring tides. This observation might suggest their strategy to remain at the river mouth as they were also found more at the bottom water. Two major phases of movement into estuaries by Engraulidae might take place; the first phase is accumulation of larvae in the near shore waters while the second phase is the process of accumulation near the estuary mouth and eventually into the river using tidal transport. The postflexion and postlarval fishes would accumulate at the river mouth during ebb tide before making use of stronger water flow during flood tide to migrate into the mangrove estuary. Besides Engraulidae, Blenniidae larvae were also observed to adopt this strategy by remaining at the bottom during ebb tide. Blenniids could be using the same mechanism to enter the mangrove estuary.

In contrast to Gobiidae and Engraulidae where their abundance were higher in the wetter NE monsoon season, abundance of Sciaenidae and Syngnathidae larvae were higher in drier SW monsoon season. Preflexion Sciaenidae were only found during neap tide in both dry and wet season. This suggests their preference to reduced water movement during recruitment into the estuary, thus depends not solely on the tidal transport. Although movement to near shore areas may partly involve passive movement following the tides, some evidence from both experimental and field work pointed out that migration of early life stages into the estuary is an active process (Boehlert & Mundy, 1988). This includes the sciaenids (Weinstein et al., 1980). Higher abundance of preflexion sciaenid at the bottom during ebb tide could suggest that these taxa move to the bottom during ebb tide to avoid being transported to offshore waters.

Higher abundance of sciaenid observed in the dry season might be due to their reproduction activities when the environmental conditions are favorable. Yap (1995) pointed out that sciaenids such as *Johnius carouna* and *Johnius weberi* are thought to spawn when salinity and dissolved oxygen increases in the dry season. This could explain the higher abundance of preflexion larvae of Sciaenidae reported in this study during dry season when salinity was higher (Table 5.12). Clupeidae, Tetraodontidae and Mugilidae were only recorded in the wet season. This might be related to the favorable environmental conditions (e.g. lower salinity) for them to enter the mangrove estuary. No clear conclusion of seasonal variations could be made to other fish larval families due totheir scarcity in the samples.

5.3.2 Lunar Phase Effect

The lunar phase may affect transport of larvae into estuaries, but the mechanism is unknown (Boehlert & Mundy, 1988). Tzeng (1985) obtained higher catches of elvers in the inner river at both full and new moon which are related to spring tides. Nevertheless, based on some studies, the lunar cycle is likely to have minor importance in regulating the composition and abundance of mangrove ichthyofauna (e.g. Boehlert & Mundy, 1987; Krumme et al., 2004). In the Vellar estuary in southeast India, the abundance of larvae was positively correlated with lunar cycle and was 2.1 times greater at the rising tide. This suggests a recruitment influenced by lunar phases and tidal stream transport (Thangaraja, 1995). The present study made some interesting observations where different families showed different peak densities in the lunar cycle at different seasons. For example, the gobiids were highly concentrated during spring tide where higher abundance was observed at full moon during dry season and new moon during the wet season. Different lunar periodicity was also observed in engraulids. Catches were more abundant in neap tides during third quarter moon in dry season and first quarter moon in

wet season. Similar to engraulids, the clupeids were observed to be higher during neap tides.

As observed in the present study, some fish larval families and some ontogenetic stages were only present at certain lunar phase. Preflexion sciaenids were only found during neap tide, while preflexion blenniids were abundant in new moon. Interestingly, *A. gymnocephalus* was not found during the full moon at both dry and wet season. This could be a strategy employed to avoid predators during a clear bright night. Cynoglossidae was only recorded at neap tide during dry and wet season. This might suggest that the cynoglossids prefer calmer water when penetrating the estuary.

5.3.3 Diel Activity Pattern

Differences in the abundance of fish larvae at night and day have been reported by many studies for a wide variety of aquatic habitats (e.g. in coral reef, Kingsford, 2001; temperate estuary, Hagan & Able, 2008). The present 24-hr sampling at a fixed station following lunar cycle for dry and wet season did not show any clear diel activity pattern for the majority of the fish larval families. In terms of family presence, eight (53.3%) fish larval families were diurnal (i.e. equally active day and night). This percentage falls within the 50% - 60% expected of diurnal or continually active species in a typical fish assemblage (Helfman et al., 1997; Ley et al., 2007). If samplings were only performed during the day, 26.7% (4 families) of the larval fish families would not have been recorded as they were present only from night samples. In contrast, by sampling at night, 20% (3 families) of the larval fish families would not have been sampled as they were present only from day samples.

Total fish larva was higher at night than day during dry season. In contrast, total fish larva was higher at day time during the wet season. Ali-Khan (1980) found two to four times more larvae during night time as compared to day time in the Gulf of Aden (East Africa). Nevertheless, whether higher night time abundance of fish larvae really occurs or simply a result of net avoidance during the day has been a contentious issue. Avoidance of plankton nets during the day is well known for many larval fish (Morse, 1989). The higher night catch during the dry season could be due to the higher salinity in the water column which encourages more migrant species into the mangrove estuary. In contrast, the wet season which often creates a salt wedge in the estuary limits the migration of marine species into the estuary during night time.

The reasons for diel differences in abundance are numerous and are specific to the behaviour and development stage of a species. In the present study, the most abundant and frequently caught larval fish families that were found to exhibit vertical migration were Gobiidae and Engraulidae. In the dry season, almost all developmental stages of Gobiidae were higher in number by two fold at night, being concentrated at the bottom water of the river mouth. Olivar & Sabatés (1997) gave evidence of nychthemeral migrations in *Crystallogobius linearis* which were not collected during daytime, indicating that the larvae probably stayed closer to the bottom during daytime. The salt wedge of higher bottom salinity water during flood tide may be preferred by gobiids. Increased number of gobiids during night time might be due to higher night-time protection provision and greater food resources. However, a different strategy was observed during the wet season whereby Gobiidae abundance was observed to be two times higher at day time, concentrating at the surface waters. 92.3% of these larvae were preflexion larvae. This observation seems to suggest that the well-mixed and less saline water column during the wet season induces the preflexion gobiid to migrate up to the

surface waters. However, the yolk-sac stage of Gobiidae was abundant at night during the wet season (30.5% of the total larvae at night). Higher abundance of yolk-sac stage indicated that nocturnal spawning probably takes place within the mangrove estuary. The spawning and dispersal of larvae during night time may lower the risk of predation as visibility is low. North & Houde (2004) observed that night time spawning of sciaenids was evident from the collected eggs. Peak concentration of sciaenid eggs also occurred during the evening in Peconic Bay, New York (Ferraro, 1980).

Engraulids were observed to be higher during the transition of tide and during dusk or dawn. Preflexion engraulids were mainly concentrated in the entire water column at day time during the dry season. However, flexion larvae were generally found at the surface water at night time during the wet season. The engraulid larvae might have their swim bladder inflated during night time. This observation was also similar to a study carried out by Olivar & Sabates (1997) in which they found that anchovy larvae of more than 7 mm occurred in surface hauls. Other stages of engraulids were found throughout the water column either during day or night.

North & Houde (2004) reported that the light/dark cycle is a cue for inflation and deflation of swim bladders by bay anchovy larvae in Chesapeake Bay. Sarpedonti (2000) however, observed that the anchovy larvae (*Stolephorus baganensis*) in Sungai Selangor, Malaysia were essentially found at the surface of the water column independent of time of the day. Garrido et al. (2009) observed that the majority of larval fish species (*Sardina pilchardus*, *Diplodus* spp., *Symphodus melops*, *Parablennius gattorugine* and *Spondyliosoma cantharus*) were also concentrated in surface waters during the night and spreading throughout the water column during daylight hours, in a 69-hour sampling. It is generally accepted that at night fish larvae inflate their air-

bladder and congregate at the surface of the water column where they are captured in high concentration (Ré, 1987). This reduction in swimming activity at night not only conserves energy but also makes the larvae less noticeable by predators such as carnivorous copepods and chaetognaths, which detect their prey through vibrations (Yamashita et al., 1985; Ré, 1987; Leis, 1991). Fish larvae may aggregate in low velocity shoreline margins during the day time (Gadomski & Barfoot, 1998). Gadomski & Barfoot, (1998) suggested that young larvae with undeveloped air bladder are more subject to drifting with the current during night or perhaps because of their minimal visual orientation in the darkness. Other similar research showed that the higher abundance of large larvae at night could be a consequence of their inability to detect or avoid the net in darkness (McGurk, 1992).

Availability of food resources regulates diel vertical distribution among fishes. Estuarine ambassids consume copepods and a variety of crustaceans (Hajisamae et al, 2004, Baker & Sheaves, 2005), with feeding peaks in the early evening and early morning (Martin and Blaber, 1983). Dispersion patterns of fish larvae suggest that larval size smaller than, and larger than 5.0 mm exhibit reciprocal diel vertical migration behaviour linked to ontogenetic changes in diet. Larvae less than 5 mm fed only during the day and preyed exclusively on rotifers, whereas larger larvae continued to feed at night and consumed mostly planktonic crustaceans (Gehrke, 1992).

Due to the patchiness of larval fish distribution, some less abundant families were not easily encountered. Some families were only restricted to either surface or near-bottom water and were scarce in the samples. Juvenile Mugilidae, a well-known long-distance migratory species (Nelson, 2006) were collected in the surface waters during night flooding. They might be following the flood tide to enter the estuary to

feed as night time provides more food resources. This nocturnal feeding trend of some Mugilidae was also observed in another tropical mangrove creek (Laroche et al., 1997). However, the pattern of diel vertical distribution of fish larvae can vary significantly with environmental conditions, food availability and oceanographic features.

5.3.4 Effects of Physical Factors and Plankton

Species-specific behavioral responses to physical factors may result in different distributions among fish larval families within the estuary. A suite of physical factors may serve as cues for such behavior (Boehlert & Mundy, 1988). North & Houde (2004) found that the mechanisms and processes that influence the distribution and dispersal of bay anchovy (*Anchoa mitchilli*) early life stages are linked to physical and biological conditions as well as to larval developmental stage. The water characteristics of Matang mangrove estuaries are not highly variable in the sense that parameters such as salinity, temperature, pH, turbidity, dissolved oxygen concentrations and water currents do not fluctuate greatly both temporally and spatially (Chong et al. 1999). Nevertheless, fish larvae may respond differently to changes in the various water parameters depending on their sensitivity and tolerance, and using that to facilitate recruitment.

Salinity and other water parameters such as turbidity, temperature, pH and oxygen were relatively different between the dry and wet season in Sangga Kecil estuary. Among the water parameters, salinity was the most distinctively different between dry and wet seasons. Salinity is known to affect stress level, osmoregulation, metabolism and growth rates of various marine organisms that will dictate their abundance (e.g. Grossman et al., 1998; Sagasti et al., 2001; Shriver et al., 2002). The average surface salinity during dry season was nearly 6‰ higher than in the wet season. Fish assemblages in almost all mangrove estuaries are subject to changes in salinity (Lin

& Shao, 1999; Blaber, 2002). Nevertheless, most fishes in the tropical estuaries are broadly euryhaline (Blaber, 1997), therefore, salinity may not be all important in structuring the fish assemblages. In the present study, the abundance of preflexion and flexion engraulids were highly correlated to salinity. Some of these larvae might belong to species which spawn in offshore waters and rely on higher salinity condition for reproduction. However, not all species of Engraulidae spawn in offshore waters. Sarpedonti (2000) observed higher larval abundance of *Thryssa kammalensis* in less saline surface waters. This observation was also similar with Wang & Tzeng (1999). Therefore, some engraulid of *Thryssa* genus may spawn around nearshore areas, near to the river mouth. The Gobiidae, Mugilidae, Leiognathidae and Scorpaenidae larvae however were observed to prefer less saline and higher turbidity waters. All life stages of gobiid were observed in less saline waters over muddy substrate. This was also observed by Blaber & Milton (1990).

Higher turbidity level during the wet season could lead to higher abundance of engraulids in this study. Turbid water might act as a cue directing fish larvae into the mangrove estuary. Blaber et al. (1997) suggested that higher turbidity estuaries support larger number of engraulids and clupeids in Sarawak, Malaysia. The DO concentrations could be an important factor influencing predator-prey interactions (North & Houde, 2004; Keister et al. 2000). Keister (2000) demonstrated that the naked goby (*Gobiosoma bosc*), bay anchovy larvae and copepod concentrations declined when DO levels were < 2.0mgL^{-1}. Similar to the present study, the gobiids and engraulids migrated up to the surface water when the DO level dropped drastically (< 3mgL^{-1}) especially at night. This was apparent during spring tide (full moon) in the dry season.

Even though physical parameters play an important role in structuring the fish larval assemblages, yet some studies showed otherwise. Joyeux et al. (2004) found that the structure and abundance of fish community did not present any obvious correlation with freshwater input, salinity and water temperature.

5.4 CONCLUSIONS

Larval fish assemblages occurring at the Matang mangrove estuary were influenced by rainfall, salinity, DO concentration, plankton, lunar phase, tidal phase and time of day. These factors were characteristic by fish families and ontogenetic stages.No clear vertical migration patterns were observed.

CHAPTER 6

RELATIONSHIP OF LARVAL FISH ABUNDANCE WITH ENVIRONMENTAL FACTORS

Summary of Important Findings

Salinity, turbidity and zooplanktonic food sources are the major environmental factors in structuring the larval fish assemblages in Matang mangrove estuary waters. Surface water temperature is higher inside the mangrove estuary than the offshore areas. Salinity increases from inshore to offshore, ranging from 14.8 ± 7.18 ‰ at 10.6 km upstream (Station 1) to 30.8 ± 1.45 ‰ at 16 km offshore (Station 7). Higher fluctuations (larger SD values) were observed in the mangrove stations for all the water parameters except turbidity. Canonical Correspondence Analysis (CCA) revealed that the larval fish assemblages including their ontogenetic stages differed between the mangrove estuary and adjacent offshore waters. All larval stages of Gobiidae, and the postflexion and postlarvae of Engraulidae, Syngnathidae, Mullidae, Leiognathidae and Terapontidae appeared to prefer the less saline but more turbid water in the mangrove, which also contained relatively higher concentrations of chlorophyll *a* and zooplankton. The chlorophyll *a* concentration was also positively correlated with all developmental stages of gobiid and prefexion engraulid ($P < 0.001$) in the offshore waters.

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6.1 INTRODUCTION

Estuaries are ecosystems characterized by environmental fluctuations (Whitfield, 1990). The rapid changes in temperature, salinity, oxygen and turbidity occur due to the effects of tides and the mixing of marine and fresh water (McLusky & Elliot, 2004). It is still

unclear why juveniles and larvae of so many fish species are attracted to mangrove forest over adjacent habitats. The fish communities living in such harsh environment should contain fewer species when interspecific competition is prevalent (Harris & Cyrus, 2000). Environmental factors such as temperature, salinity, turbidity and pH are known to attract late stage larvae, with suitable transport processes/ currents to these nursery grounds (Boehlert & Mundy, 1988; Miller et al., 1988). Few important environmental factors which could influence their growth rate include temperature (Sponaugle et al., 2006), salinity (Jana et al, 2006; Labonne et al., 2009) and food availability (Admassu & Ahlgren, 2000). The dynamic nature of these factors in the mangrove estuary will have a strong bearing on larval recruitment and survival in the mangrove and therefore on the structure and abundance of the juvenile fish community.

Early developmental stages of fishes are highly dependent on physical and biological processes. The variation across spatial and temporal scales (Robertson & Duke, 1990), with environmental variables (Griffiths, 2001; Ramos et al., 2006) creates the distinct larval fish assemblages associated with the dynamic nature of estuaries (Drake & Arias, 1991). Environmental factors may affect communities indirectly by influencing physiological and behavioural responses of organisms and directly by, affecting the distribution and abundance patterns of each species (Moser & Smith, 1993).

It is thus hypothesized that the physical and biological factors are responsible for the spatial and temporal differences of the fish larval assemblages in MMFR. To test this hypothesis, the following approach was taken: (1) measure and describe the environmental characteristics of the Matang mangrove estuary and adjacent coastal waters and (2) relate the abundance of larval fish to the physical and biotic

characteristics of the mangrove estuary and coastal waters using Canonical Correspondence Analysis.

The match-mismatch hypothesis (Cushing, 1975) postulates that the timing of fish spawning is linked to larval food availability in temperate waters because of the regular seasonal cycles in temperature and irradiance. This is important to reduce wastage and conserve energy because only then can spawners cue their reproduction to food production at exactly the same season. The recruitment variability results from either a 'match' of larval abundance (spawning) with its food which would increase larval survival, or a 'mismatch' resulting in subsequent recruitment failure. However, this hypothesis may be less relevant in the estuarine than in the marine environment as larval presence is extended and the high density of food is constantly available to fish larvae in tropical waters (Newton, 1996).

The match-mismatch hypothesis appeared to explain larval prawn (Chong, 1993) and larval engraulid recruitment in tropical waters (Sarpedonti & Chong, 2001). They showed that the peaks of larval penaeid and engraulid abundance 'matched' the peaks of abundance for phytoplankton and zooplankton respectively. The cue for prawn or fish spawning is apparently provided by the regional, large scale meteorological event – the monsoons, whose arrivals in April (SW Monsoon) and November (NE Monsoon) are regular but no doubt variable. Thus, it would be enlightening to test the match-mismatch hypothesis further in tropical waters given the available data obtained from this study (see Chapter 2, Section 2.5.4.3 for Methodology). This study will test the hypothesis based on the abundance of the preflexion larvae of Gobiidae and Engraulidae, the two most dominant families.

6.2 RESULTS

6.2.1 Environmental Parameters

6.2.1.1 Rainfall

The annual total rainfall for 2002 and 2003 was 3483.5 mm and 4198.8 mm respectively. The average monthly precipitation was 290.3 mm (± 161.3 mm) and 349.9 mm (± 173.1 mm) respectively for year 2002 and 2003 (Figure 6.1). Based on the SPI, the mean monthly rainfall regime showed drier weather conditions from May to July and wetter weather conditions from November to April. The rainfall data showed a relatively lower number of rainy days and amount of rainfall between May 2002 to August 2002 and May 2003 to September 2003 with an average rainfall of 10 mm or less than 10 mm monthly. During this study, July 2002 was the driest month which recorded a total rainfall of only 69.6 mm (mean 2.18 mm) with only 9 days of rain.

Two annual peaks for rainfall can be distinguished as the study area experienced wetter condition with the percentage of rainfall either at average or above average (323.8 mm). The February - April peak coincided with the Southwest monsoon (SW) period while the November - December peak coincided with the arrival of the Northeast monsoon (NE). The Southwest Monsoon, which is comparatively drier (< 323.8 mm mo^{-1}) starts from late May to September. However, the Northeast Monsoon brings heaviest rainfall (> 200 mm mo^{-1}) starts from early November to March. One-way ANOVA revealed significant differences in rainfall volume between the two monsoon seasons ($P < 0.05$). The two periods were interceded by two short periods (inter-monsoon) of variable winds, in April and October. Both months recorded relatively high monthly rainfall (281 mm in October 2002, 358 mm in April 2003 and 513 mm inOctober 2003) and rainy days. The ‘dry spell’ during the wetter NE monsoon is in January-February whereas the ‘wet spell’ during the SW monsoon is in August (Figure 6.1).

