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NAME: Mrs. Pailin Jitchum

THIS THESIS HAS BEEN ACCEPTED BY

________________________ **THESIS ADVISOR**
(Professor Ladda Wongrat, M.S.)

________________________ **THESIS CO-ADVISOR**
(Assistant Professor Thanitha Thapanand Chaidee, Ph.D.)

________________________ **THESIS CO-ADVISOR**
(Mrs. Suree Satapoomin, Ph.D.)

________________________ **DEPARTMENT HEAD**
(Assistant Professor Narong Veeravaitaya, M.S.)

APPROVED BY THE GRADUATE SCHOOL ON ________________________

________________________ **DEAN**
(Associate Professor Gunjana Theeragool, D.Agr.)

THESIS

COMMUNITY STRUCTURE OF PLANKTONIC COPEPODS AND PRODUCTION OF ACARTIA ERYTHRAEA GIESBRECHT IN THE COASTAL AREAS OF THE UPPER GULF OF THAILAND

PAILIN JITCHUM

A Thesis Submitted in Partial Fulfillment of
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Community structure of planktonic copepods was studied biweekly from September 2006 to August 2007 in the coastal areas of the upper Gulf of Thailand. Production of copepods focusing on *Acartia erythraea* Giesbrecht, the most important species, was carried out in the laboratory during in January to August 2008. A total of 46 copepod species from 27 genera were identified. Calanoid was the most diverse group (22 species), followed by cyclopoid (9 species) and harpacticoid (4 species). The estuarine and neritic species were dominant in the study areas namely *A. erythraea*, *Acrocalanus gibber*, *Centropages furcatus*, *C. orsinii*, *Euterpina acutifrons* and *Pseudodiaptomus aurivilli*. Occurrence of two species *Labidocera bataviae* A. Scott and *L. pectinata* are reported for the first time in the coastal area of Manao Bay, while *Kelleria australica* Bayly, 1971 was recorded for the first time in Thai waters. Abundance of copepods fluctuated temporally at both studied areas, namely east coast (Si Racha Bay) and west coast (Manao Bay). Nauplii and copepodites dominated throughout the study period and more abundant at the east coast (70%) than the west coast (60%). Abundance and community structure of copepods were positively related to hydrographic variables, particularly water temperature and chlorophyll a. The present investigation is the first report of production study on *A. erythraea* in the upper Gulf of Thailand. Average abundance was 300 ± 181 ind. m^{-3}, with average biomass of 1.08 ± 0.73 mg C m^{-3}. Equation for the relationship between prosome length and carbon weight is: $\ln CW = 2.48 \ln PL - 16.1$, $R^2 = 0.74$. Generally, mean values of egg production rate (EPR), secondary production rate and specific growth rate calculates at the Si Racha Bay were higher that those at the Manao Bay. The average values recorded were 1.02 ± 0.94 eggs f^{-1} d^{-1}, 0.0003 mg C m^{-3} d^{-1} and 0.0096 ± 0.006 d^{-1}, respectively. From this study, the increasing rate of egg production according to chlorophyll a concentration suggests that egg production was limited by food availability.

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INTRODUCTION

Copepods are dominant meso-zooplankton in marine environment, comprising as much as 80% of total biomass (Bradford-Grieve *et al*., 1999; Mauchline, 1998; Woodd-Walker *et al*., 2002). They are important grazers on phytoplankton and micro-zooplankton and form a major trophic link to many predatory invertebrates and fish (Suwanrumpha, 1983; Runge, 1988; Landry *et al*, 1995; Uye *et al*., 1996; Uye and Shimazu, 1997; Uye *et al*, 2000). Thus marine copepods are reflected with their abundance, diversity and trophic structures in pelagic ecosystem (Ara, 2004; Chang and Fang, 2004; Lo *et al*, 2004).

In general aspects, the cause of pollution or environmental changes in the coastal ecosystems might reduce the species diversity of marine animals or increase population size of certain dominant species and finally may change in the trophic community structure (Norse, 1993; Poulet *et al*, 1995; Krumme and Liang, 2004; Morgado *et al*, 2007). Understanding how pelagic copepods respond to environmental variability and stresses can be applied by the measurements of growth and reproduction (Runge and Roff, 2000). Because of growth and production rate of copepods depend on the variability of temperature and food supply. The temperature and food conditions prevailing during the development of copepods affect its size at maturity and also hence its maximum potential weight and egg production rate (Durbin *et al*., 1983). Food limitation affecting growth and egg production rate were less than maximal in the field and were positively correlated with chlorophyll a concentration (Landry, 1978; Checkley, 1980). Many estimations of growth and reproductive rate of marine copepods have become a central aspect of marine plankton researches in worldwide (e.g. Hirst and Lampitt, 1998; Hirst and McKinnon, 2001; Hirst and Bunker, 2003; Neilsen *et al*., 2006; Liu and Hopcroft, 2007; Putland and Iverson, 2007).