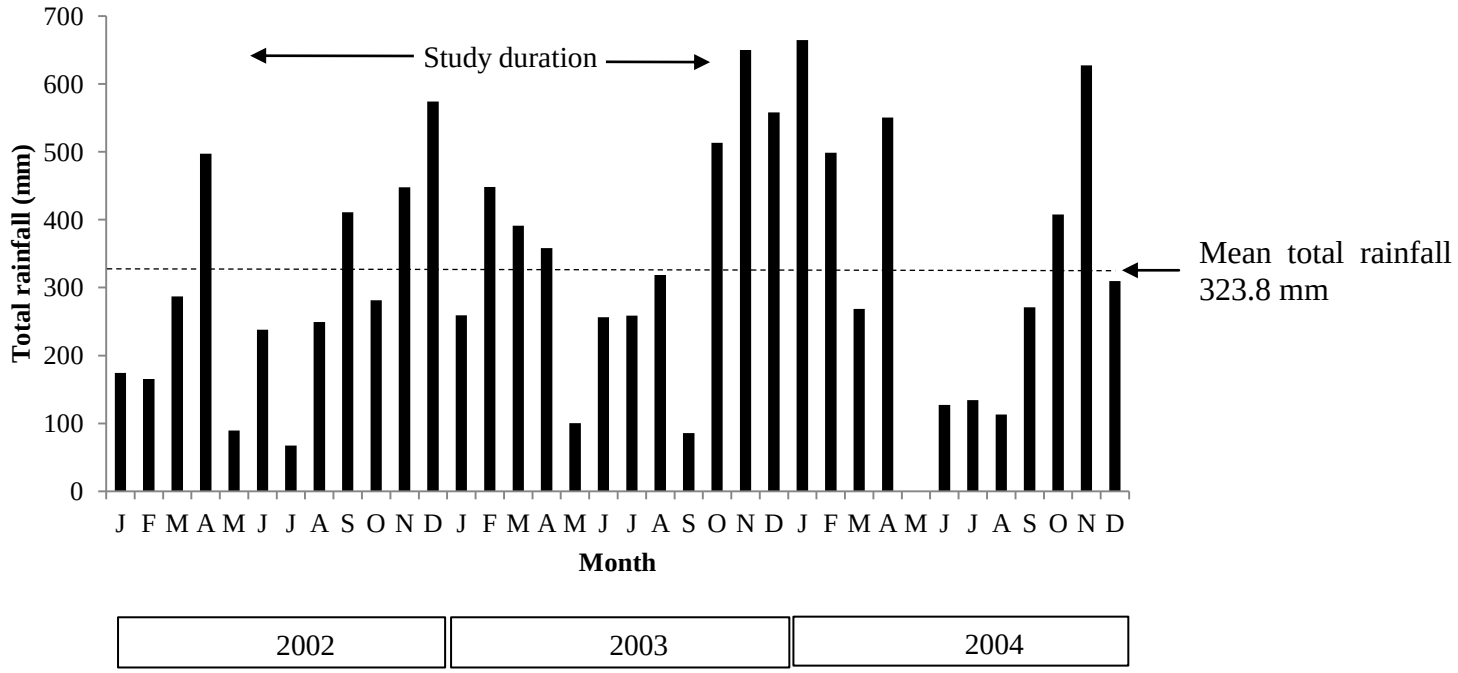

Figure 6.1. Total monthly rainfall of Taiping (Perak) area from January 2002 to December 2004. (Study duration for monthly sampling was from May 2002 to October 2003).

6.2.1.2 Monthly and Spatial Variations of Water Parameters

The monthly variations of water parameters were monitored at seven stations in the Matang Mangrove estuary and adjacent coastal waters from May 2002 to October 2003 (Table 6.1). These factors not only differed between months but also among the seven stations (Table 6.2). A 2-way ANOVA shows that all water parameters except temperature and turbidity were significantly different ($P < 0.05$) among months and stations. Temperature and turbidity readings only showed significant difference among months. Figure 6.2 shows the monthly mean values of temperature, salinity, dissolved oxygen, turbidity and pH in the Matang mangrove estuary and adjacent coastal waters, which are further described below:

a) Temperature

Mean water temperature was always higher in the mangrove stations than the offshore except in May 2002 (Table 6.1 & Figure 6.2a). Mean water temperature from Station 2 to Station 5 in the estuary fluctuated more than at Station 6 and 7 in offshore waters (Figure 6.3). A two-way ANOVA shows that temperature showed statistical differences spatially ($P < 0.01$) and temporally ($P < 0.01$). Mean temperature at Station 1 was significantly higher than other stations. It had temperatures more than 30 °C between December 2002 and September 2003. Water temperatures of less than 30 °C were recorded particularly at Station 7 from June to October (Figure 6.4).

b) Salinity

As predicted, salinity increased significantly from inshore to offshore ranging from 14.8 ± 7.18 ‰ (Station 1) to 30.8 ± 1.45 ‰ (Station 7). Mean salinity fluctuated greatly from month to month inside the mangrove estuary, from Station 1 to 4 (6.9‰ to 29.0‰) (Table 6.2, Figure 6.2b). At Station 5 to 7, monthly salinity was more consistent (24.6‰

– 32.3‰) (Figure 6.5). The salinity differed significantly between the 18 months ($P < 0.01$). In offshore waters, salinity was highest in June 2003 with a mean of 31.9 ± 0.4 ‰ while the lowest was in December 2002 with a mean of 23.7 ± 7.1 ‰. Mean salinity was more marked at the upper estuary (Station 1) where water was less saline at only 14.8 ± 7.2 ‰. Mean salinity was below 15‰ occurring between May to October 2003 except July 2003 (Figure 6.5 & 6.6).

c) Dissolved Oxygen

Mean concentration of surface dissolved oxygen (DO) was also statistically different between sampling months ($P < 0.01$) and stations ($P < 0.01$). The highest reading was recorded in May 2003 (11.4 ± 1.3 mgL^{-1}) at Station 1 (Figure 6.7). DO value increased significantly ($P < 0.01$) from upper estuary (Station 1) towards the offshore area (Station 7) where mean DO measured were 5.1 ± 1.5 mgL^{-1} and 5.9 ± 0.8 mgL^{-1}, respectively (Table 6.1 & Figure 6.8). Higher fluctuations of DO value were observed at stations 1 to 5 within the estuary.

d) Turbidity

The turbidity readings were statistically different among the 18 months of sampling. January 2003 recorded the highest mean turbidity at 129 ± 133.11 NTU, with very high SD values especially at Station 3 to 5 (Figure 6.9). The lowest mean turbidity was

Table 6.1. Mean surface water parameter readings from May 2002 to October 2003 in mangrove estuary (Station 1-5) and offshore stations (Station 6 & 7) in the Matang Mangrove Forest Reserve.

Month	Temperature (°C)				Salinity (‰)				Dissolved Oxygen (mgL^{-1})				Turbidity (NTU)				pH			
	Mangrove		Offshore		Mangrove		Offshore		Mangrove		Offshore		Mangrove		Offshore		Mangrove		Offshore	
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
May 2002	31.44	0.53	31.53	0.28	22.98	2.74	27.05	2.65	5.97	1.19	6.67	0.58	14.13	3.27	7.25	3.30	7.37	0.20	7.67	0.19
June	30.19	0.49	29.73	0.13	27.36	2.94	29.85	1.35	5.81	0.50	6.32	0.13	19.00	8.33	20.50	5.80	7.67	0.34	7.96	0.16
July	29.66	0.72	29.43	0.13	23.76	2.23	30.21	0.72	5.27	0.32	6.24	0.08	47.75	19.15	30.75	15.02	7.40	0.18	7.92	0.06
August	30.59	0.58	30.00	0.00	27.82	0.99	29.44	0.00	5.16	0.44	6.29	0.00	13.25	6.52	19.00	0.00	7.73	0.06	7.82	0.00
September	30.38	0.63	29.78	0.21	21.62	2.03	29.45	0.80	5.24	0.68	6.14	0.34	36.75	25.93	19.50	4.51	7.22	0.16	7.86	0.06
October	31.34	0.70	30.20	0.22	21.85	2.85	30.25	0.41	5.56	0.62	6.87	0.42	9.75	2.05	10.00	1.15	7.29	0.21	7.90	0.03
November	30.41	0.91	29.60	0.29	18.44	2.71	28.10	2.72	5.77	1.07	7.34	0.69	16.38	7.05	23.00	24.26	7.32	0.20	8.04	0.20
December	31.58	0.38	30.98	0.17	18.39	1.78	23.74	7.07	4.53	0.96	5.21	1.09	25.90	8.01	33.37	21.56	7.29	0.25	7.70	0.56
January 2003	30.57	0.42	30.18	0.24	24.86	2.09	29.07	0.88	3.34	1.55	4.80	0.40	165.79	141.74	36.93	26.40	7.30	0.20	7.90	0.08
February	31.22	0.79	30.70	0.13	15.42	4.11	28.43	0.65	3.59	0.62	4.95	0.09	13.31	6.60	10.91	3.06	7.15	0.29	7.95	0.02
March	31.57	0.44	31.63	0.24	25.03	2.16	30.31	0.10	3.79	1.34	5.61	0.49	50.59	31.03	35.61	31.21	7.26	0.35	7.95	0.06
April	31.70	1.24	31.65	0.26	20.69	3.44	29.44	1.00	6.33	0.87	5.96	0.28	15.18	5.80	27.03	32.53	7.73	0.32	8.07	0.04
May	32.17	0.79	31.17	0.45	21.89	5.18	30.31	0.63	7.52	2.51	6.10	0.33	17.72	6.42	31.87	33.39	7.56	0.24	7.94	0.02
June	30.83	0.71	30.77	0.28	20.97	6.80	31.89	0.44	5.34	1.30	5.81	0.03	12.22	2.91	4.52	0.56	7.46	0.46	8.02	0.04
July	30.07	0.43	29.52	0.01	25.02	2.79	31.69	0.00	5.42	0.67	5.42	0.08	23.09	10.47	33.58	7.04	7.59	0.11	7.98	0.02
August	30.84	0.55	30.00	0.03	19.25	6.06	30.66	1.28	4.24	0.80	5.75	0.21	17.63	8.14	13.48	5.43	7.15	0.39	7.95	0.02
September	31.63	1.12	30.51	0.15	21.51	4.40	30.10	0.81	5.12	0.56	6.16	0.12	21.82	10.11	5.94	3.90	7.28	0.26	7.94	0.03
October	29.59	0.29	29.10	0.03	17.83	4.73	28.06	1.39	4.70	1.27	6.07	0.32	50.80	42.80	37.59	24.91	7.14	0.38	7.89	0.02
Overall Mean	**30.88**	**0.98**	**30.40**	**0.81**	**21.90**	**4.80**	**29.18**	**2.79**	**5.11**	**1.47**	**5.98**	**0.75**	**33.06**	**52.26**	**22.20**	**19.91**	**7.38**	**0.32**	**7.91**	**0.19**

Table 6.2. Mean surface water parameter readings in the mangrove estuary (stations 1-5) and offshore waters (6 & 7) in Matang Mangrove Forest Reserve.

Station	Temperature (ºC)			Salinity (ppt)			Dissolved Oxygen (mgL^{-1})			Turbidity (NTU)			pH		
	Mean	±SD	Range	Mean	±SD	Range	Mean	±SD	Range	Mean	±SD	Range	Mean	±SD	Range
1	31.32	1.05	29.45 - 32.99	14.8	7.2	6.9 - 30.4	4.91	2.66	2.45 - 12.26	27.85	22.09	7.05 - 98.50	6.99	0.43	6.54 - 8.01
2	30.80	0.98	29.01 - 33.63	20.4	3.7	12.2 - 27.9	4.83	1.47	2.30 - 9.61	29.88	38.53	5.35 - 205.63	7.22	0.30	6.61 - 7.98
3	30.84	0.94	29.19 - 32.87	22.0	3.7	15.2 - 29.0	4.82	1.17	2.00 - 7.83	37.16	60.47	9 - 365.17	7.35	0.26	7.03 - 7.86
4	30.85	0.85	29.00 - 32.85	23.2	3.3	17.1 - 29.0	5.20	1.19	1.92 - 7.78	30.86	43.90	6.43 - 229.83	7.47	0.22	7.17 - 7.99
5	30.83	1.08	28.7 - 32.40	25.2	2.7	19.7 - 31.5	5.65	1.12	1.96 - 7.97	35.59	71.20	1.63 - 436.40	7.65	0.18	7.33 - 8.15
6	30.31	0.80	29.08 - 31.70	28.7	2.0	24.6 - 31.7	6.01	0.75	4.37 - 7.97	28.52	22.46	4 - 81.63	7.89	0.12	7.49 - 8.15
7	30.49	0.82	29.09 - 31.94	30.2	1.0	27.9 - 32.3	6.03	0.61	4.84 - 7.34	14.95	14.11	1.93 - 63.15	7.98	0.09	7.73 - 8.23

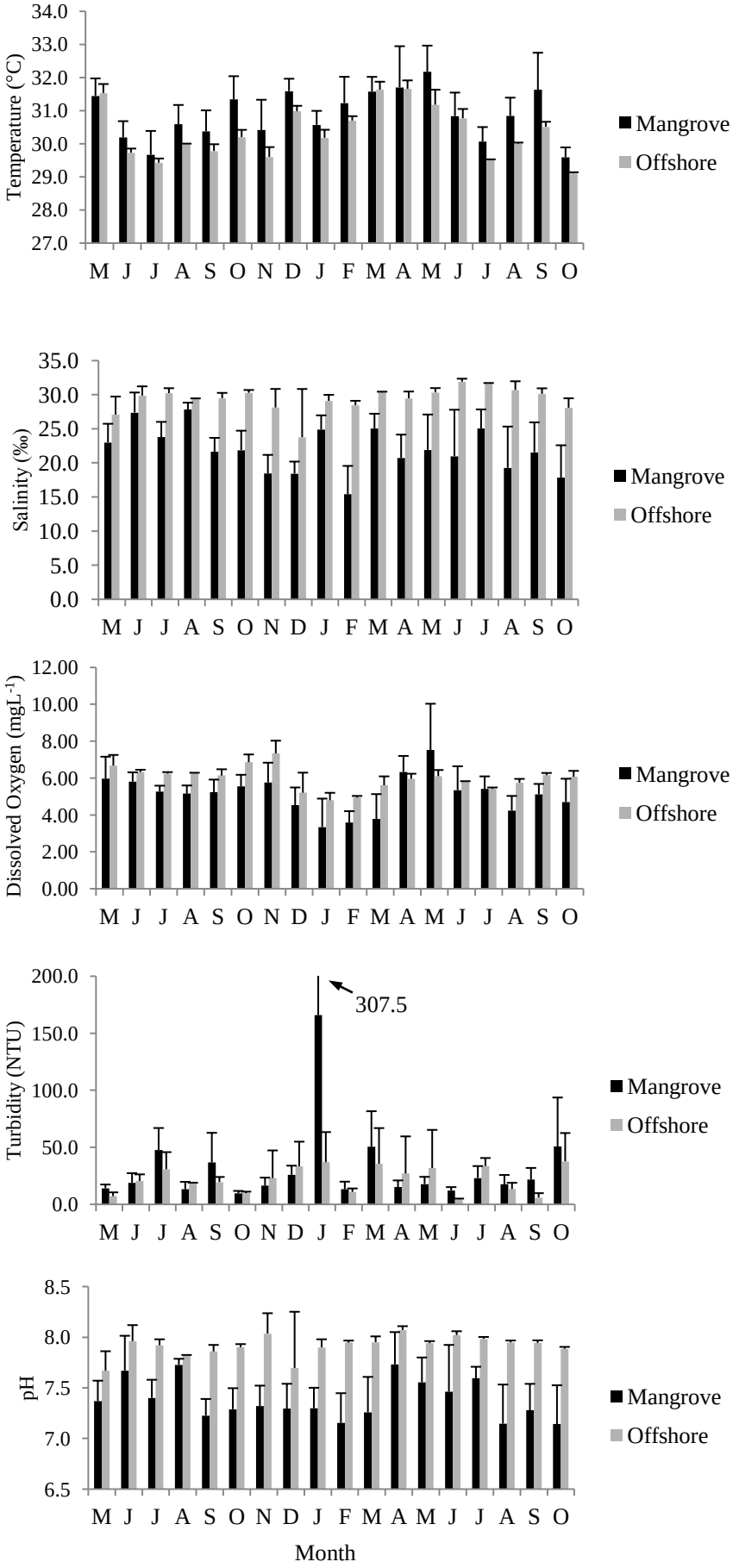

Figure 6.2. Surface monthly mean values of temperature, salinity, dissolve oxygen, turbidity and pH in Matang mangrove estuary (Station 1-5) and adjacent offshore waters (Station 6 & 7).

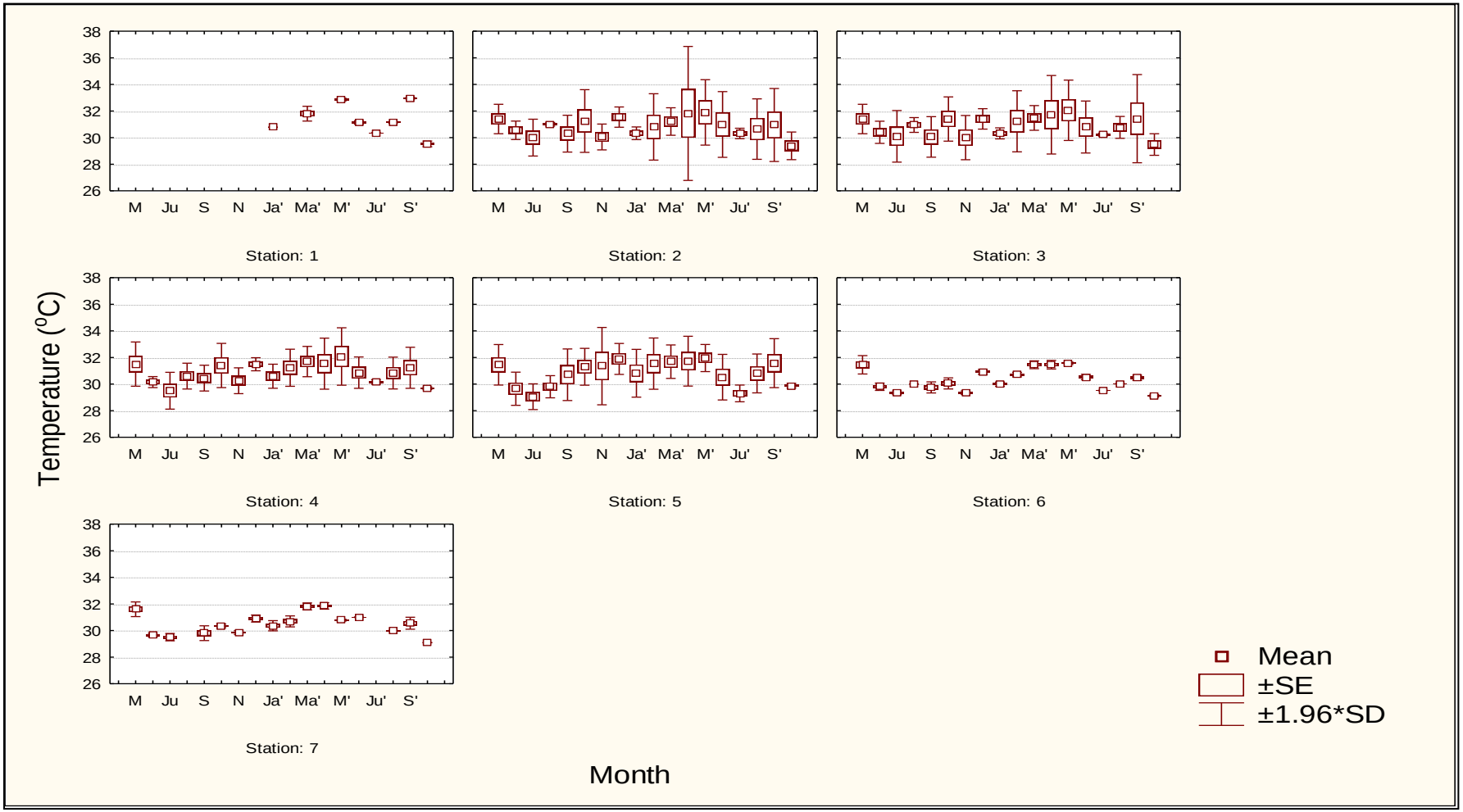

Figure 6.3. Surface monthly mean temperature (±SE) and 95% confidence intervals at different stations from May 2002 to October 2003.

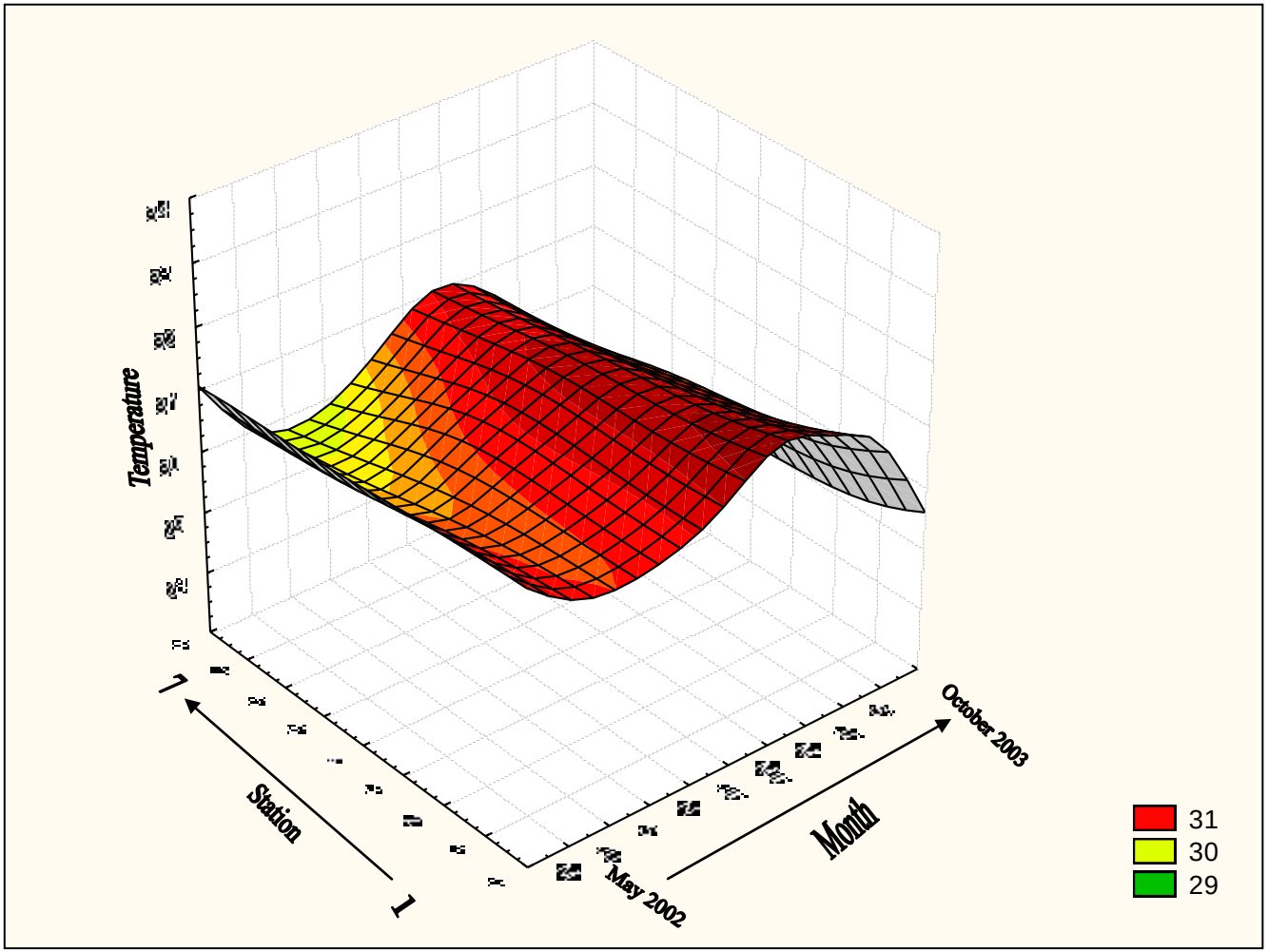

Figure 6.4. 3-D Surface plot of temperature (ºC) at different stations from May 2002 to October 2003.

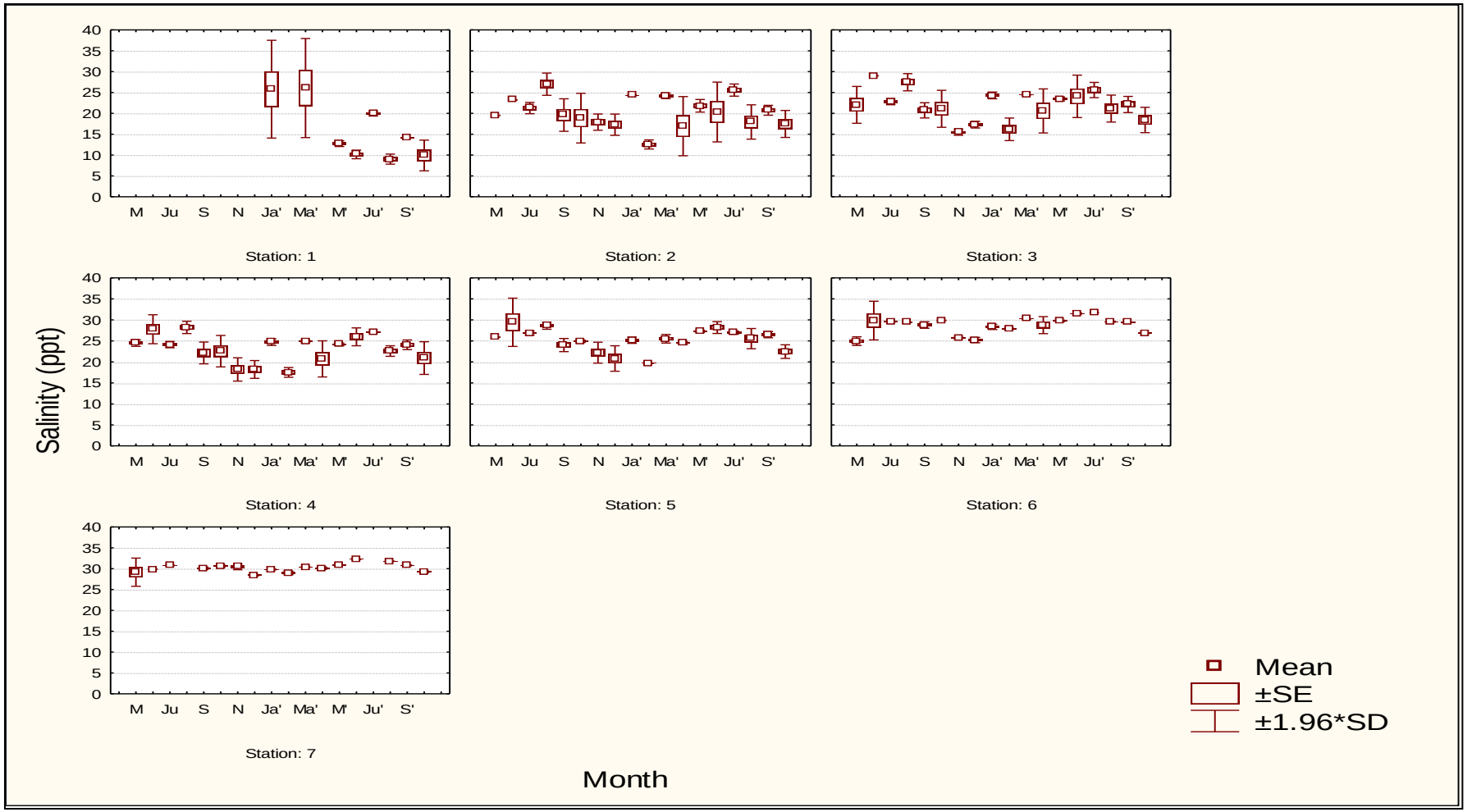

Figure 6.5. Surface monthly mean salinity (±SE) and 95% confidence intervals at different stations from May 2002 to October 2003.

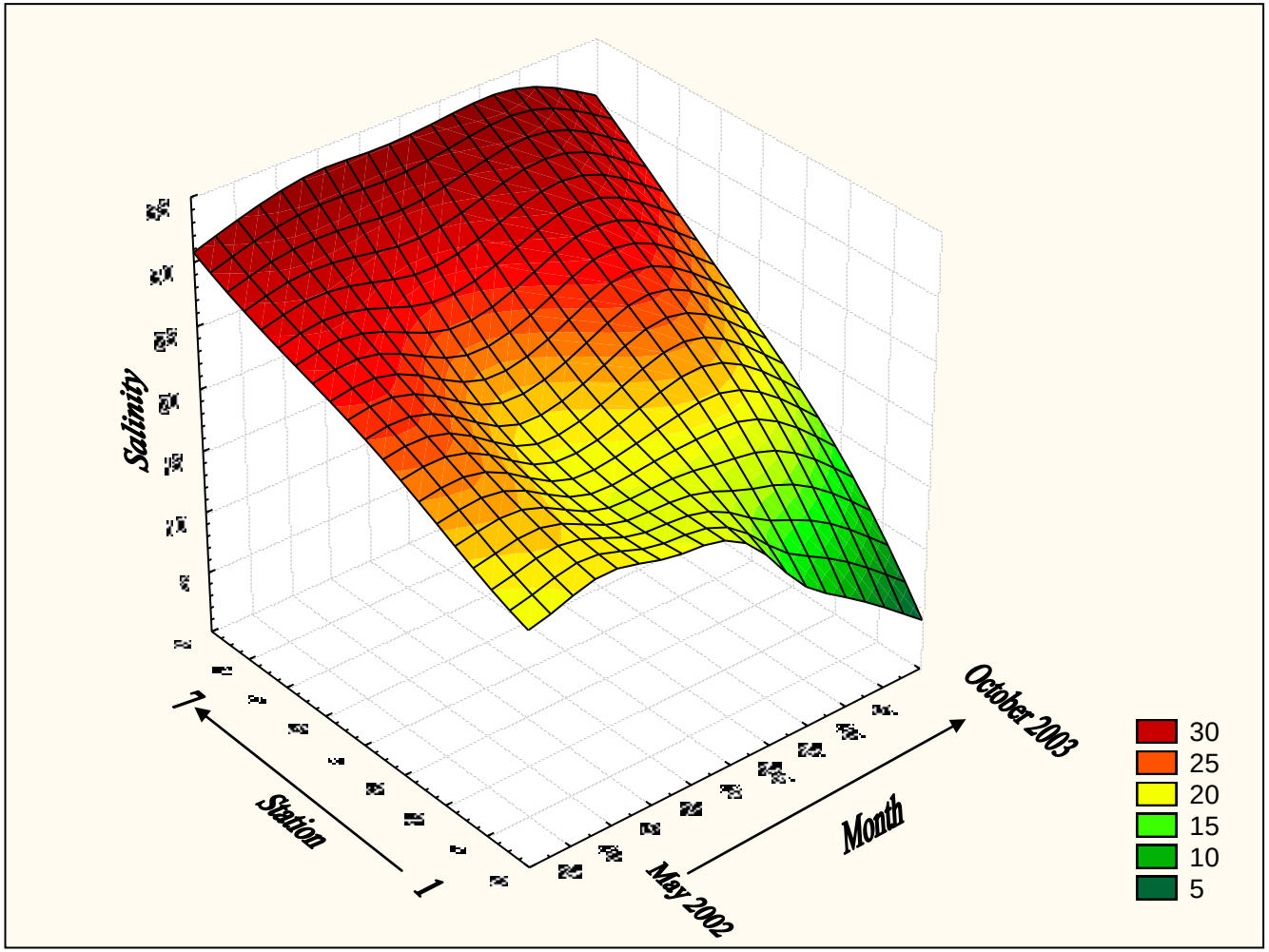

Figure 6.6. 3-D Surface plot of salinity (‰) at different stations from May 2002 to October 2003.

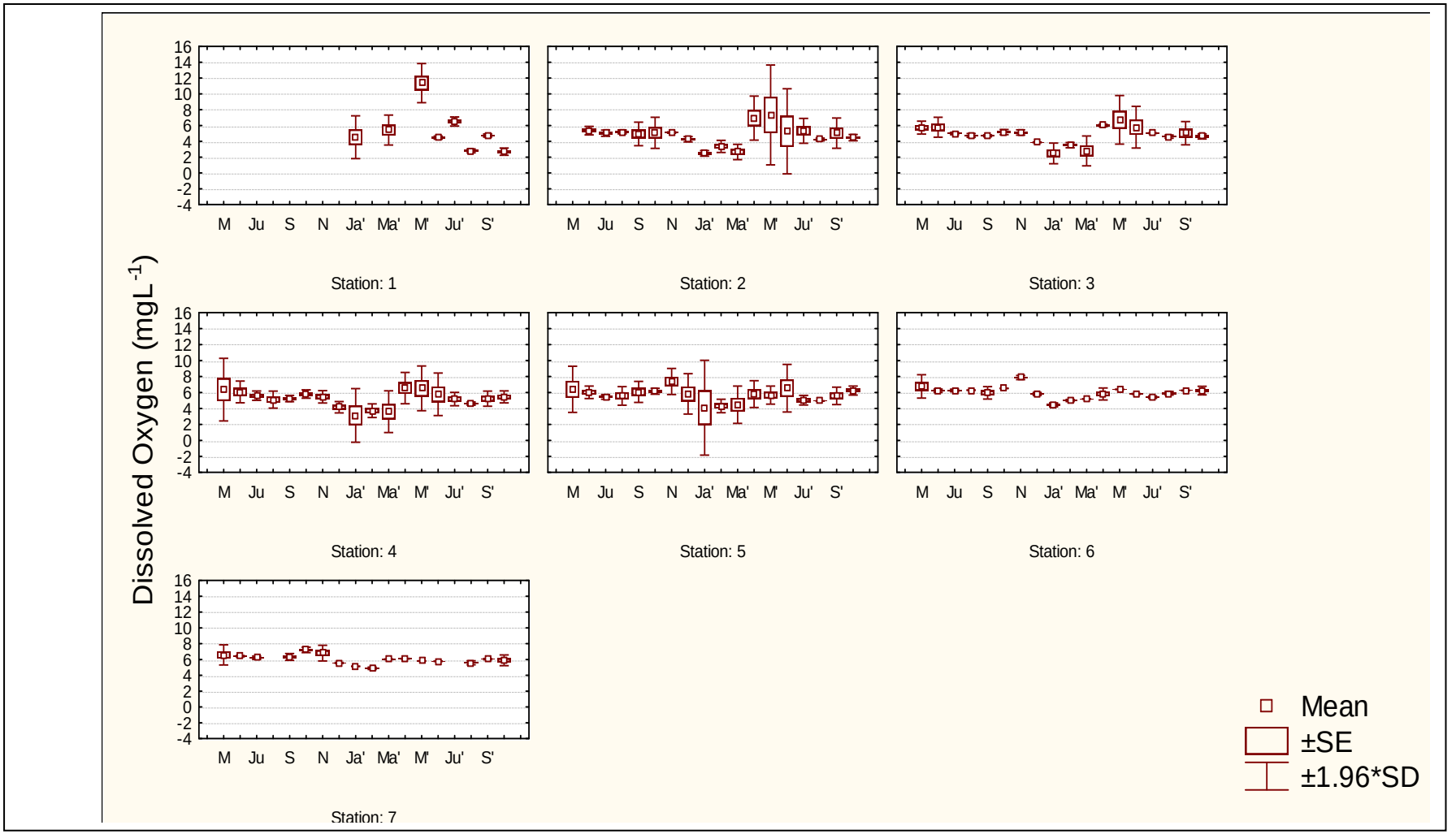

Figure 6.7. Surface monthly mean dissolved oxygen (±SE) and 95% confidence intervals at different stations from May 2002 to October 2003.

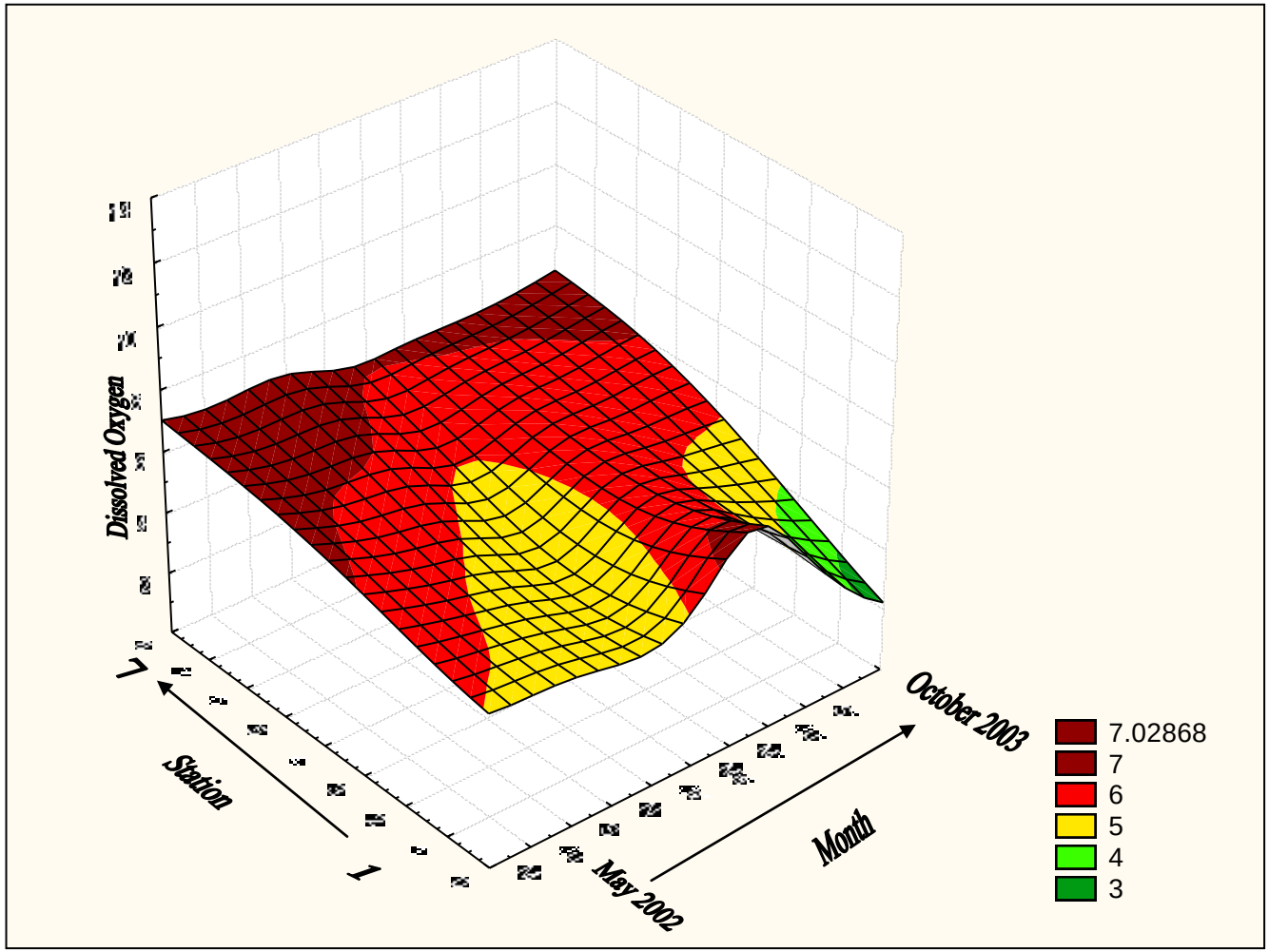

Figure 6.8. 3-D Surface plot of dissolved oxygen (mgL^{-1}) at different stations from May 2002 to October 2003.

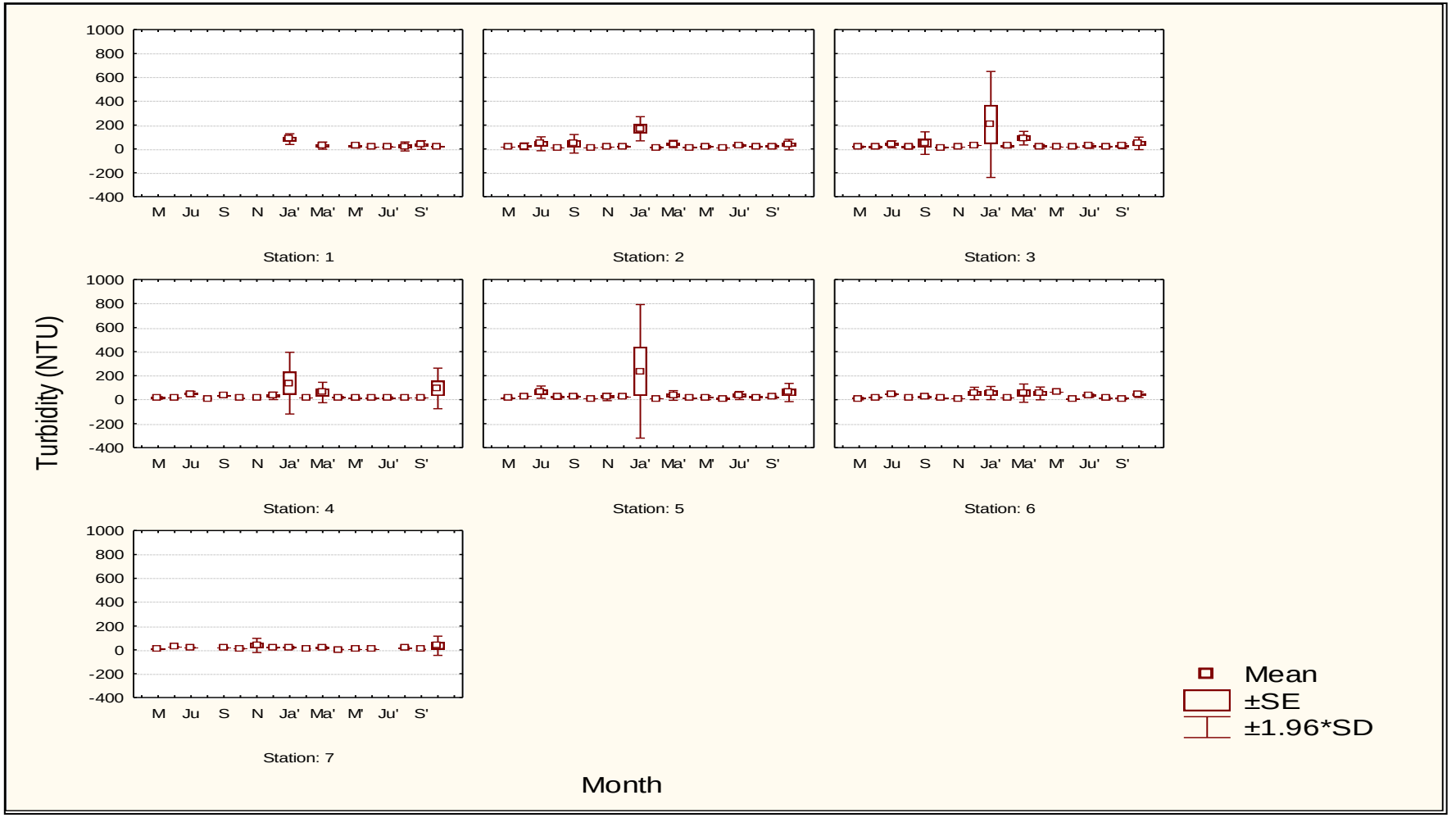

Figure 6.9. Surface monthly mean turbidity (±SE) and 95% confidence intervals at different stations from May 2002 to October 2003.

recorded in June 2003 (9.3± 4.8 NTU) (Table 6.1, Figure 6.2d). In the mangrove estuary, mean turbidity ranged from 9.8 ± 2.1 NTU to 165.8 ± 141.7 NTU. Offshore waters were generally less turbid with mean of 22.2 ± 29 NTU (Table 6.2).

e) pH

The mean pH values during the 18 months of sampling varied (Figure 6.10) and were significantly different among months ($P < 0.001$). Generally, Matang estuaries were slightly alkaline ranging from 6.6 to 7.9, with mean pH around 7.5 (Table 6.2). April 2003 recorded the highest reading with mean pH of 7.9 ± 0.3. The lowest reading was recorded in February 2003 (7.3 ± 0.5) (Figure 6.2e). Higher fluctuations of pH values at Stations 1 to 4 between March 2003 and June 2003 were observed (Figure 6.10). The pH reading increased from upper estuary towards the offshore water (Figure 6.11). Overall, the pH was significantly higher in the offshore areas (7.8 ± 0.4) than in the mangrove estuary (7.3 ± 0.4).