Production of pelagic copepods can be estimated from their growth rate and biomass. The most popular expression of the growth rate is the weight-specific growth rate (day^{-1})

(Hirst and Lampitt, 1998), which is the increasing in body weight per day given as a proportion of body weight of the female or stage of development (Mauchline, 1998). Egg production rate (EPR) is a measurement of population birth or recruitment rate and also considered as the net production rate of the adult female copepods (Kiørboe and Sabatini, 1995).

Secondary production is a determination of energy flow through a population and as an indicator of its physiological or nutritional state, as a rate averaged over a time interval (Longhurst and Pauly, 1987). The secondary production rate was redefined by Kimmerer (1987) as the instantaneous rate of production of biomass by a population that is an integrated production during an interval is equal to the yield to consumers and decomposers, plus changing in biomass during the interval time. These estimations are ways to approach a measurement of enrichment of the sea and provide a better understanding of the extent to which potential variability influence on the copepods community in the pelagic ecosystem.

Many methods for estimating egg production rate, weight-specific growth rate, biomass and secondary production are mostly based on the investigations conducted in polar, temperate and subtropical ecosystems (e.g. Neilsen *et al*., 2006; Liu and Hopcroft, 2007; Putland and Iverson, 2007), only a few studies in tropical planktonic copepods that have been carried out, such as in the Andaman Sea (Satapoomin, 1999; Satapoomin *et al*., 2004) and Jamaica waters (Hopcroft and Roff, 1998; Hopcroft *et al*., 1998).

Copepods of the family Acartiidae are common inhabitants of coastal and estuarine environment in all oceans of the world (Seuront, 2005). The genus *Acartia* is also important component of the neritic zooplankton in Thai waters. In the Gulf of Thailand, 8 species of *Acartia* were recorded: *A. amboinensis*, *A. clausi*, *A. erythraea*, *A. longiremis*, *A. neglilens*, *A. pacifica*, *A. plumosa* and *A. spinicuada* (Flemiger, 1963; Suwanrumpha, 1978, 1980b, 1984, 1987; Suvapepun, 1980; Pinkaew, 2003; Salakij, 2009) while only 5 species were recorded in the Andaman sea is established: *A. amboinensis*, *A. australis*, *A. erythraea*, *A. neglilens* and *A. pacifica* (Satapoomin, 1999; Punnarak, 2004; Phukham, 2008). Among these, *A. erythraea* is a dominant species in near-shore brackish water occurring throughout the year.

The objectives of this study were to investigate community structure of planktonic copepods in coastal water in the upper Gulf of Thailand. Studies on length – weight relationship, egg production rate, weight - specific growth rate, biomass and secondary production of *A. erythraea* were conducted. The major hypothesis was based on the concept that the variation of quantity and quality of food available is the major effect on copepod community, in association with variation of hydrographic conditions in the field.

Two coastal areas in the upper Gulf of Thailand were selected for the comparative studies, one in Manao Bay, Prachuap Khiri Khan Province and the other in Si Racha Bay, Chon Buri Province. Manao Bay is a small, semi-enclosed and protected bay with a shallow water body (Jansang *et al*., 1999). Si Racha Bay is a large raft-culture area of green mussel, *Perna viridis* (Linnaeus, 1758) (Seekao *et al*., 2006). The study areas were selected as representatives of the two different level of natural resources exploitation. The study also determined the annual and seasonal patterns of phytoplankton and zooplankton communities.

OBJECTIVES

1. Overall objectives

The principle objectives of this study are to investigate seasonal variation in abundance, species composition and community structure of planktonic copepods, focusing on *Acartia erythraea* Giesbrecht, effects of environmental parameters on estimated growth, biomass and secondary production in two coastal areas in the upper Gulf of Thailand**.**

2. Specific objectives

1. To study seasonal variations in abundance and community structure of planktonic copepods in the coastal areas of the upper Gulf of Thailand

2. To determine growth rate of *A. erythraea* in the coastal areas of the upper Gulf of Thailand

3. To compare secondary production of *A. erythraea* in two different areas in the upper Gulf of Thailand

This study consists of four parts as follows:

1. Seasonal variations in abundance and community structure of planktonic copepods in Manao Bay and Si Racha Bay

The objectives of this study are to fill the gap of the seasonal variations in species composition, abundance and community structure of planktonic copepods in the upper Gulf of Thailand with an attempt to relate those variations to environmental parameters. Finally, the conclusion of this study will be compared with the previous results reported in the Gulf of Thailand by Suvapepun (1978, 1980); Suwanrumpha (1980b, 1984, 1987); Pinkaew (2003) and Salakij (2009).

2. Length-weight relationship of *A. erythraea* in Manao Bay, upper Gulf of Thailand

The objective of this study is to examine the prosome length, width length, dry weight and carbon weight of *A. erythraea* in the Manao Bay, upper Gulf of Thailand. The results will be presented as the length and weight relationship in regression equation to provide a further calculation of biomass and secondary production for coastal zone in tropical area.

3. Weight - specific growth rates of *A. erythraea* in Manao Bay and Si Racha Bay

The purposes of this study are to measure the weight - specific growth rate of *A. erythraea* in the upper Gulf of Thailand, calculated from their egg production rates. Data analyses will reveal the relationship between seasonal environmental parameters and sampling sites on egg production rate and weight – specific growth rate of *A. erythraea*.

4. Biomass and estimated production of *A. erythraea* in the upper Gulf of Thailand

The objective of this study is to determine seasonal variation in biomass, secondary production and turnover rate (production/biomass or P/B ratio) of *A. erythraea* in the upper Gulf of Thailand. The results received should explain the effects of environmental parameters, time and sampling sites on the secondary production of *A. erythraea*, and how planktonic calanoid copepod responds to environmental variations in tropical coastal water.

LITERATURE REVIEWS

1. What is a copepod?

Copepod is a small crustacean, usually between 0.2 – 12 mm in length. Copepods form a large assemblage representing marine, estuarine, freshwater habitat. More than 10,000 species of free-living and parasitic copepods are known from all the biological zones of the world in neritic and oceanic waters, from the surface to abyssal depths (Bradford-Grieve *et al*., 1999; Brusca and Brusca, 2003). They are important consumers of detritus, diatoms, and other algae, and they are food for carnivores, especially fish and invertebrate animals (Runge, 1988; Calbet and Landry, 2004; Calbet, 2008).

Bowman and Abele (1982) established the copepod taxonomy as Phylum Arthropoda, Subphylum Crustacea, Class Maxillopoda and Subclass Copepoda. Ten orders were recognized as Platycopioida, Calanoida, Misophrioida, Harpacticoida, Monstrilloida, Mormonilloida, Gelyelloida, Cyclopoida, Siphonostomatoida and Poecilostomatoida (Bradford-Grieve *et al*., 1999). Boxshall and Halsey (2004) proposed only nine orders and the family of formerly belongings to Order Poecilostomatoida are included within Order Cyclopoida.

The marine planktonic copepod, Calanoida is the most diverse order that is found in marine, brackish and fresh water. At least 41 families have been recorded (Boxshall and Halsey, 2004). They form a large proportion in total abundance and biomass of marine zooplankton. The second dominant order is Cyclopoida that composed of 8 families, followed by Harpacticoida (6 families) and Siphonostomaoida (3 families), respectively. Misophrioida, Mormonilloida and Monstrilloida have 1 family in each order. Families of marine planktonic copepods in 7 orders are listed in Table 1.

2. General characteristics of copepod

The body is cylindrical or oval shape that divided into 3 main regions called caphalosome, metasome and urosome (Figure 1). The whole body has sixteen or seventeen segments. The cephalosome includes head, with large antennule, antenna, mandible,

Table 1 Family lists of marine planktonic copepods in 7 orders.

Order	Family		
Calanoida	Acartiidae	Aetideidae	Arietellidae
	Augaptilidae	Bathypontiidae	Boholonidae
	Calanidae	Candaciidae	Centropagidae
	Clausocalanidae	Diaixidae	Discoidae
	Epacteriscidae	Eucalanidae	Eucahetidae
	Fosshageniidae	Heterorhabdidae	Hyperbionychidae
	Lucicutiidae	Mecynoceridae	Megacalanidae
	Mesaiokeratidae	Metridinidae	Nullosetigeridae
	Paracalnidae	Parapontellidae	Phaennidae
	Pontellidae	Pseudocyclopidae	Pseudocyclopiidae
	Pseudodiaptomidae	Rhincalanidae	Ridgewayiidae
	Ryocalanidae	Scolecitrichidae	Spinocalanidae
	Stephidae	Sulcanidae	Temoridae
	Tharybidae	Tortanidae	
Misophrioida	Misophriidae		
Harpacticoida	Aegisthidae	Clytemnestridae	Ectinosomatidae
	Euteripinidae	Miraciidae	Thalestridae
Mormonilloida	Mormonillidae		
Cyclopoida	Clausidiidae	Corycaeidae	Lubbockiidae
	Oithonidae	Oncaeidae	Paralubbockiidae
	Sapphirinidae	Urocopiidae	
Siphonostomatoida	Megapontiidae	Pontoeciellidae	Rataniidae
Monstrilloida	Monstrillidae		

Source: Boxshall and Halsey (2004)

maxillule and maxilla (Figure 2). The cephalosome often bears a median eye which is only a few ocelli, usually three. The first thoracic segment of metasome is always fused with cephalosome bearing the maxilliped and the fourth and fifth segments are also fused and may seem some species have three segments. The first pair of swimming leg is called the first pedigerous somite. There are seven postcephalic thoracic somites: the maxilliped-bearing somite, five pedigerous somites, each bearing a pair of swimming leg and the genital somite.