6.2.1.3 Chlorophyll *a* and Zooplankton Variations

Figure 6.12 showed monthly variation of mean concentration of chlorophyll *a* at different stations. Measurement of chlorophyll *a* first started in July 2002. During the 16 months, values were relatively low from July to November 2002, ranging from 10.4 to 18.7 μgL^{-1} before increasing to its peak in January 2003 (55.3 ± 36.9 μgL^{-1}). Mean concentrations of Chl *a* in January 2003 was more than 40 μgL^{-1} at Stations 1 to 5. It decreased drastically in February 2003 (9.06 ± 2.14 μgL^{-1}) before it peaked again in March 2003 with a mean of 36.4 μgL^{-1}. Comparing between the mangroves and offshore stations, Chl *a* concentration was higher in the mangrove estuary, ranging from 5.3 to 122.2 μgL^{-1}. The Chl *a* concentration decreased towards the offshore direction

(Figure 6.13). The mean Chl *a* in the offshore areas was 10.9 μgL^{-1} ($\pm$ 6.3 μgL^{-1}), ranging from 4.9 to 31.8 μgL^{-1}.

There was no significant difference of zooplankton biomass among stations ($P > 0.05$). However, it was significantly different among months ($P < 0.01$), with the highest recorded in October 2003 (mean 1.80 $\pm$ 0.78 gm^{-3}). Mean total zooplankton biomass was above 2 gm^{-3} in October 2003, at Station 2 to 6 (Figure 6.14). Station 6 recorded the highest total zooplankton biomass with mean of 0.90 $\pm$ 0.43 gm^{-3}. Peak mean concentration of zooplankton was observed in December 2002 (0.86 $\pm$ 0.78 gm^{-3}), August (0.97 $\pm$ 0.52 gm^{-3}) and October 2003 (1.80 $\pm$ 0.78 gm^{-3}).

6.2.2 Relationship between Fish Larval Assemblages and Physical Parameters

The abundance of fish larvae was related to five water parameters (salinity, temperature, dissolved oxygen, pH and turbidity) and two indicators of fish food abundance (zooplankton and chlorophyll *a*) by using Canonical Correspondence Analysis (CCA). The first CCA axis (Eigenvalue = 0.242) alone modelled 55.7% of the total explained variance, demonstrating a high species-environmental correlation (0.819) (see Appendix 6.2). The second axis represented 14% of the explained variance, while the third and fourth axis additionally explained 15.5% of the variance each. Therefore, the first two CCA axes accounted for 69.7% of the variance in the correlation of species-environmental parameters. Salinity appeared to be the most significant factor influencing the distribution and abundance of most larval fish. Mugilid, sciaenid, cynoglossid, triacanthid and platycephalid larvae generally preferred more saline, well oxygenated offshore waters (Figure 6.15). All larval stages of the Gobiidae, the postflexion and postlarvae of Engraulidae, Syngnathidae and Mullidae were more

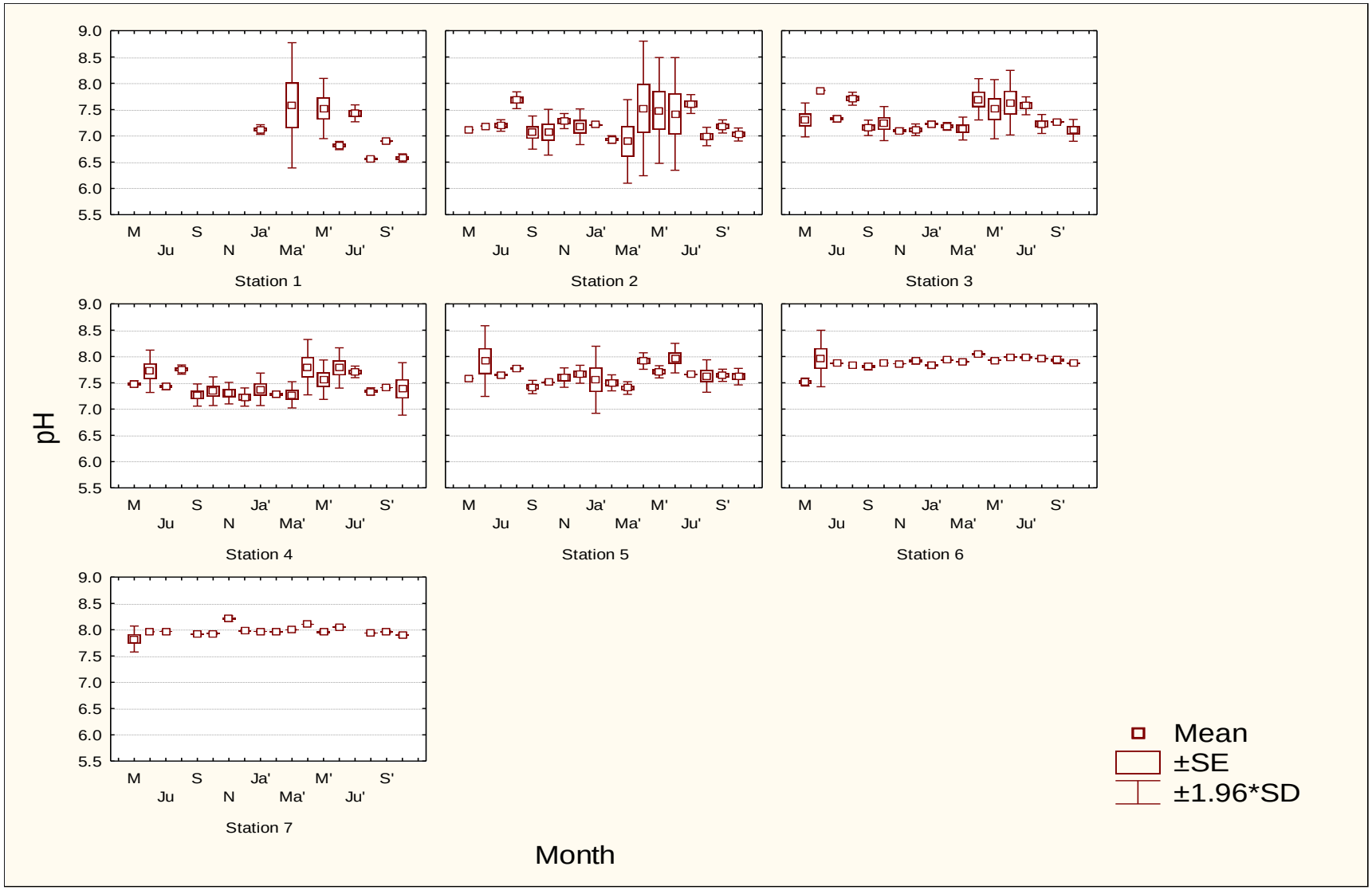

Figure 6.10. Surface monthly mean pH (±SE) and 95% confidence intervals at different stations from May 2002 to October 2003.

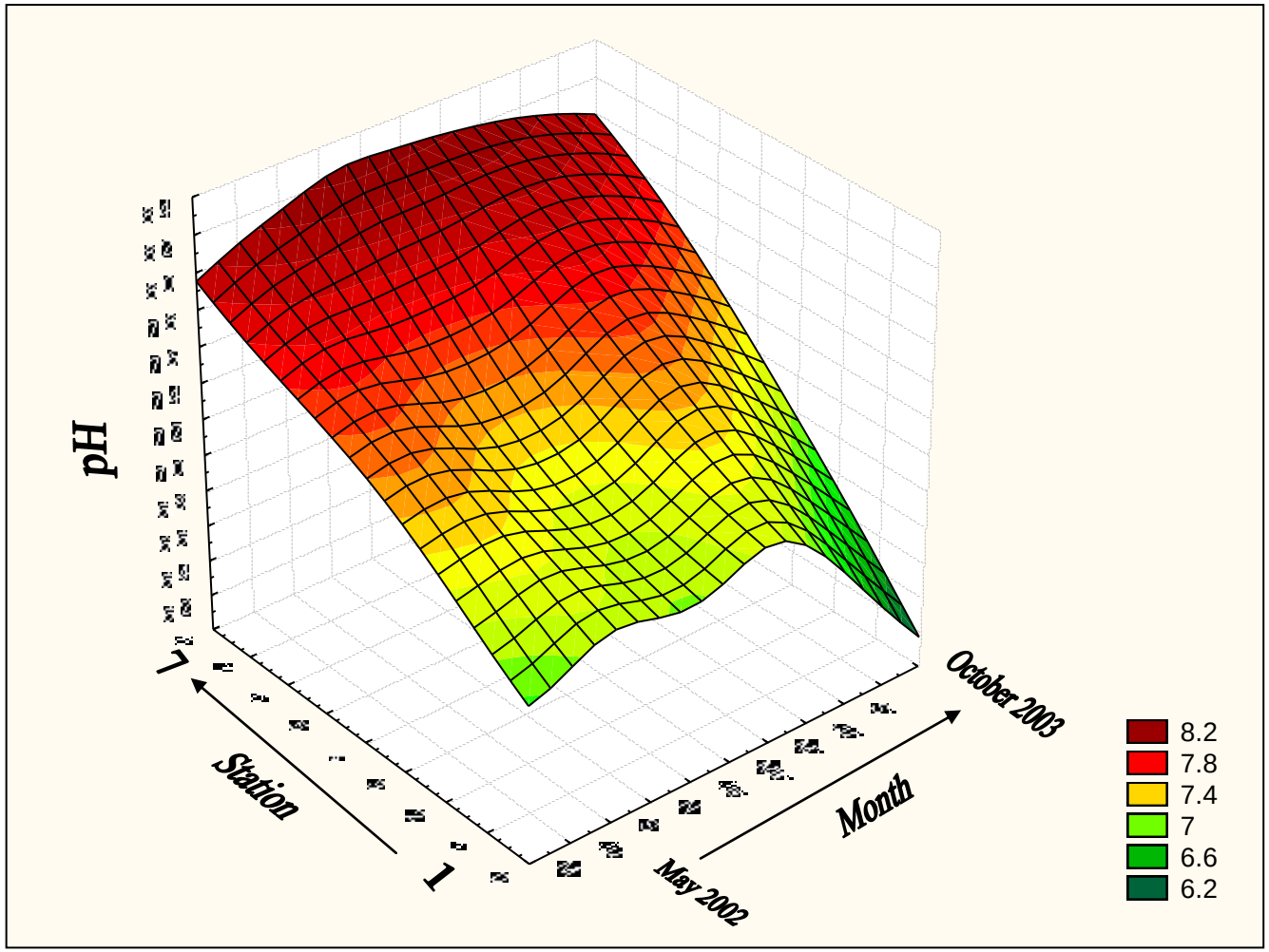

Figure 6.11. 3-D Surface plot of pH at different stations from May 2002 to October 2003.

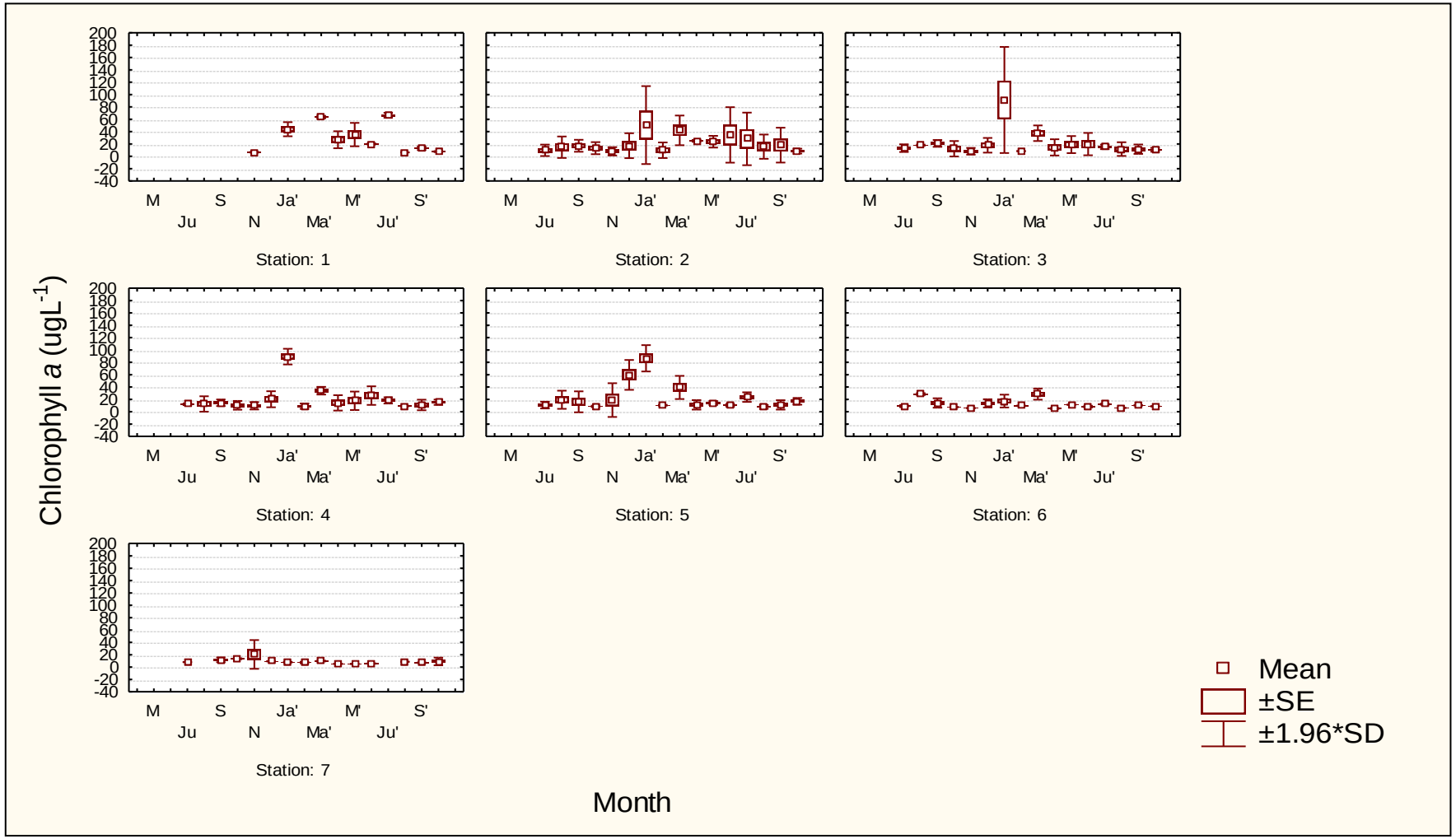

Figure 6.12. Surface mean chlorophyll *a* (±SE) and 95% confidence intervals at different stations from May 2002 to October 2003.

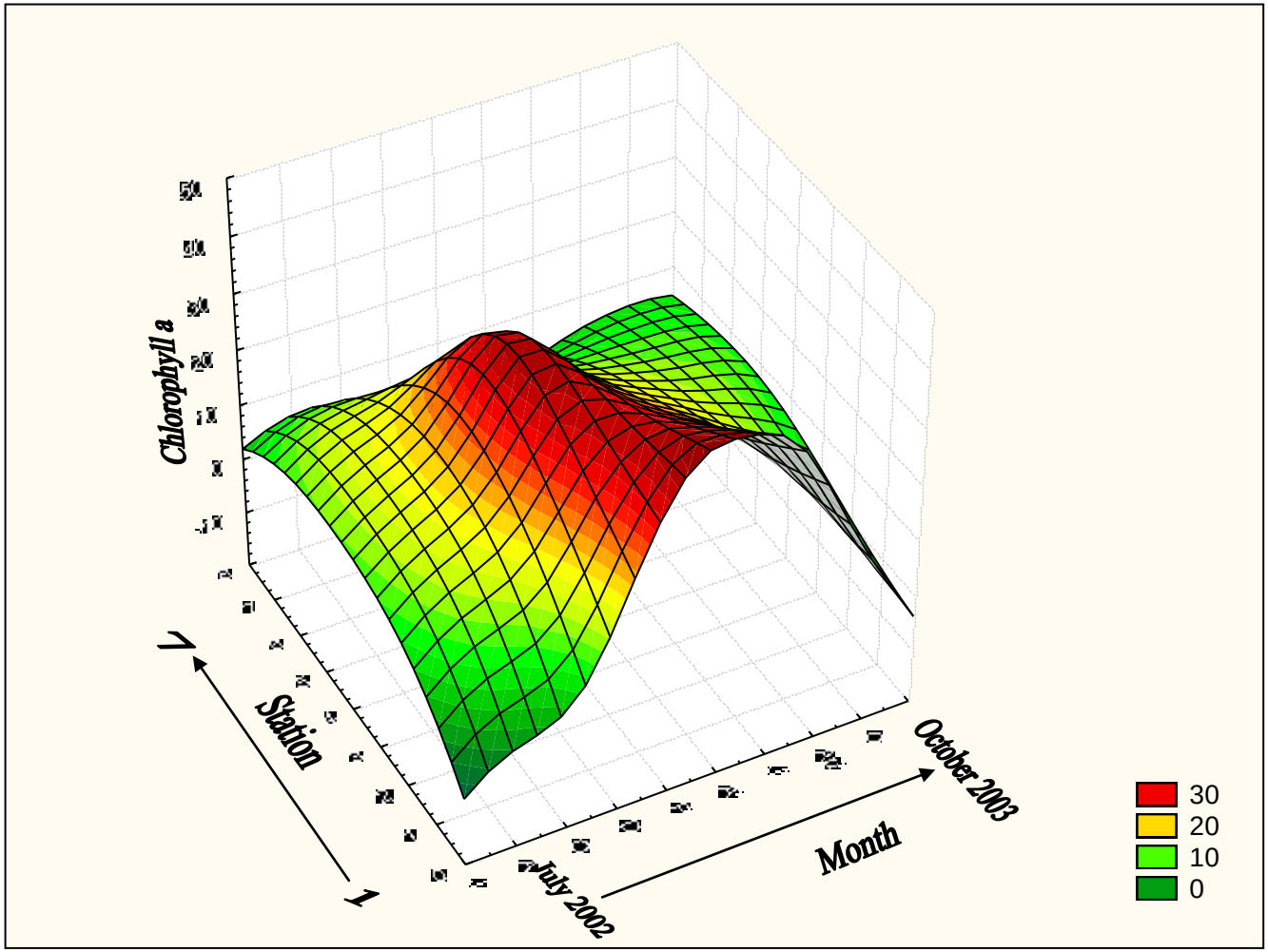

Figure 6.13. 3-D Surface plot of chlorophyll *a* (μgL^{-1}) at different stations from May 2002 to October 2003.