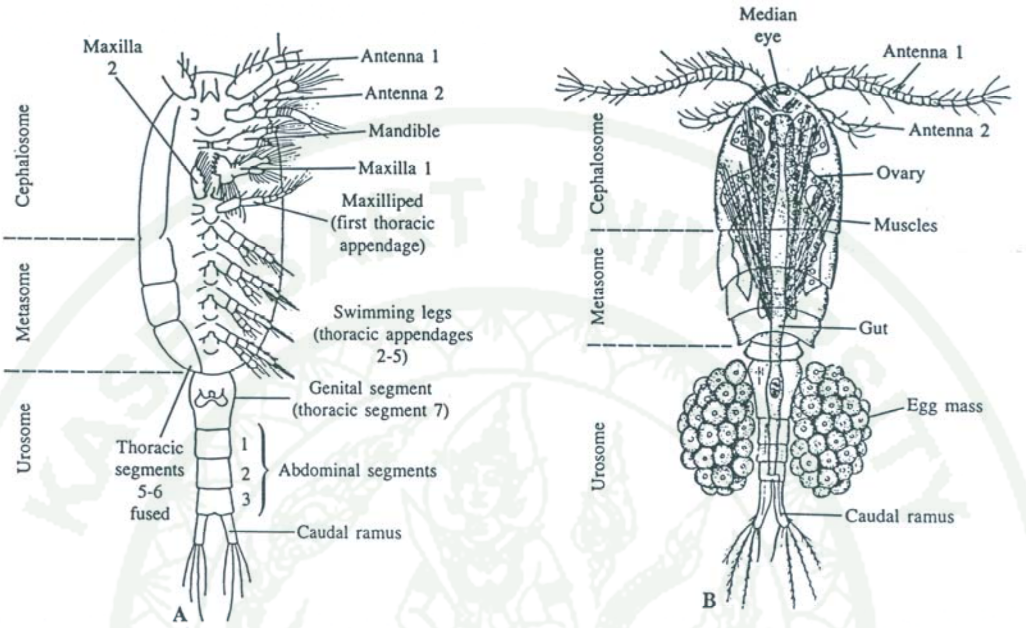


Figure 1 Diagram of a female *Pseudocalanus* (Order Calanoida), ventral view (A) and female *Cyclops strennus* (Order Cyclopoida) (B).

Source: Kozloff (1990)

The metasome begins with either the second or the third thoracic segment and extent to where the body usually abruptly narrow. The cephalosome and metasome together is called cephalothorax or prosome. The urosome includes the genital somite and three abdominal segments and telson in posterior of body. One or two pregenital thoracic segments are also incorporated into the urosome (Figure 1). Male has five pairs of swimming leg and females the fifth pair is usually absent or much reduced. There are no appendages on the abdominal segments of copepods but the telson has a pair of caudal rami (Bradford-Grieve *et al*., 1999; Kozloff, 1990).

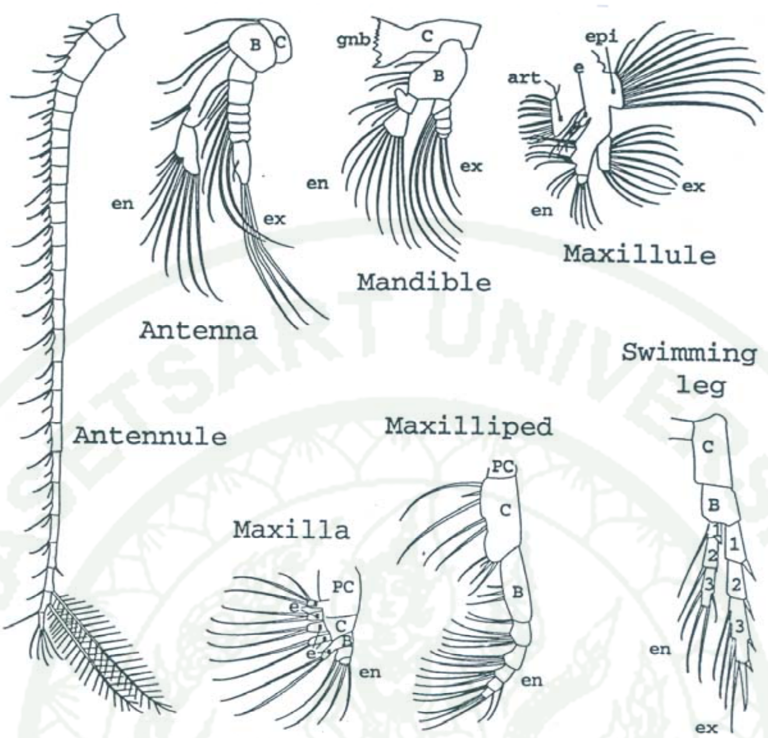


Figure 2 Diagram of the appendages of a calanoid opepod. The swimming legs usually have develop endopods and exopods with up to three segments, numbered 1-3 here. art (arthrite); B (Basis); C (Coxa); e (endite); en (endopod); ex (exopod); epi (epipodite); gnb (gnathobase); PC = praecoxa.

Source: Mauchline (1998)

There are two major plans of the body organization (tagmosis) into anterior prosome and a posterior urosome, separately by the major body articulation. In the gymnoplean tagmosis has found in Order Platycopioida and Calanoida, the major body articulation is located between the fifth pedigerous somite, bearing the fifth swimming leg and the genital somite (Figure 3). In the podoplean type has found all remaining orders, the major articulation primitively lies between the fourth and the fifth pedigerous somite (between the fifth and six thoracic somites) (Muachline, 1998; Bradford-Grieve *et al*., 1999). Figure 4 shows the comparison in shape of three important orders in pelagic copepods.