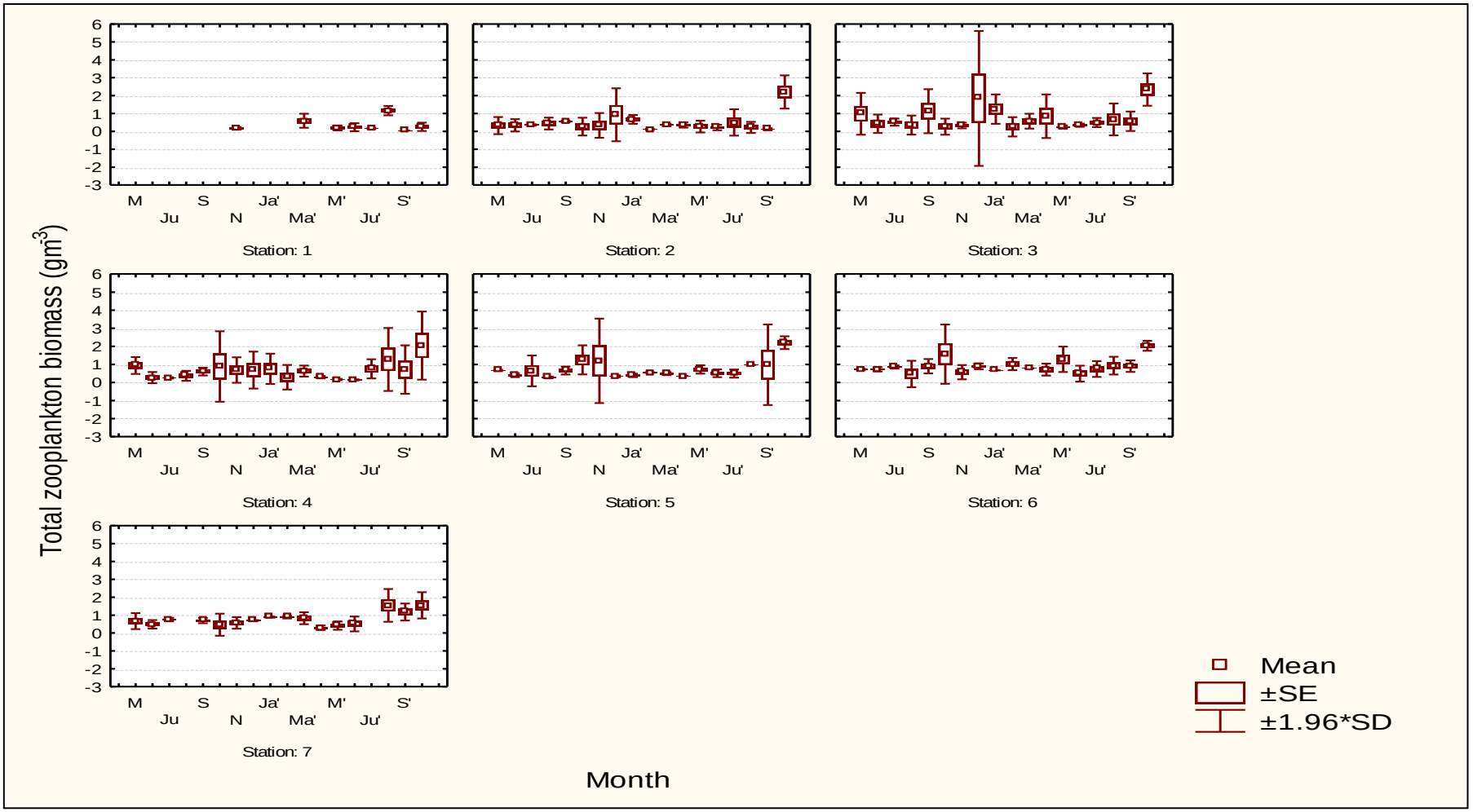

Figure 6.14. Surface mean of zooplankton biomass (gm^{-3}) (±SE) and 95% confidence intervals at different stations from May 2002 to October 2003.

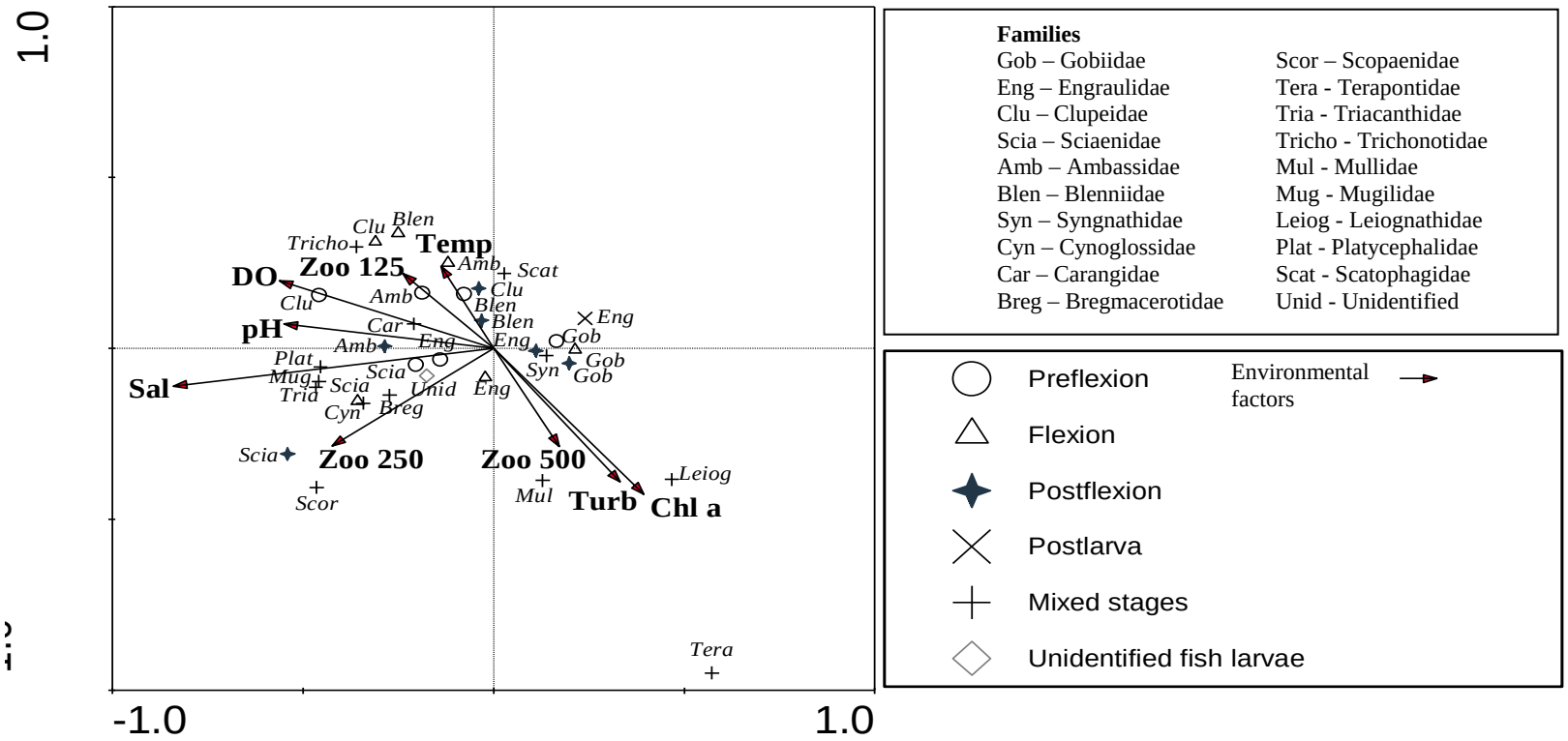

Figure 6.15. Biplots of larval fish abundance (various symbols) in relation to environmental factors (arrows). Only 6 families (Gobiidae, Engraulidae, Clupeidae, Sciaenidae, Ambassidae and Blenniidae) are presented in developmental stages. Legend to larval fish families and developmental stages are given in right boxes. Sal – salinity, Temp – temperature, DO – dissolved oxygen, Turb – turbidity, Chl *a* – Chlorophyll *a*, Zoo 500 – wet weight of '>500µm' zooplankton, Zoo 250 – wet weight of '250-500µm' zooplankton, Zoo 125 – wet weight of '125-250µm' zooplankton.

abundant in the less saline, zooplankton richer water inside the mangrove estuary. Also in the mangrove estuary were the Leiognathidae and Terapontidae which preferred the more turbid, cooler and greener water.

6.2.2.1 Gobiidae

In mangrove waters, all larval stages of Gobiidae appeared to prefer the less saline but more turbid water.All developmental stages of Gobiidae were positively correlated with turbidity (preflexion and postflexion, $P < 0.001$; flexion stage, $P < 0.05$) in the mangrove estuary and adjacent coastal water (Table 6.3). Preflexion larvae were ubiquitous being quite spread out over the coastal belt although higher densities were observed in the more turbid water inside the mangrove estuary (Figure 6.16 a). At Station 1, preflexion larvae were strongly related to bigger sized zooplankton (Figure 6.16a). Postflexion larvae were however more abundant inside the mangrove estuary (Figure 6.16c). The chlorophyll *a* concentration was also positively correlated with all developmental stages of gobiid in the offshore waters. As revealed in stable isotope analysis, larger gobiid larvae in the estuary fed on zooplankton that largely utilized mangrove carbon as reflected by their $\delta^{13}C$ value of -24.3‰ (Figure 6.17).

6.2.2.2 Engraulidae

The preflexion larvae were preponderant in coastal waters where they were likely spawned. However, these larvae entered the mangrove estuaries at the flexion stage or postflexion stage which showed affinity for more turbid and greener water (Figure 6.18 a-d). Postlarval Engraulidae appeared to prefer the less saline but more turbid water, which also contained relatively higher concentrations of chlorophyll *a* and zooplankton (Figure 6.18d). The postflexion larvae showed positively correlation with turbidity ($P < 0.001$) (Table 6.4). Flexion and postflexion stages inside the estuary showed greater

preference for bigger sized zooplankton food, with positive correlation ($P < 0.001$). Preflexion engraulid larvae preferred more saline offshore waters and higher abundance of smaller sized zooplankton prey (Figure 6.18a). They were positively correlated with chlorophyll *a* concentration ($P < 0.001$) in the offshore areas. At the early life stages, contribution by phytoplankton carbonin their diet is important as indicated by $\delta^{13}C$ values (-16.7‰ to -16.5‰) detected in the offshore waters (see Figure 6.17).

6.2.2.3 Clupeidae

Clupeid larvae were spawned in less turbid and well oxygenated offshore waters. All developmental stages of clupeid were negatively correlated with chlorophyll *a* concentration ($P < 0.05$) (Table 6.5). Although maintaining their position in offshore waters, postflexion larvae did enter mangrove waters to feed on the richer zooplankton resources (Figure 6.19).

6.2.2.4 Sciaenidae

Preflexion larvae of sciaenids occurred mainly in coastal waters although they were also present inside the estuary in sites where zooplankton was abundant. At offshore waters, preflexion sciaenid was positively correlated with chlorophyll *a* concentration ($P < 0.001$). Nevertheless, they were positively correlated with zooplankton (> 500µm) inside the mangrove estuary ($P < 0.05$) (Table 6.6). The flexion and postflexion larvae moved towards more saline coastal waters with higher abundance of smaller sized zooplankton (Figure 6.20 b & c).

Table 6.3. Spearman rank correlation between abiotic factors and zooplankton with different developmental stages of Gobiidae in mangrove estuary (Station 1-5) and adjacent coastal waters (Station 6 & 7).
Temp- temperature; Sal- salinity; DO - dissolved oxygen; Turb - turbidity; Chl *a* - chlorophyll *a*; Zoo 500- wet weight of '>500µm' zooplankton;Zoo 250 – wet weight of '250-500µm' zooplankton, Zoo 125 – wet weight of '125-250µm' zooplankton.
Asterisk indicates a *P*-value statistically significant (**P*<0.05; ***P*<0.01; ****P*<0.001)

	Temp	**Sal**	**DO**	**Turb**	**pH**	**Chl *a***	**Zoo 500**	**Zoo 250**	**Zoo125**
Mangrove									
Preflexion	-0.05	0.12	-0.12	0.45***	0.30***	0.13	0.15	0.14	0.03
Flexion	-0.10	0.13	-0.11	0.17*	-0.02	-0.02	0.11	-0.09	-0.11
Postflexion	-0.24**	-0.06	0.15	0.39***	-0.03	0.29***	0.15	0.08	-0.10
Total	-0.07	-0.14	-0.07	0.49***	-0.27***	0.22**	0.18*	0.14	0.04
Offshore									
Preflexion	-0.09	-0.14	-0.15	0.46***	-0.003	0.37**	0.22	-0.08	0.14
Flexion	-0.32**	-0.02	0.01	0.30*	-0.13	0.32*	0.16	-0.20	-0.10
Postflexion	-0.03	-0.09	-0.09	0.41***	-0.17	0.30*	0.05	-0.11	-0.08
Total	-0.08	-0.18	-0.13	0.49***	-0.09	0.42***	0.21	-0.10	0.11

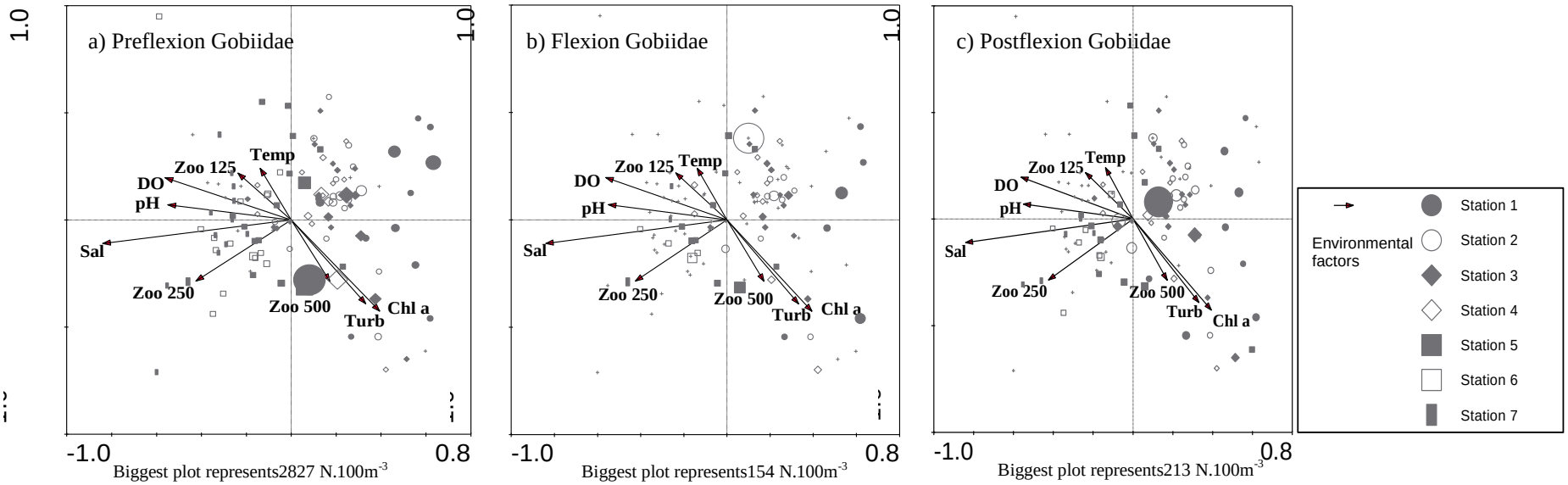

Figure 6.16. CCA attribute biplots of Gobiidae larval abundance (various plots according to stations) in relation to environmental factors (arrows), a) preflexion stage, b) flexion stage and c) postflexion stage. Sal – salinity, Temp – temperature, DO – dissolved oxygen, Turb – turbidity, Chl *a* – Chlorophyll *a*, Zoo 500 – wet weight of '>500µm' zooplankton, Zoo 250 – wet weight of '250-500µm' zooplankton, Zoo 125 – wet weight of '125-250µm' zooplankton.

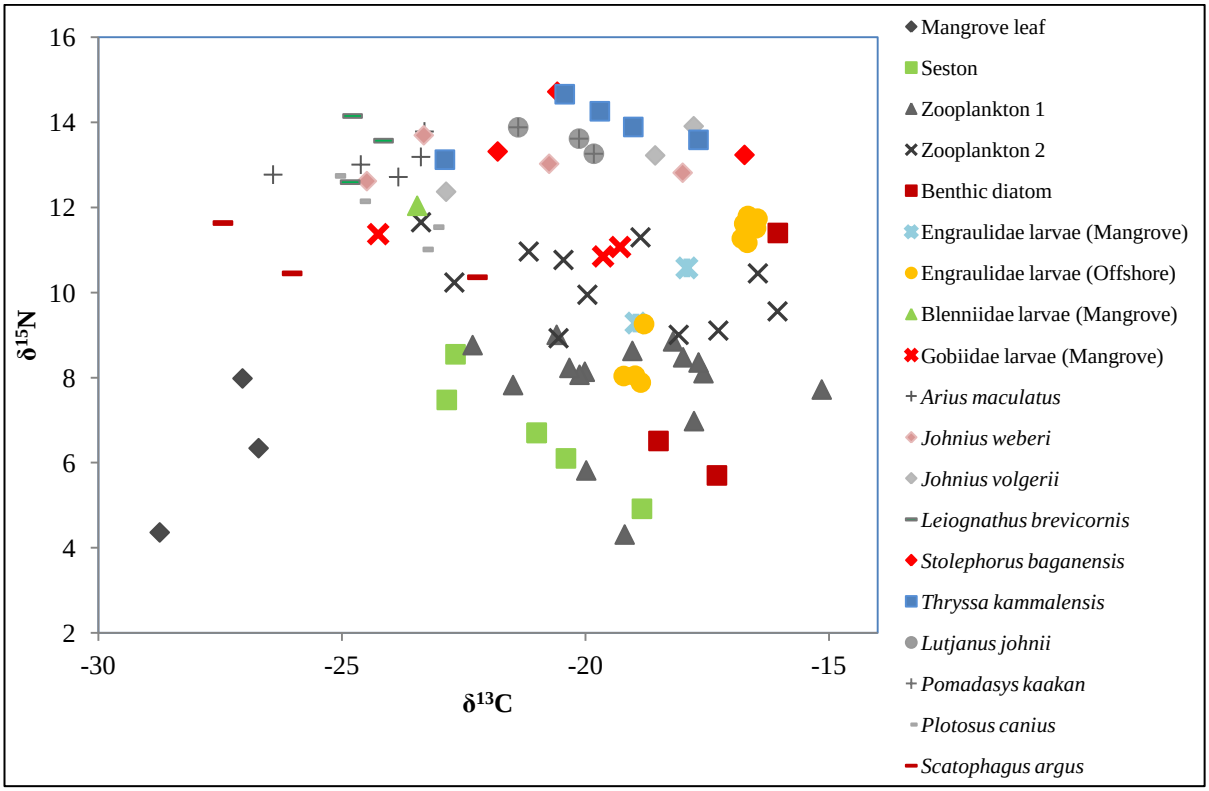

Figure 6.17. Stable isotopes of primary producers and consumers (fishes) in the Matang Mangrove Forest estuaries.
Primary producers denote values from mangrove, seston (Hayase et al., 1995) and benthic diatoms (from Okamura et al., 2010). Zooplankton 1 denotes values from copepods, *Acetes*, mysids, *Lucifer*, ostracods. Zooplankton 2 denotes chaetognaths, porcellanid larvae, stomatopod larvae, caridean larvae and brachyuran larvae. Fish larvae include the larvae of dominant fish larvae belonging to gobiids, engraulids and blenniid (data from the present study). Juvenile fish includes ten major fish species (data from Then, 2008).