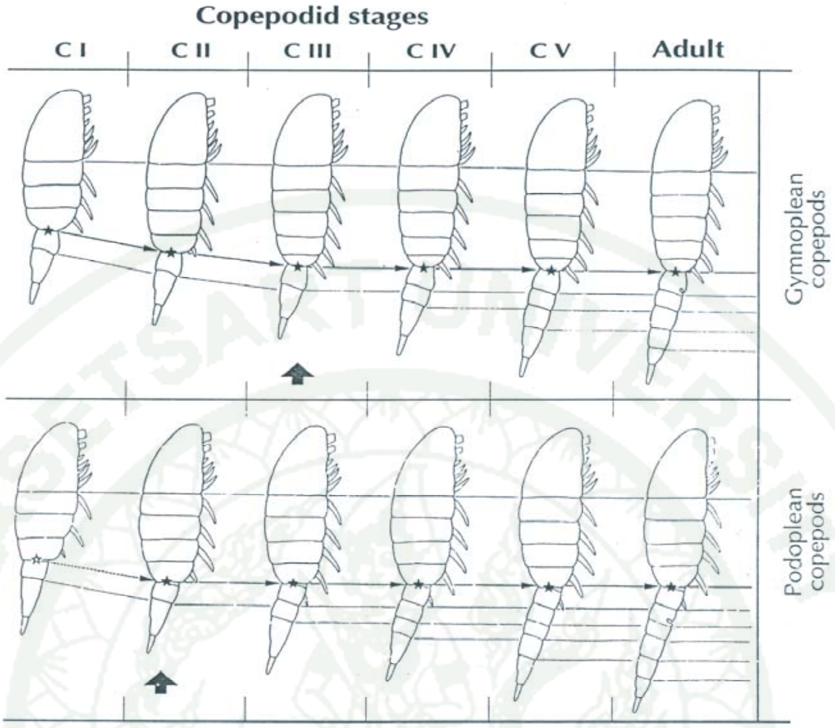
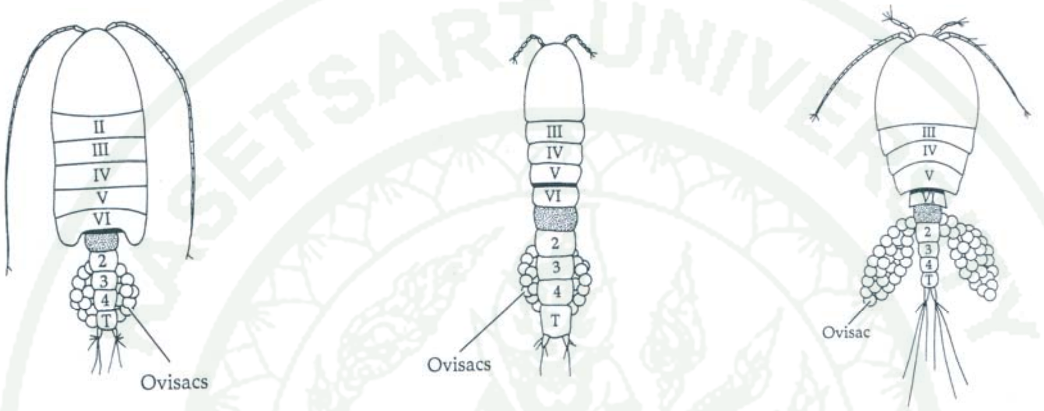


Figure 3 Comparison of the development pattern in podoplean and gymnoplean copepods. CI-CV: first copepodid to fifth copepodid developmental stages: solid stars indicate flexure planes, hollow star indicates poorly defined flexure planes, heavy arrows indicate the stage at which the definitive tagmosis is attained and specialization of the joint commences.

Source: Mauchline (1998)

There are no gills in free-living copepods except in the calanoids and some parasitic species. There is neither heart nor blood vessels. The excretory organs are maxillary glands (Ruppert *et al.,* 2004).

Copepods are sexually dimorphic with males are smaller than females. The gonads are anterior of urosome. Males have a single testis and either one or two sperm ducts. If there are two ducts, there are two genital pores. Females usually have one ovary, with two oviducts that produces large numbers of egg. Fertilization is copulation when the male transfers one or more spermatophores to the female’s genital somite. Then the sperm is transferred through the female's copulatory pore and stored in seminal receptacles. Fertilized eggs are released through the gonopores that represent the oviduct openings. Some female of calanoid copepods hold their eggs in a ventral egg sac until the nauplii hatch and others produced the eggs are directly to drop from the genital pore into the water column (Bradford-Grieve *et al*., 1999).



(a) (b) (c)

Figure 4 The general body forms of calanoid copepod (a); harpacticoid copepod (b) and cyclopoid copepod (c).

Source: Brusca and Brusca (2003)

The fecundity of a female varies among species, and also depending on the amount and quality of food, season, hydrographic conditions and latitudinal zones (Bradford-Grieve *et al*., 1999). Development time of eggs depends on temperature and may vary from one day to several months. Diapause eggs are recorded from calanoid copepods of Family Acartiidae Centropagidae, Pontellidae and Temoridae (Mauchline, 1998). Unfortunately most investigations of resting eggs in marine calanoid copepods have been made in the northern temperate waters, a few in subtropical waters and none in the tropical region (Marcus, 1996).