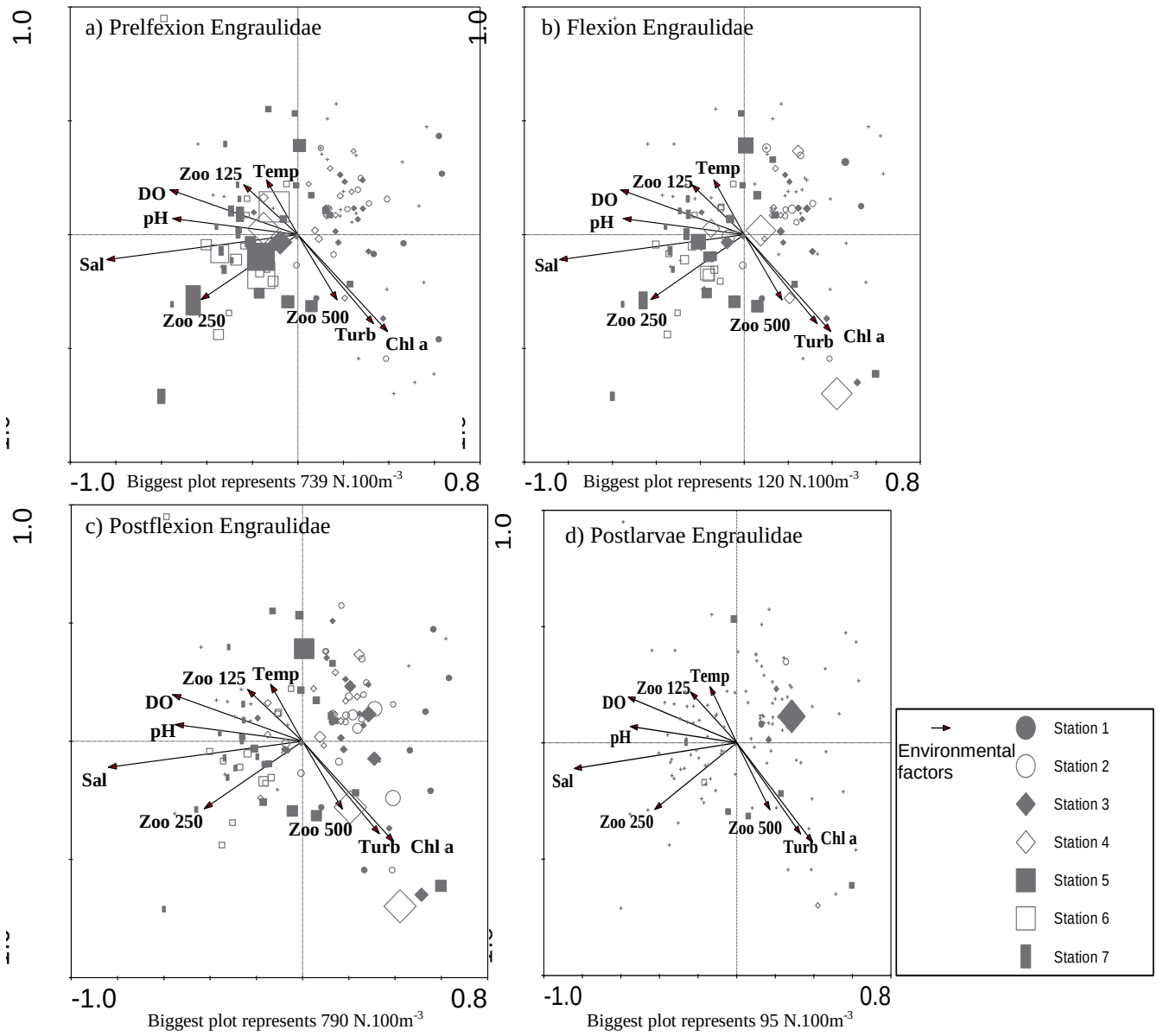

Figure 6.18. CCA attribute biplots of Engraulidae larval abundance (various plots according to stations) in relation to environmental factors (arrows), a) preflexion stage, b) flexion stage, c) postflexion stage and d) postlarvae stage. Sal – salinity, Temp – temperature, DO – dissolved oxygen, Turb – turbidity, Chl *a* – Chlorophyll *a*, Zoo 500 – wet weight of '>500µm' zooplankton, Zoo 250 – wet weight of '250-500µm' zooplankton, Zoo 125 – wet weight of '125-250µm' zooplankton.

Table 6.4. Spearman rank correlation between abiotic factors and zooplankton with different developmental stages of Engraulidae in mangrove estuary (Station 1-5) and adjacent coastal waters (Station 6 & 7).
Temp- temperature; Sal- salinity; DO - dissolved oxygen; Turb - turbidity; Chl *a* - chlorophyll *a*; Zoo 500- wet weight of '>500µm' zooplankton;Zoo 250 – wet weight of '250-500µm' zooplankton, Zoo 125 – wet weight of '125-250µm' zooplankton
Asterisk indicates a *P*-value statistically significant (**P*<0.05; ***P*<0.01; ****P*<0.001)

	Temp	**Sal**	**DO**	**Turb**	**pH**	**Chl *a***	**Zoo 500**	**Zoo 250**	**Zoo 125**
Mangrove									
Preflexion	-0.18*	0.34***	0.19*	-0.10	0.40***	-0.23**	0.38***	0.13	0.01
Flexion	-0.24**	0.35***	-0.01	0.27***	0.27***	0.05	0.45***	0.15*	0.08
Postflexion	-0.29***	0.16*	-0.13	0.27***	0.005	0.05	0.38***	0.16*	0.05
Juvenile	0.04	0.09	0.05	0.15	0.015	0.17*	0.11	-0.05	0.03
Total	-0.30***	0.32***	-0.02	0.21*	0.21**	-0.01	0.46***	0.18*	0.06
Offshore									
Preflexion	-0.34**	0.02	0.18	0.25*	-0.24*	0.50***	0.30*	0.11	-0.12
Flexion	-0.18	0.05	-0.03	0.32**	-0.21	0.44***	0.13	0.05	-0.17
Postflexion	-0.32**	0.06	-0.20	0.51***	-0.09	0.47***	0.21	0.12	0.04
Juvenile	0.004	0.06	-0.02	0.21	0.00	0.19	0.07	-0.06	-0.11
Total	-0.33**	-0.02	0.08	0.37**	-0.33**	0.57***	0.30*	0.11	-0.12

Table 6.5. Spearman rank correlation between abiotic factors and zooplankton with different developmental stages of Clupeidae in mangrove estuary (Station 1-5) and adjacent coastal waters (Station 6 & 7).
Temp- temperature; Sal- salinity; DO - dissolved oxygen; Turb - turbidity; Chl *a* - chlorophyll *a*; Zoo 500- wet weight of '>500µm' zooplankton;Zoo 250 – wet weight of '250-500µm' zooplankton, Zoo 125 – wet weight of '125-250µm' zooplankton
Asterisk indicates a *P*-value statistically significant (**P*<0.05; ***P*<0.01; ****P*<0.001)

	Temp	**Sal**	**DO**	**Turb**	**pH**	**Chl *a***	**Zoo 500**	**Zoo 250**	**Zoo 125**
Mangrove									
Flexion	0.14	0.04	-0.01	-0.02	0.10	0.01	-0.02	0.14	0.12
Postflexion	0.14	0.07	0.27***	-0.12	0.20*	-0.10	0.03	0.11	0.12
Total	0.16*	0.05	0.23**	-0.10	0.17*	-0.07	0.02	0.12	0.13
Offshore									
Preflexion	0.44***	0.28*	-0.17	-0.37**	0.48***	-0.55***	-0.32**	-0.15	0.02
Flexion	0.41***	0.07	-0.08	-0.15	0.24*	-0.41**	-0.23	-0.12	0.08
Postflexion	0.22	-0.36**	0.05	-0.02	0.01	-0.28*	-0.05	0.00	-0.05
Total	0.39***	-0.05	-0.03	-0.30*	0.21	-0.54***	-0.30*	0.00	0.05

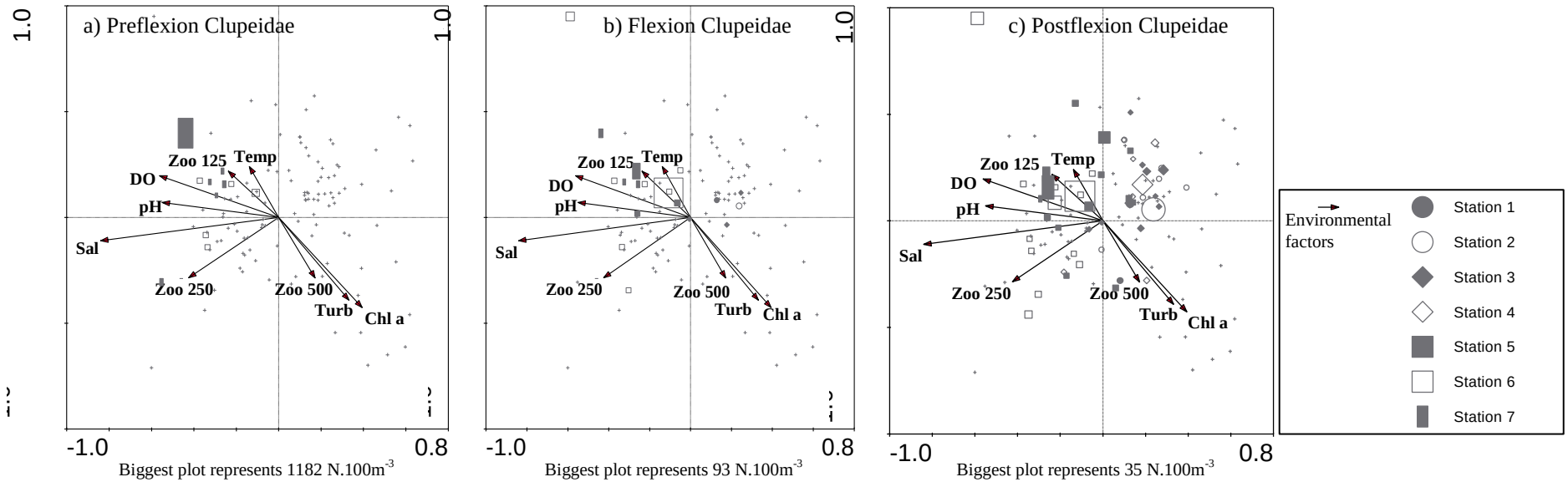

Figure 6.19. CCA attribute biplots of Clupeidae larval abundance (various plots according to stations) in relation to environmental factors (arrows), a) preflexion stage, b) flexion stage and c) postflexion stage. Sal – salinity, Temp – temperature, DO – dissolved oxygen, Turb – turbidity, Chl *a* – Chlorophyll *a*, Zoo 500 – wet weight of '>500µm' zooplankton, Zoo 250 – wet weight of '250-500µm' zooplankton, Zoo 125 – wet weight of '125-250µm' zooplankton.

Table 6.6. Spearman rank correlation between abiotic factors and zooplankton with different developmental stages of Sciaenidae in mangrove estuary (Station 1-5) and adjacent coastal waters (Station 6 & 7).
Temp- temperature; Sal- salinity; DO - dissolved oxygen; Turb - turbidity; Chl *a* - chlorophyll *a*; Zoo 500- wet weight of '>500µm' zooplankton;Zoo 250 – wet weight of '250-500µm' zooplankton, Zoo 125 – wet weight of '125-250µm' zooplankton
Asterisk indicates a *P*-value statistically significant (**P*<0.05; ***P*<0.01; ****P*<0.001)

	Temp	**Sal**	**DO**	**Turb**	**pH**	**Chl *a***	**Zoo 500**	**Zoo 250**	**Zoo 125**
Mangrove									
Preflexion	-0.14	0.26***	0.15	0.09	0.23**	-0.03	0.25**	0.19*	0.04
Flexion	-0.02	0.11	-0.10	0.13	0.03	0.05	0.05	0.06	0.12
Postflexion	0.02	0.12	-0.0009	-0.09	0.10	-0.09	0.09	-0.08	-0.10
Total	-0.15	0.29***	0.11	0.12	0.23**	0.01	0.25**	0.19*	0.07
Offshore									
Preflexion	-0.26*	0.09	-0.03	0.29*	-0.14	0.45***	0.17	-0.02	0.07
Flexion	-0.10	0.11	-0.07	0.25*	0.04	0.12	-0.06	-0.07	0.16
Postflexion	0.10	0.14	-0.25*	0.18	-0.03	0.18	-0.09	0.05	0.16
Total	-0.25*	0.09	-0.06	0.29*	-0.14	0.45***	0.13	-0.02	0.12

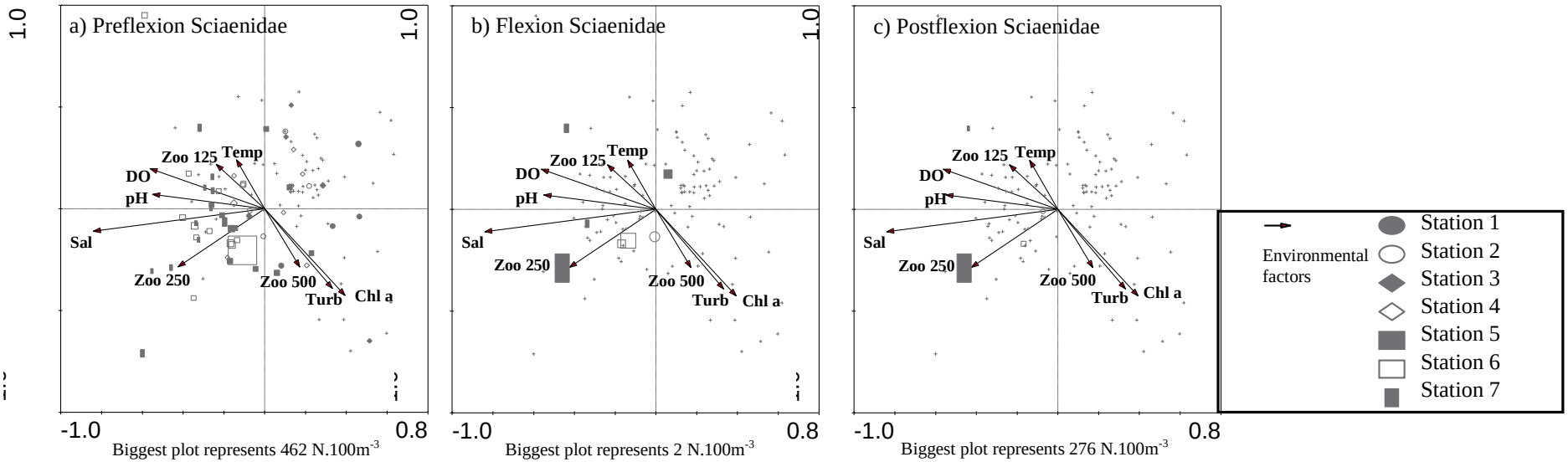

Figure 6.20. CCA attribute biplots of Sciaenidae larval abundance (various plots according to stations) in relation to environmental factors (arrows), a) preflexion stage, b) flexion stage and c) postflexion stage. Sal – salinity, Temp – temperature, DO – dissolved oxygen, Turb – turbidity, Chl *a* – Chlorophyll *a*, Zoo 500 – wet weight of '>500µm' zooplankton, Zoo 250 – wet weight of '250-500µm' zooplankton, Zoo 125 – wet weight of '125-250µm' zooplankton.

6.2.2.5 Ambassidae

Preflexion and flexion larvae appeared to prefer warmer and clearer waters of both coastal area and estuary (Figure 6.21 a-b). In the latter, their abundance was negatively correlated with zooplankton abundance (Table 6.7). More postflexion larvae were however, encountered in warmer, more oxygenated and higher salinity waters (Figure 6.21 c).

6.2.2.6 Blenniidae

Blenniid larvae of all ontogenetic stages were found in warmer, more oxygenated and less turbid waters, with a preference for zooplankton (Figure 6.22). They were positively correlated with salinity and dissolved oxygen and negatively correlated with turbidity and phytoplankton in mangrove estuary (especially at Station 5, river mouth) (Figure 6.21 a & Table 6.8).

6.2.2.7 Other families

Inside the mangrove estuary, Sygnathidae was negatively correlated with temperature ($P < 0.01$) and positively correlated with turbidity ($P < 0.05$) (Table 6.9). Cynoglossidae was positively correlated with salinity ($P < 0.05$) inside the mangrove estuary. It was also positively correlated with chlorophyll *a* concentration and zooplankton in the offshore waters. The scorpaenid larvae were also positively correlated with zooplankton in the offshore waters ($P < 0.05$).

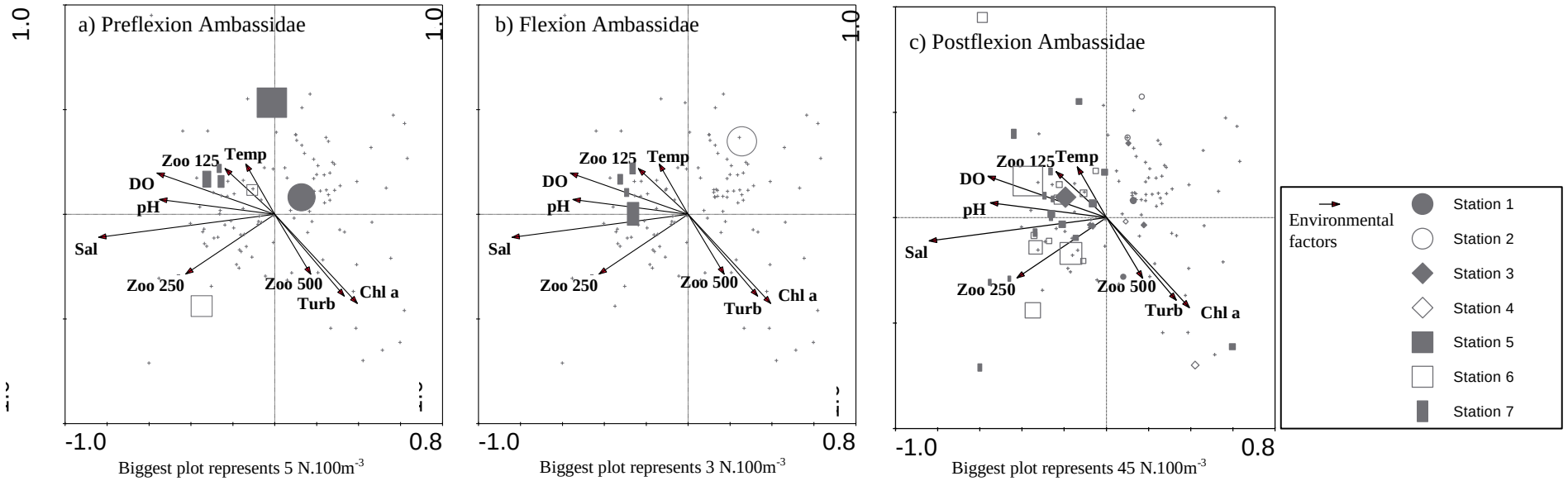

Figure 6.21. CCA attribute biplots of Ambassidae larval abundance (various plots according to stations) in relation to environmental factors (arrows), a) preflexion stage, b) flexion stage and c) postflexion stage. Sal – salinity, Temp – temperature, DO – dissolved oxygen, Turb – turbidity, Chl *a* – Chlorophyll *a*, Zoo 500 – wet weight of '>500µm' zooplankton, Zoo 250 – wet weight of '250-500µm' zooplankton, Zoo 125 – wet weight of '125-250µm' zooplankton.