Free-living copepods have 12 developmental stages, 6 naupliar and 6 copepodid stages, which the sixth copepodid as adult (Figures 5, 6 and 7). The first naupliar stage has 3 pairs of appendages: antennule, antenna and mandible. The sixth naupliar stage has all appendages up to the second swimming leg present (Bradford-Grieve *et al*., 1999). Duration of each stage is very short. The fifth copepodid stage of some species may live longer than others (Mauchline, 1998). Continuous breeding is characteristic of tropical copepods; while in temperate regions breeding cycles strongly vary (Bradford-Grieve *et al.*, 1999).

Takahashi and Ohno (1996) had observed the development of *Acartia tsuensis* by rearing experiments (Figure 5). Most of naupliar stage 1 hatched within one day after spawning. The median development time for *Acartia tsuensis* at 30°C from N1 to C6 was 6.4 days. Six naupliar stages and six copepodid stages are described as follows:

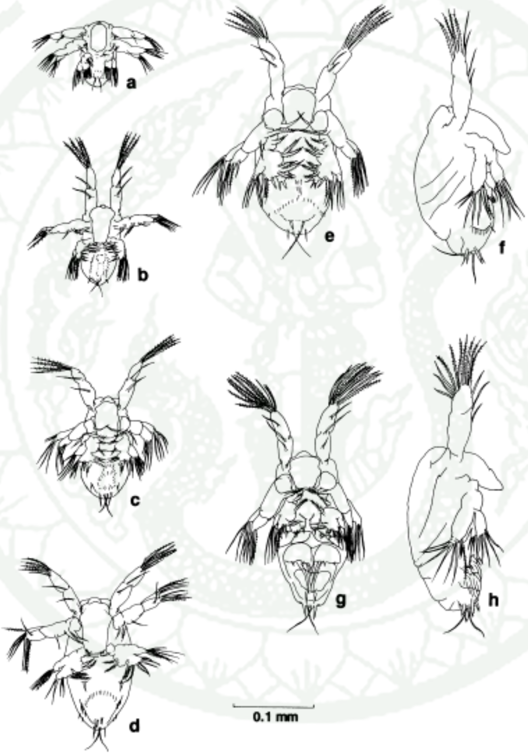


Figure 5 *Acartia tseunsis*, naupliar stages: a-d, stage 1-4; e-f, stage 5; g-h stage 6.

Source: Takahashi and Ohno (1996)

1. Naupliar stage 1 (N1) averages length 0.115 mm. The antennules, antennae and mandibles are rudimentary.

2. Naupliar stage 2 (N2) averages length 0.138 mm. There are four terminal setae in the antennule on the distal segment and setae added at the middle of the proximal segment.

3. Naupliar stage 3 (N3) averages length 1.164 mm. The maxilllule is presented posterior to the mandible. A pair of slight end hooks is presented at the postero-ventral end of the body.

4. Naupliar stage 4 (N4) averages length 0.192 mm. A pair of relatively large ventral hooks is present anteriorly to end hooks (Figure 4).

5. Naupliar stage 5 (N5) averages length 0.227 mm. Cuadal armature is similar to that of N4. The rudiments of maxilla and maxilliped are present.

7. Naupliar stage 6 (N6) averages 0.261 mm. The body is slightly elongated compared to N5. Two pairs of the first indication of swimming legs are present on the posteroventral part of body.

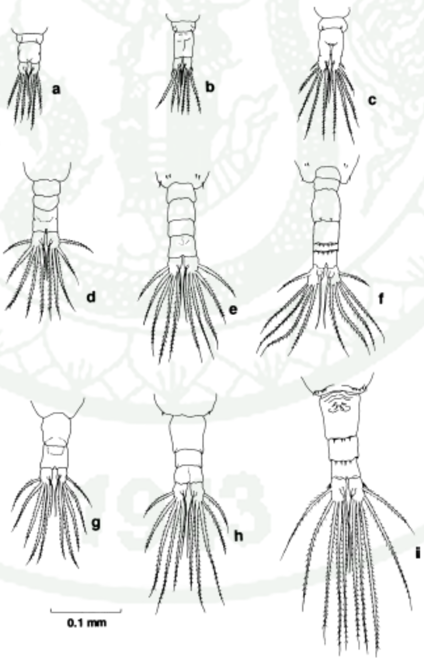


Figure 6 Dorsal view of the urosome of copepodid and adult of *Acartia tseunsis*. a-c, stages 1-3; d-f, male of stages 4-6; g-i, female stages 4-6.

Source: Takahashi and Ohno (1996)

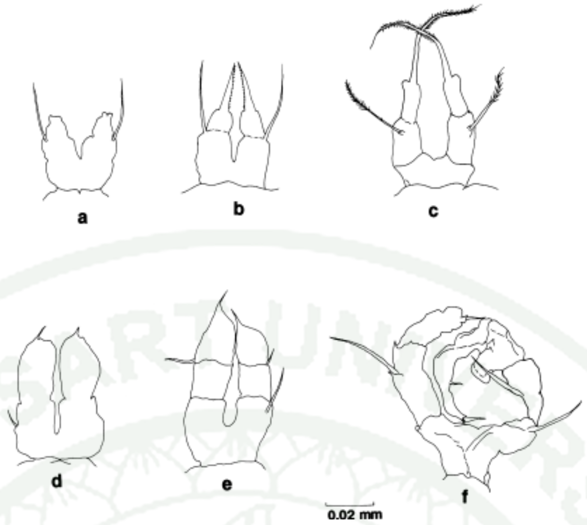


Figure 7 Fifth legs of *Acartia tseunsis* in posterior view. a-c, fifth leg of female of stages 4-6; d-f, fifth leg of male of stages 4-6.

Source: Takahashi and Ohno (1996)

8. Copepodid stages swimming legs appear on the ventral side of body. Copepodid stage 1 (C1) has two pairs of swimming legs (Figure 6). The number of legs increases by one pair following the advancement of each stage up to copepodid stage 4 (C4), which attains the adult complements of five of swimming legs. The sex appearance of copepodid stage starts from C4 by the differences in the shape of the urosome and fifth legs (Figure 7).

3. Feeding

Copepods are defined as selective suspension or particle feeders and may be herbivorous, carnivorous (predatory feeders), omnivorous, saphrophages or coprophages copepods. Some copepods are able to switch from one feeding mode to another according to the environmental variability. The type of feeding mode is usually reflected in the structure of oral appendages (antennules, antennae, mandibles, maxillules and maxillae) and also the type of locomotion. The morphology of suspension feeding calanoid copepods has feeding appendages likely long, strong densely plumose setae. On the other hand, carnivores have strongly chitinized sharp teeth on the cutting edge of mandibles and usually are sharper on ventral teeth in the raptorial predator. Omnivores have the intermediate characteristics between suspension feeders and predators (Bradford-Grieve *et al*., 1999).

Harpacticoid copepods are recognized to be carnivores, suspension feeders and mucus trap feeders. Cyclopoids more probably are carnivores, capturing food activity, but some species such as *Oithona similis* are mainly herbivores. Oncaeidae was observed to be active predators on larger zooplankton. Mauchline (1998) reviewed the feeding modes of calanoid copepods predominantly herbivorous, carnivorous and omnivorous genera and families based on their stomach contents (Table 2).

Most information on diets and feeding of copepods concerned coastal and epipelagic species and supposed omnivore and carnivore species higher than herbivores species. The main food items for suspension feeders are phytoplankton and microzooplankton (ciliates, tintinnids and copepod nauplii) (Bradford-Grieve *et al*., 1999). Lebour (1922) and Marshall (1924) studied on the stomach contents of copepods indicated the omnivores and diets varied in seasonal reflecting the food available in the sea. The dietary components from stomach contents in *Calanus* species were as follows:

1. Green algae
2. Flagellates
3. Dinoflagellates i.e. *Peridinium*, *Dinophysis*, *Gymnodinium*, *Phalacroma* and *Prorocentrum*
4. Coccolithophores i.e. *Pontosphaera huxleyi*
5. Silicoflagellates i.e. *Distephanus*, *Dictyocha*, *Ebria*
6. Diatoms i.e. *Biddulphia*, *Chaetoceros*, *Coscinodiscus*, *Ditylum*, *Fragilaria*, *Paralia*, *Phaeocystis*, *Rhizosolenia*, *Skeletonema*, *Thalassiosira*)
7. Tintinnids i.e. *Tintinnopsis ventricosa*, *Tintinnus subulatus*
8. Radiolarian i.e. *Acanthonia mülleri*
9. Bits of copepods

Cannibalistic feeding of calanoids was studied by Øresland (1991, 1995) and Øresland and Ward (1993) who identified the prey species i.e. *Metridia gerlachei*, *Calanoides acutus*, *Pareuchaeta* spp., *Heterorhabdus* spp., *Microcalanus* spp. *Drepanopus* spp., *Oncaea* spp. and *Oithona* spp. in the stomach of four species of *Pareuchaeta* from the Atlantic Ocean. The food items of carnivorous copepods were chaetognaths, copepods, polychaetes, pelagic molluscs, larvaceans, fish eggs, fish larvae (Mauchline, 1998).

Little information on feeding of nauplii and copepodid larval stages were studied. According to Sekiguchi (1974), the nauplii of calanoids divided two feeding types; i) the gnathobase of mandible is developed by nauplius IV: i.e. the NI is the first feeding stage (*Pseudodiaptomus coronatus*), the NII (*Rhincalanus nasutus*, *Pontellopsis regalis*, *Acartia* species and *Temora longicornis*) and the NIII or NIV in many species and ii) those in which does not developed until the copepodid I (CI) and do not feed but have oil sacs: i.e. *Aetideus*, *Bradyidius*, *Chiridius*, *Pareuchaeta*, *Candacia* and *Tortanus*. Nauplii graze smaller particles such as phytoplankton and naupliar faecal pellets (Green *et al*., 1992). The diets in stomach contents of copepodid larval stages contained the similar food with adult.