Table 6.7. Spearman rank correlation between abiotic factors and zooplankton with different developmental stages of Ambassidae in mangrove estuary (Station 1-5) and adjacent coastal waters (Station 6 & 7).
Temp- temperature; Sal- salinity; DO - dissolved oxygen; Turb - turbidity; Chl *a* - chlorophyll *a*; Zoo 500- wet weight of '>500µm' zooplankton;Zoo 250 – wet weight of '250-500µm' zooplankton, Zoo 125 – wet weight of '125-250µm' zooplankton
Asterisk indicates a *P*-value statistically significant (**P*<0.05; ***P*<0.01; ****P*<0.001)

	Temp	**Sal**	**DO**	**Turb**	**pH**	**Chl *a***	**Zoo 500**	**Zoo 250**	**Zoo 125**
Mangrove									
Preflexion	0.06	0.15	0.12	0.003	-0.03	0.10	0.08	-0.10	0.08
Flexion	0.02	-0.06	0.11	-0.06	-0.09	_	0.08	-0.08	-0.12
Postflexion	0.04	0.26***	0.11	-0.06	0.28***	0.07	-0.03	0.09	0.06
Total	0.06	0.28***	0.15	-0.07	0.23**	0.10	0.01	0.04	0.05
Offshore									
Preflexion	0.27*	0.08	-0.04	-0.25*	0.20	-0.41***	-0.01	-0.14	-0.13
Flexion	0.06	0.15	0.12	-0.14	0.13	-0.30*	-0.12	-0.20	-0.35**
Postflexion	0.06	0.22	0.19	-0.17	0.11	-0.26*	-0.26*	0.08	0.01
Total	0.11	0.25*	0.16	-0.23	0.18	-0.35**	-0.30**	-0.02	-0.02

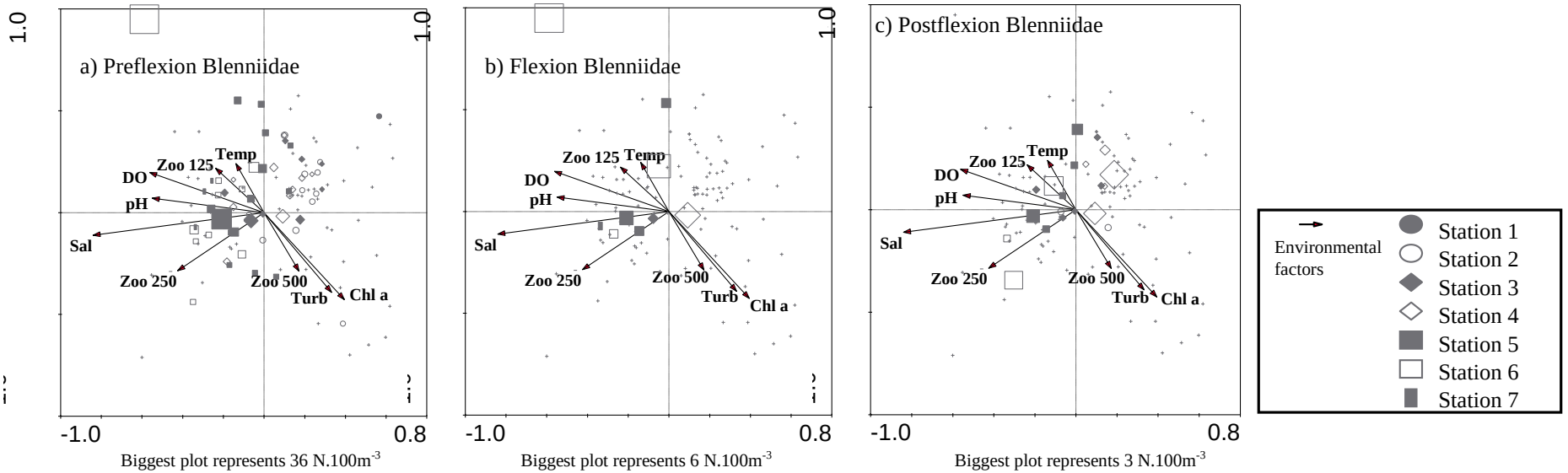

Figure 6.22. CCA attribute biplots of Blenniidae larval abundance (various plots according to stations) in relation to environmental factors (arrows), a) preflexion stage, b) flexion stage and c) postflexion stage. Sal – salinity, Temp – temperature, DO – dissolved oxygen, Turb – turbidity, Chl *a* – Chlorophyll *a*, Zoo 500 – wet weight of '>500µm' zooplankton, Zoo 250 – wet weight of '250-500µm' zooplankton, Zoo 125 – wet weight of '125-250µm' zooplankton.

Table 6.8. Spearman rank correlation between abiotic factors and zooplankton with different developmental stages of Blenniidae in mangrove estuary (Station 1-5) and adjacent coastal waters (Station 6 & 7).
Temp- temperature; Sal- salinity; DO - dissolved oxygen; Turb - turbidity; Chl *a* - chlorophyll *a*; Zoo 500- wet weight of '>500µm' zooplankton;Zoo 250 – wet weight of '250-500µm' zooplankton, Zoo 125 – wet weight of '125-250µm' zooplankton
Asterisk indicates a *P*-value statistically significant (**P*<0.05; ***P*<0.01; ****P*<0.001)

	Temp	**Sal**	**DO**	**Turb**	**pH**	**Chl *a***	**Zoo 500**	**Zoo 250**	**Zoo 125**
Mangrove									
Preflexion	-0.01	0.31***	0.22**	-0.32***	0.41***	-0.28***	0.12	-0.01	-0.06
Flexion	-0.04	0.17*	0.04	-0.15	0.14	-0.08	0.11	-0.03	0.00
Postflexion	-0.02	0.21**	0.15	-0.26**	0.21**	-0.18*	0.15	0.18*	0.05
Total	0.01	0.33***	0.24**	-0.37***	0.43***	-0.32***	0.16*	0.04	-0.05
Offshore									
Preflexion	-0.08	-0.32**	0.38**	0.09	-0.19	-0.10	0.10	0.14	-0.06
Flexion	-0.13	-0.20	0.25*	0.02	-0.11	0.05	-0.12	0.18	0.05
Postflexion	0.19	-0.25*	-0.17	0.09	0.12	-0.13	0.16	0.09	-0.11
Total	-0.03	-0.41***	0.26*	0.08	-0.17	-0.10	0.14	0.19	-0.09

Table 6.9. Spearman rank correlation between abiotic factors and zooplankton with larval fish families in mangrove estuary (Station 1-5) and adjacent coastal waters (Station 6 & 7).
Temp- temperature; Sal- salinity; DO - dissolved oxygen; Turb - turbidity; Chl *a* - chlorophyll *a*; Zoo 500- wet weight of '>500µm' zooplankton;Zoo 250 – wet weight of '250-500µm' zooplankton, Zoo 125 – wet weight of '125-250µm' zooplankton
Asterisk indicates a *P*-value statistically significant (**P*<0.05; ***P*<0.01; ****P*<0.001).

	Temp	**Sal**	**DO**	**Turb**	**pH**	**Chl *a***	**Zoo 500**	**Zoo 250**	**Zoo 125**
Mangrove									
Syngnathidae	-0.24**	0.11	-0.01	0.16*	0.08	-0.10	0.29***	0.09	-0.05
Scatophaghidae	0.05	0.01	0.06	-0.04	0.07	-0.07	-0.02	-0.04	-0.07
Cynoglossidae	-0.04	0.18*	0.09	0.10	0.15	-0.07	0.18*	0.03	-0.02
Carangidae	-0.13	0.08	0.07	-0.07	-0.01	0.03	0.01	-0.13	-0.20*
Bregmacerotidae	0.07	-0.02	-0.04	0.09	-0.08	0.12	-0.04	0.07	0.04
Platycephalidae	—	—	—	—	—	—	—	—	—
Scorpaenidae	0.003	0.03	-0.13	0.07	-0.13	0.10	-0.01	0.01	0.00
Leiognathidae	-0.06	0.03	-0.18*	0.21	-0.08	0.09	0.14	0.10	0.18*
Terapontidae	0.01	0.04	0.08	0.09	0.03	0.14	-0.03	0.04	0.06
Trichonotidae	—	—	—	—	—	—	—	—	—
Triacanthidae	—	—	—	—	—	—	—	—	—
Mullidae	—	—	—	—	—	0.05	—	—	—
Mugilidae	—	—	—	—	—	—	—	—	—
Unidentified	-0.06	0.18*	-0.02	.20*	0.03	0.05	0.15	0.07	-0.09
Offshore									
Syngnathidae	0.06	-0.15	0.01	-0.03	-0.06	-0.14	0.06	0.01	-0.07
Scatophaghidae	0.08	0.05	-0.02	-0.09	0.05	-0.14	-0.04	0.10	-0.11
Cynoglossidae	-0.23	0.06	0.09	0.19	-0.10	0.37**	0.22	-0.04	-0.04
Carangidae	-0.10	0.10	0.14	0.04	0.06	0.02	-0.11	-0.23	-0.20
Bregmacerotidae	-0.22	-0.01	0.14	0.10	0.02	-0.14	0.18	-0.11	-0.15
Platycephalidae	-0.06	0.07	-0.05	-0.06	0.10	-0.25*	0.09	0.02	0.10
Scorpaenidae	-0.26*	-0.06	0.03	0.13	-0.29*	0.20	0.20	0.07	-0.06
Leiognathidae	—	—	—	—	—	—	—	—	—
Terapontidae	—	—	—	—	—	—	—	—	—
Trichonotidae	0.19	0.07	0.02	-0.19	0.19	-0.20	-0.16	-0.18	-0.17
Triacanthidae	-0.03	-0.02	-0.05	0.00	0.11	-0.14	0.04	-0.01	0.01
Mullidae	0.01	-0.06	0.07	-0.05	-0.07	0.07	-0.04	0.10	-0.06
Mugilidae	-0.09	0.06	0.14	0.16	0.20	0.21	-0.14	-0.11	0.06
Unidentified	0.02	0.11	-0.02	0.18	-0.05	0.33**	0.07	0.01	-0.06

6.2.3 Match-Mismatch Hypothesis

Results show that preflexion gobiid larvae were relatively more abundant (above mean annual abundance) in March and October 2003 in both the mangrove waters and adjacent coastal waters (arrows). Figure 6.23a and b show similar "matching" monthly peaks between plankton abundance (both phytoplankton and copepods) and preflexion larval density of Gobiidae at these two months. The phytoplankton bloom and zooplankton in March 2003 "match" the peak abundance of preflexion gobiid, whereas in October 2003 and November 2002 the peak abundance of preflexion gobiid was matched by especially the high abundance of copepods. However, since the gobiids were not identified to species level, it is possible that different species of Gobiidae were recruited during these two peaks. It is apparent that during these two peak periods, the recruitment success of gobiid larvae depends on food abundance, thus, lending support to the match-mismatch hypothesis (Cushing, 1975) in tropical waters. Nevertheless, a third matching peak observable in September 2002 or July 2003 (the driest months of strong winds) in the offshore population (Figure 6.23b) cannot be ascribed to the monsoons.

In offshore waters where the engraulid fish spawns, the larval peaks that match the larval food occurred only in March and December during or near the start of the monsoons, as well as in August (Figure 6.24 b). This trend is generally similar to that of the Gobiidae. Interestingly, although a large larval peak was observed outside and inside the mangrove estuary in July-August 2002 (boxed area) it was not matched (mismatch) to sufficient larval food; hence, it is likely to have resulted in recruitment failure.

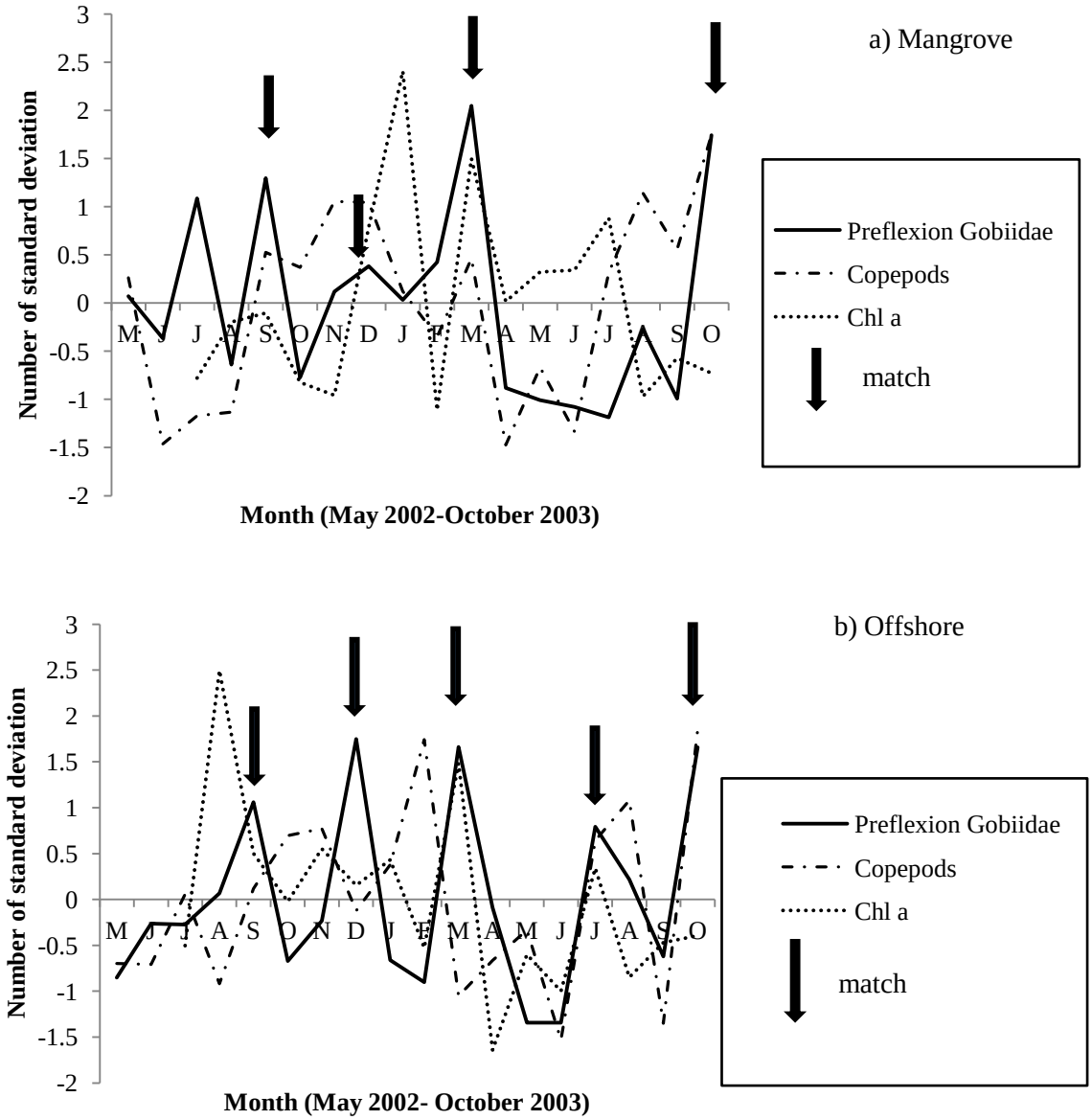

Figure 6.23. Monthly variations of preflexion gobiids, copepods and chlorophyll *a* in (a) Matang estuary and (b) adjacent coastal waters. The zero baseline corresponds to the mean of these three parameters over the 18 months of survey. Values above this baseline indicate a larval density of plankton production above the average whereas negative values indicate a density of production below the average.

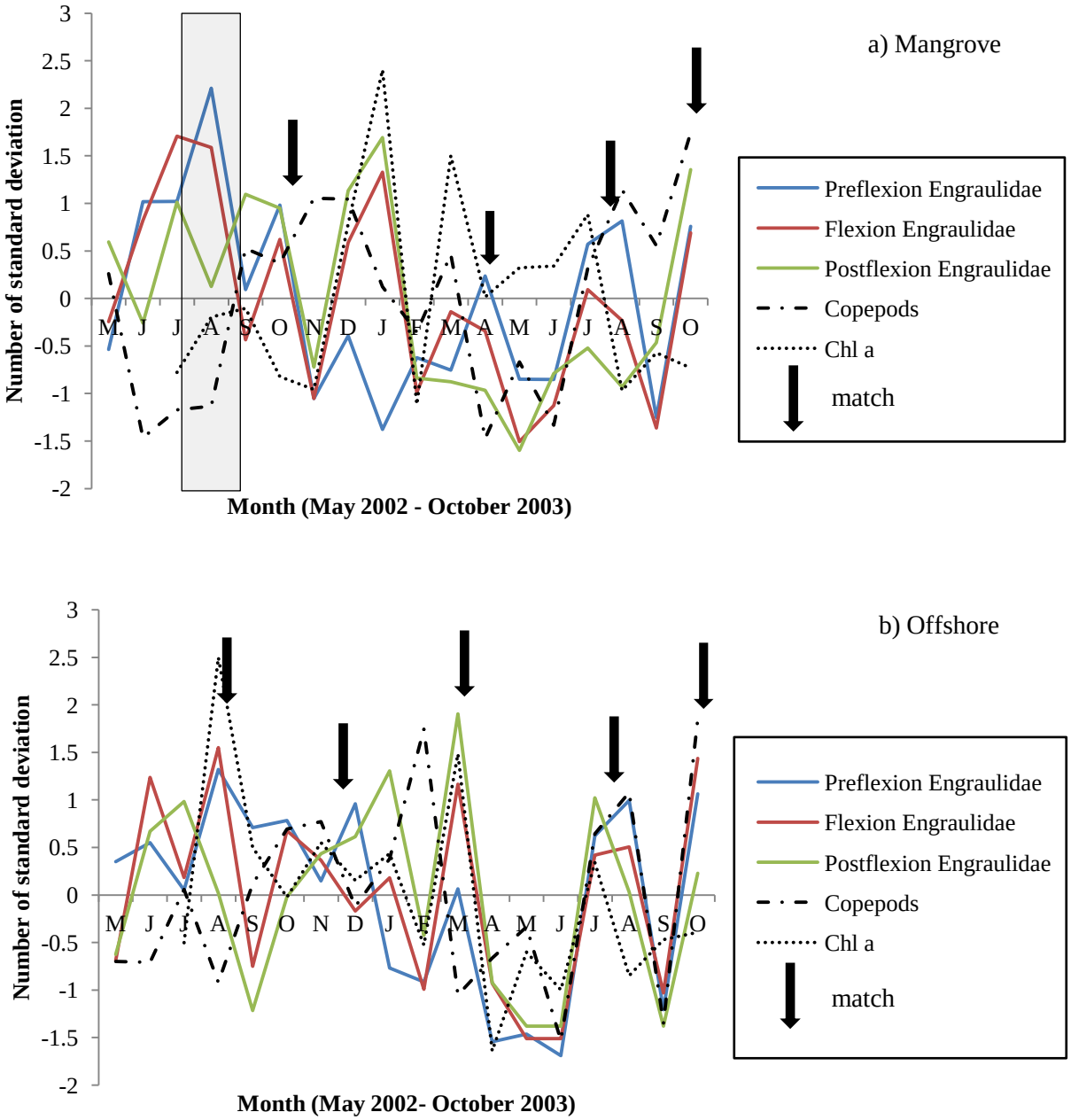

Figure 6.24. Monthly variations of preflexion Engraulidae larvae, copepods and chlorophyll *a* in (a) Matang estuary and (b) adjacent coastal waters. The zero baseline corresponds to the mean of these three parameters over the 18 months of survey. Values above this baseline indicate a larval density of plankton production above the average whereas negative values indicate a density of production below the average. Abundance of flexion and postflextion larvae were also plotted in the graph. The boxed area in (a) indicates a mismatch.

6.3 DISCUSSION

Estuaries are physically unstable areas characterized by large spatial and temporal variations in temperature, salinity, oxygen concentration, turbidity and other factors (Day et al., 1989). High fluctuations were observed in the Matang mangrove waters for temperature, salinity, dissolved oxygen, turbidity and pH values. These fluctuations are due to the influence of tides and the mixing of marine and fresh waters characteristic of an estuarine ecosystem (McLusky & Elliot, 2004). Despite the great variations of physical factors in the estuaries, the basic structure of estuarine fish communities is stable and fishes have more or less predictable patterns of abundance and distribution (Moyle et al., 1982).

Environmental factors greatly affect the ichthyoplankton assemblage of mangrove estuaries. North and Houde (2004) concluded that the complex and interacting biological and physical factors are determinants of the characteristics of larval fish nursery areas in estuaries. In KwaZulu-Natal estuaries, the larval fish assemblage apparently depended on environmental conditions such as salinity, temperature and turbidity at the time of recruitment (Harris & Cyrus, 1995). In Taiwan, Huang and Chiu (1998) showed that the abundance of *Acanthopagrus schlegelii* larvae was negatively correlated with water temperature and positively correlated with salinity and dissolved oxygen. In the Ganges estuary, mudskippers of three genera spawned during the monsoon period when the salinity was low, and turbidity, temperature and plankton biomass were high, a strategy adopted to ensure sufficient food while reducing predation (Clayton, 1993).Increased turbidity inside mangrove estuary may decrease predation risk for small fishes and is believed to havepositive effect on fish abundance (Blaber, 2000). The present study also shows a similar strategy adopted by gobiids in

the Matang mangrove estuary where all larval stages showed preference for lower salinity, high turbidity and higher plankton food (see Figure 6.15).

Highly variable salinities may influence species diversity that led to the dominance of estuarine larval fish communities by a few species (Tzeng et al., 2002). The mean salinity inside the Matang mangrove estuary fluctuated between 14.8‰ and 25.2‰. Although less variable, the diversity was dominated by Gobiidae and Engraulidae. Ramos et al. (2006) also reported that fish larvae in Lima river (Portugal) were dominated by a single resident taxa, *Pomatochistus* spp. Longitudinal gradients in salinity could have also regulated the distribution of a few euryhaline species (clupeid, engraulid and sciaenid) as indicated by the decreasing shift from offshore stations to upstream stations in the mangrove estuary (10.6 km from river mouth).

The response of fish larvae to environmental variables is likely species specific, and hence may not equally apply to all species within a family (Tzeng & Wang, 1992; Strydom et al., 2003). In a Lima estuary in Portugal, Ramos et al. (2006) reported that the presence of temporary estuarine residents was controlled by the spawning seasonality while the resident species were controlled by climate and hydrodynamics variations. Sarpedonti & Chong (2008) also noticed that the different development stages from the same species were not correlated with the same environmental factors. The newly-hatched *Stolephorus baganensis* was positively correlated with the dissolved oxygen. In the present study, flexion, postflexion and juveniles of engraulid larvae were also closely associated with higher turbidity and their planktonic food (see Figure 6.15) found in the mangrove estuary. Their upstream migration and taking residence in the estuary has been viewed as a migratory behaviour that enhances juvenile survival (Blaber, 1997). Younger engraulid larvae were usually found in higher salinity waters at

nearshore or offshore waters. Nevertheless, different species in the same family can withstand different salinity tolerances. For example, Sarpedonti and Chong (2008) found that *Stolephorus baganensis* spawned in clearer and relatively deep coastal waters whereas *Thryssa kammalensis* spawned at nearshore waters nearer to the mangrove estuary.

Even though turbidity and salinity have been shown to be important factors in attracting juvenile fishes into the mangrove estuary, some studies do not agree. Laegdsgaard & Johnson (1995) suggested that other factors must be responsible for the differences in juvenile fishes as the turbitidy, salinity and temperature did not vary greatly among the mudflats, seagrass and mangrove estuaries.

Predation has direct and indirect effects on the distribution of fish larvae other than environmental factors. No study was carried out in the present study regarding the prey and predator, but through observations and encounter of several predators, a few assumptions could be made. Stomach content analysis of small and juvenile fishes in the Matang estuary revealed that 10 of the 26 major species examined depended heavily on copepod as food (Chew et al., 2007). The fish diet comprised of 47 taxa of prey food with copepods and *Acetes* shrimps constituted 53% and 16%, respectively.

The present study in the Matang mangrove system is generally in agreement that spawning of fish was closely related with the abundance of their potential food sources (plankton). Therefore, the match-mismatch hypothesis may be applicable to tropical waters (see Cushing, 1990). Sarpedonti & Chong (2008) also supported the match-mismatch hypothesis in tropical waters where they found that the larval production of anchovies was timed to the increased natural food production. Although spawning of

fish occurs throughout the year, peak spawnings cued to the higher rainfall and/or the strong wind forcing associated with the monsoons may be a strategy adopted by many tropical fishes. Chew and Chong (2011) showed peaked abundance of zooplankton during higher rainfall when monsoon rains increased nutrient input into the estuaries and coastal waters and increased phytoplankton production. Hence, spawning of fish prior to heavy rainfall when environmental conditions are most favorable for larval survival would be advantageous since the resultant larvae would likely encounter more available food (Cushing, 1990; Ikejima et al., 2003). Nonetheless, the full interpretation of the results of match-mismatch is cautioned here because the exact species and their larval foods, the time lags between larval and food abundance, and the variable trophic processes and interactions, in relation to the physical environment are not known.

6.4 CONCLUSIONS

Larval abundance and distribution in Matang mangrove estuary and adjacent waters were influenced by water parameters and plankton biomass. Salinity, turbidity and zooplanktonic food sources are shown to be the major environmental factors structuring the larval fish assemblages. Higher fluctuations of water parameters were observed in the mangrove estuary. The spatio-temporal variations of larval fish assemblages including their ontogenetic stages differed between the mangrove estuary and adjacent coastal waters. These were related to the variations of water parameter especially the higher fluctuations inside the mangrove estuary.

The results from this study supported the first tested hypothesis that the spatial and temporal distribution of larvae is influenced by the physical factors and plankton abundance. The results also support the second hypothesis, the match-mismatch hypothesis, for tropical waters, at least for the dominant families of the Gobiidae and

Engraulidae. However, since the test was carried out at the family level, it is not known whether all species are responding to the environmental cue, i.e. the onset of the monsoons, in a similar manner.

CHAPTER 7

GENERAL DISCUSSION

Results of the various studies have been fully discussed in their respective chapters according to their specific objectives. Therefore, the objective of this chapter is to collate and synthesize the main findings in the previous chapters in order to address the following questions: (1) what are the strategies adopted by larval fish to utilize habitats in mangrove estuaries? (2) what are the challenges and future perspectives of fish larval studies in Malaysia?

7.1 What are the Strategies Adopted by Larval Fish to Utilize Mangrove Habitats?

Different fish species at different developmental stages showed some degree of habitat preference which leads to the discrepancy between juvenile and larval fish species in the present study. They utilize the mangrove system at different time and place for different purposes (Rountree & Able, 1997). They are influenced by tidal currents, physical factors and hydrographic structures within and adjacent mangrove habitat. Therefore, there's a need for tactics and strategies for larvae to meet all these challenges in order to reside permanently or temporary in the mangrove habitat. Some fish use the mangrove habitat as a spawning area, while others utilize it as a nursery and feeding ground or refugia from predation. Many fish species show ontogenetic changes in diet which may directly influence the life cycle migration patterns of coastal fishes (Cocheret de la Moriniére et al., 2003). Fish larvae that occur in the mangrove estuary consumed mainly zooplankton which derived their energy mainly from phytoplankton. This was supported by Chew et al. (2007) and Chong (2007) who showed that the dependence of zooplankton on phytoplankton carbon became increasingly more obvious from the upper estuary to offshore waters. Utilization of mangrove habitats by some resident

species (R), e.g. Gobiidae and short distance migrant species (SDM), e.g. Engraulidae larvae is discussed below.

Some Gobiidae (e.g. subfamily Oxurdercinae) are known to be amphidromous and inhabit mudflats or mangrove swamps and also the lower reaches of rivers (e.g. Khaironizam & Norma-Rashid, 2003). In the present study, Gobiidae larvae were ubiquitous in mangrove estuaries, indicating that the mangroves are utilized as a spawning and nursery ground for some species. Preflexion larvae occur mainly along the mangrove estuary and nearshore waters whereas juveniles are usually found inside the mangrove waters. This shows ontogenetic migration from nearshore waters towards the estuary for certain species. All larval stages of the Gobiidae prefer the lower salinities and turbid waters in the mangrove estuary. Occurrence of higher abundance of zooplankton especially copepod at the nearshore area (Chew & Chong, 2011) provides food to the gobiid larvae. Larger gobiid larvae in the estuary fed on zooplankton (Sampey et al., 2007). Yokoo et al. (2009) found that two species of juvenile gobies, *Acentrogobius kranjiensis* and *A. malayanus* occurred within the Sikao creek and tributaries inThailand and were not collected from the surf zone outside the creek mouth. Prior to that, Ikejima (2003) also showed that adults of the same two *Acentrogobius* species occurred only within the creek in the same area. This indicates that both species spend most of their life histories within estuarine habitats. Yokoo et al. (2009) also suggested that juveniles of these two species migrate between estuarine habitats with development, although migration patterns differ between species. Similar post-settlement movements within mangrove estuaries have been reported for three *Eleotris* species (Maeda & Tachihara, 2005) and three *Butis* species (Yokoo et al., 2006). Chang et al. (2006) using otolith elemental fingerprints revealed that gobioids utilized estuaries as nursery ground during their early larval stages. Some gobioid

species e.g. *Eleotris acanthopoma* and *E. melanosoma* were more widespread spending their postflexion larval periods not within estuaries but in surf zones, although their juveniles were still concentrated in estuarine habitats (Maeda & Tachihara, 2005). Polgar (2009) found that four mangrove localities hosted different mudskipper communities along the west coast of Peninsular Malaysia. In each locality, species were differently distributed along the intertidal gradient. Given the harsh mangrove environment where high fluctuations of environmental factors often occur, Gobiidae are still dominant here as a result of morphological adaptations to this environment. Various species confine or segregate themselves to certain areas (Takita et al., 1999) to avoid confrontation and competition for resources such as food, spawning and nursery areas. In a mangrove swamp in Indonesia, amphibious common mudskippers used a well developed behavioral escape response to avoid unfavorable environments (Taylor et al., 2005).

In the offshore waters, anchovy larvae are smaller in size (preflexion stage) and their size increases from offshore towards the coastal and mangrove estuary. The higher abundance of postlarval engraulid indicates that the estuary of Matang is a suitable nursery environment for post larvae and early juveniles. Some larvae remain in the mangrove estuary as long as possible to maximize protection from predation and time for feeding. Engraulids are attracted to the higher abundance of food in mangrove estuary as shown by ontogenetic shift in diet from the offshore to nearshore waters (see Chapter 6, Section 6.2.2.2). Towards the mangrove estuary, larger engraulid larvae depended more on zooplankton once they start to ingest zooplankton. Then (2008) reported that the juvenile engraulids caught in MMFR waters displayed a wide range of carbon isotope ratios (-23.88‰ to -16.30‰). Nevertheless, those caught offshore clearly showed $\delta^{13}C$ enrichment in their tissue compared to those caught inshore, which reflect

ontogenetic diet shift from copepods (assimilating phytoplankton and/or microphytobenthos carbon) to mysid/ *Acetes* shrimps (assimilating a mixture of phytoplankton and mangrove carbon) for juvenile engraulids. Janekarn and Boonruang (1986) reported that Engraulidae in mangrove estuaries developed to reach the young adult stage and were therefore classified as 'partial residents of mangroves by Mongkolprasit (1983). The engraulids mass spawned when rainfall was high where copepod production also peaked (Chew & Chong, 2011). Postflexion engraulids were abundant at the time when copepods were also found to be abundant in the MMFR waterways (Ooi et al., 2005, 2007). Sarpedonti (2000) reported that *S. baganensis* larvae had stronger dependence on exogenous feeding as compared to *T. kammalensis* larvae which possessed higher endogenous reserves. In a demographic analysis, Chen and Chiu (2003) indicated that the offshore anchovy larvae had smaller body size and their size increased from offshore towards the coastal waters. Stable larval development was achieved as the larvae reached the coastal area. The abundance of anchovy postlarvae is possibly influenced by the factors of calm water, food availability, predation pressure and effects of temperature and salinity. Nevertheless, some engraulid larvae e.g. *Thryssa setirostris* and *T. hamiltonii* occurred at the surf zone outside the river mouth which had higher salinity than the main river channel and tributaries in Sikao river, Trang, Thailand (Kanou et al., 2002).

Figure 7.1 shows a conceptual model on how larval fish of long distance migrant (LDM), short distance migrant (SDM) and resident (R) species take advantage of the abundant food supply that the estuary and nearshore waters provide in the mangrove estuary. One of the advantages of the strategy adopted by SDM and R species are less over dispersion of larvae due to the shorter distance travelled between spawning ground and the nursery ground in the estuary. In R species, the nursery ground is the spawning

ground itself. The mortality rate is lower due to less vagarant of larval fish but mortality may be higher due to predation. However, larval fish found in this habitat displayed different types and degrees of behavioral and physiological adaptations to mitigate daily salinity, thermal and oxic stress. Nevertheless, due to higher abundance of food resources in nearshore and mangrove estuary, there is higher predation risk. Besides that, competition for food resources and cannibalism also occurs. The smaller-sized zooplankton must be available for first-feeding at the feeding site for this strategy to be successful.

Long distance migrant species (LDM) are subjected to vagaries of nature (e.g. monsoon, strong winds, turbulent sea) and long-distance dispersion. Due to this, some larval fish could have drifted out of good feeding areas into poor ones. Nevertheless, the strong winds during monsoon could also influence the recruitment of LDM species into the estuary. In the present study, one larval fish peak occurred in August (see Figure 4.1) which could be due to wind forcing. The LDM species may take advantage of the strong southwesterly onshore winds (Chew, 2012) to move into the mangrove estuary. The long distance movements between habitats are likely to increase mortality because detection by predators is substantially increased by prey movement (Crowl, 1989). Predation is often a major source of mortality (Hunter, 1981). Therefore, fewer LDM larval fish survive to enter nursery. Nevertheless, when LDM species reach the mangrove estuary where their size are now larger, they are able to exploit a wider range of small to large sized prey in the nursery ground (Chew et al., 2007; Then, 2008). Since freshwater flow dilutes the salinity of marine water, and the salinity limits the distribution of less tolerant species, it is not surprising that these factors may be responsible for structuring the larval fish assemblage of the MMFR into the two main groups, estuarine (R) and euryhaline (SDM). In connection to the model, several

interesting research questions arise: 1) are the larvae of R and SDM species less tolerant of high salinity? and 2) are LDM species most tolerant of low and high salinity? Based on the model, one could test the hypothesis that SDM larvae are more susceptible to starvation risk in the event of a shortfall in food supply. For instance, as a result of anthropogenic impact such as severe pollution. Therefore, as a result of this need for adequate food supply, it may be necessary for such species to be found near to naturally rich coastal habitats (e.g. mangrove, seagrass beds, etc.).

Other adaptations include nocturnal spawning to avoid predation as observed in the present study by certain species of Gobiidae (see Chapter 5, Section 5.2.3.1). Other morphological adaptations include melanophores along the gut and on the ventral midline between the anus and caudal fin in Engraulidae. When it expands, the gut melanophores will help to conceal the larvae by masking light refracted from gut contents. Similarly, the melanistic shield which forms over the gas bladder reduces light refraction as a visual cue to potential predators (Moser, 1981). Hunter (1972) show that sighting distance and visual field are major limitations for feeding when anchovy larvae notice and strike at food particles.

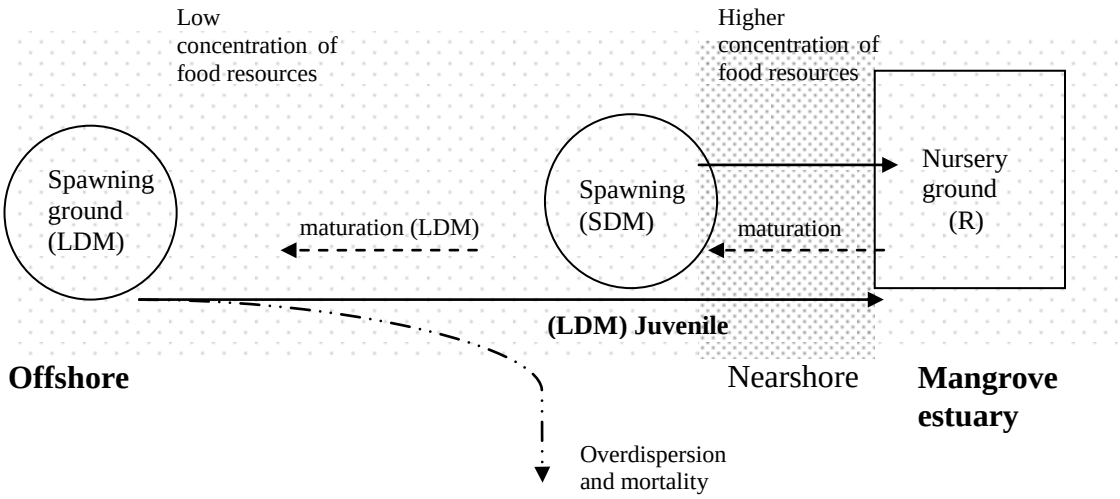

Figure 7.1. A conceptual model of early life history strategies of tropical mangrove fishes, in particular for Matang waters. Arrows indicate movements between habitats by long distance migrant species (LDM) e.g. Lutjanidae and Serranidae and short-distance migrant species (SDM) e.g, Engraulidae and Sciaenidae. Resident species (R) e.g. Gobiidae, spawn and mature within the mangrove estuary.

7.2 Limitations of Present Study and Recommendations for Further Study

Limitations of the present study:

1. Identification of larval fish in the present study is reported at the family level of organization and not at a finer level of resolution. Therefore, there is an inadequacy of identification at the family level. This is due to the serious lack of larval identification keys for this region and also this country. The high biodiversity of fish species in the present study (138 species) has aggravated the taxonomic problem. The co-presence of several species and genera (in same family, e.g. Sciaenidae) at the same sampling site has made identification more difficult to trace the larval series of similar morphotype to its identifiable juvenile. Furthermore reliable identification keys of tropical mangrove larval fish are very limited.
2. Monthly routine sampling was carried out in the present study. Weekly sampling would have been ideal or at least bimonthly (at least once during spring and neap

tide). This would help average out possible tidal differences and increase data resolution for both larval and environmental data. This was not carried out in the present study because of sampling effort, time and funding limitations. The most important limitation to more samplings is the time used in sorting and identification of larval fish. Nevertheless, intensive samplings totaling eight 24 hr samplings to cover all lunar phases for the dry and wet period were attempted to resolve these issues.

3. Only surface sampling was done in the present study. The entire water column sampling or at specific depths would be ideal for more accurate population estimates and stratification studies, respectively. The column sampling by oblique tow would allow for larval estimates per m^2 (Omori & Ikeda, 1984). But these were not done as explained in Chapter 2, Section 2.2.1. This is because there is a risk of the net hitting the bottom due to shallow water. However, sampling of surface and near bottom was carried out in the 24 hr study.
4. Only day sampling was carried out in the monthly routine sampling. However, 24-hour samplings included day and night samplings which encompassed the whole tidal cycle at all moon phases (weekly).
5. Location. The present survey used bongo nets and Clarke Bumpus nets to sample the mid-region of the mangrove channels due to the shallow depths. More locations inside the mangrove estuary could have been sampled using other nets, for example, among the inundated prop-roots using scoop nets. This could help to further understand the role of mangroves as refugia to fish larvae.

Future studies:

1. Concurrent sampling of juveniles/adults as future studies would allow the estimation of recruitment success/failure. Adult samplings could further confirm fish spawnings.
2. The study although with samplings as far as 16 km may not be far enough to cover the spawning grounds of some marine species, e.g. groupers and lutjanids whose larvae were not sampled in the present study although their juveniles were present in the mangrove. Future studies to sample further offshore would be informative.
3. One of the most important influences on the survival of fish larvae is the availability of suitable food. Information on diet, food availability and feeding behavior of fishes is fundamental to the understanding of their community structure, their distribution pattern and their life history strategies. This could be achieved by using both stable isotope analysis and stomach content analysis. The stable isotope ratios in animal tissues are based on actual food assimilation and reflect, on average, their diet over the previous weeks to months (Hobson, 1999), whereas stomach-content analysis is based on ingested prey and usually represents the animal's diet over the last few hours.
4. There is no way to test if the data from the current study depict a normal year of larval abundance without additional years of sampling. Therefore, seasonal patterns should be examined over long periods. However, this is for future studies.
5. Molecular techniques and genetic tools as well as fish rearing studies are required to ascertain the identity of both identified and unidentified larvae to species level. When such methods could not be carried out, the larvae are united to the family level (Joyeux et al., 2004), resulting in the inevitable loss of

specific information on taxa biology and ecology. This is the case in the present study where fish larvae have been largely identified to the family level. Hence, fish rearing and molecular studies should be carried out in the near future to fully identify mangrove fish larvae.

Future investigations on the role of the pelagic environment and its relation to the early stages of fishes must ultimately address the more general subject of zooplankton contagion and adaptations that larval fish have evolved to find and exploit food patches resulting from contagious distribution. Multispecies approaches to the study of fish populations are emerging, as are comprehensive studies on plankton communities; larval fish assemblages are subsets of these. Together with the present study on fish larvae, a concurrent study on zooplankton dynamics was done by Ms. Chew Li Lee (Chew, 2012).

7.3 CONCLUSIONS

The present study can be considered as the first comprehensive ecological study on mangrove and nearshore larval fish assemblages in Malaysia. This study has shown that the mangrove estuary and adjacent coastal waters are important to the different developmental stages of fish that occur in these habitats either as a spawning, feeding or nursery ground. The main finding of the study is that the larval fish community using mangrove estuary and nearshore waters mainly consists of a few key families of resident (e.g. Gobiidae) and euryhaline fishes (e.g. Engraulidae), whereas the wider diversity of other fish families in the estuary that were not collected in larval stages suggest that they must enter as juveniles. Another major finding is that the larval fish occurrence and distributions are largely influenced by environmental parameters and zooplankton abundance. Although the present study is unable to identify all larval fish

to the species level, all larvae have been identified to the family level, which is used as the ecological unit. Nevertheless, even at this level new knowledge on tropical larval fish and their ecology has emerged which is relevant to fishery and coastal resource management. In particular, the protection of larval fish aggregation areas such as the nearshore coastal belt adjoining and inside the mangrove estuaries is imperative to protect young fish stocks in their feeding and nursery areas. Unfortunately, in the Malaysian context, the management of fisheries resources has never considered the importance of mangrove forests or other coastal biotopes while on the other hand, mangrove forest management has never been for the fisheries purpose. The present study further points to this weakness of incomplete or partial management, for instance, any altered water quality (under the jurisdiction of the Department of Environment) could greatly affect larval fish recruitment and survival. Thus, this study strongly supports the call for integrated coastal zone management.