Table 2 Predominantly herbivorous, carnivorous and omnivorous genera and families of calanoid as determined by examination of their stomach contents. Species are often detritivores when present in the benthopelagic environment.

Feeding mode	**Genera/Families**		
1. Herbivorous	*Acartia*	*Calanoides*	*Calanus*
	Pseudocalanidae	*Rhincalanus*	Spinocalanidae
2. Omnivorous	*Acartia*	*Aetideopsis*	*Aetideus*
	Bathypontiidae	*Centropages*	*Chiridius*
	Eucalanus	*Euchirella*	*Gaetanus*
	Haloptilus	*Limnocalanus*	Lucicutiidae
	Metridinidae	*Paracalanus*	*Pseudochirella*
	Scolecitrichidae	*Scopalatum*	*Temora*
3. Carnivorous	Candaciidae	*Euaugaptilus*	Euchaetidae
	Heterorhabdidae	*Pachyptilus*	Phaennidae
	Pontellidae	Tharybidae	Tortanidae

Source: Mauchline (1998)

4. What are the roles of copepods in ecosystem?

Planktonic copepod is a major important organism in marine epipelagic ecosystem. They interact with their biological environment. Some calanoid species compete with some cyclopoid species for living space and resources (Mauchline, 1998). Planktonic copepods are recognized as selective suspension feeders that may be herbivores, omnivores, or carnivores (Bradford-Grieve *et al*., 1999). The main food items for suspension feeder are phytoplankton and micro-zooplankton (ciliates, tintinnids, and copepod nauplii) (Uye and Shimazu, 1997; Uye *et al*., 1998; Uye *et al*., 2000). The herbivorous copepod feeds on phytoplankton and forms a direct linkage between itself and fish such as herring, sardine and pilchard. Copepods are the smallest size-spectrum of food for baleen whale and are also eaten by a vast variety of marine invertebrate animals. Herbivorous species can control populations of phytoplankton in some area. They must also influence the distribution and sizes of populations of their predator (Longhurst and Pauly, 1987; Mauchline, 1998).

Some species within the certain genera of calanoid copepods are key species in the ecosystems that they dominate. The other species within the same genera are important within the geographical regions in which they occur but they may not all be important enough to be key species within their respective ecosystems. There are many genera that are known to have key species in large or smaller ecosystem. Coastal ecosystems have key species representing in genera *Acartia*, *Centropages*, *Eurytemora*, *Paracalanus*, *Parvocalanus*, *Pseudocalanus* and *Pseudodiaptomus*. They are successful species as shown by their dominance within their communities (Mauchline, 1998).

5. Ecological studies of planktonic copepods

A. Species composition of planktonic copepods in Thai waters

The species composition of marine epipelagic copepods varies among 4 orders in the Thai waters: The Gulf of Thailand and Andaman Sea. A total of 199 species 49 genera 29 families 4 orders of epipelagic copepods were recorded by Fleminger (1963), Suvapepun (1980), Suwanrumpha (1980b), Suwanrumpha (1984), Nishida (1985), Suwanrumpha (1987), Pinkaew (2003), Punnarak (2004), Phukham (2008) and Salakij (2009). The most diverse group is Order Calanoida, comprising 135 species, followed by Order Poecilostomatoida, comprising 36 species. Less diverse groups are Order Harpacticoida (15 species) and Order Cyclopoida (13 species). The species composition of epipelagic copepods is shows in Table 3.

Table 3 Species lists of marine planktonic copepod in Thai waters.

No.	**Taxa**	**Gulf of Thailand**								**AS**	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	Order Calanoida										
	Family Augaptilidae										
1	*Haloptilus spiniceps* (Giesbrecht)										✓
	Family Arietellidae										
2	*Metacalanus aurivilli* (Claus)		✓	✓	✓	✓					
	Family Lucicutiidae										
3	*Lucicutia flavicornis* (Claus)					✓					✓
	Family Acartiidae										
4	*Acartia amboinensis* Carl	✓	✓						✓	✓	✓
5	*A. cluasi* Giesbrecht		✓			✓					
6	*A. erythraea* Giesbrecht		✓	✓	✓	✓	✓		✓	✓	✓
7	*A. longiremis* Lilljeborg		✓			✓					
8	*A. negligens* Dana	✓	✓			✓					✓
9	*A. pacifica* Steuer						✓		✓	✓	✓
10	*A. plumosa* A.Scott						✓				
11	*A. spinicauda* Giesbrecht		✓	✓		✓	✓				
12	*Acartiella sinensis* Shen&Lee					✓	✓				
	Family Candaciidae										
13	*Candacia aetiopica* (Dana)					✓					
14	*C. bipinnata* Giesbrecht					✓					
15	*C. bradyi* A.Scott	✓	✓		✓	✓			✓		✓
16	*C. catula* Giesbrscht	✓	✓			✓			✓		✓
17	*C. curta* (Dana)		✓			✓					
18	*C. discaudata* A.Scott	✓	✓		✓	✓				✓	✓
19	*C. pachydactyla* (Dana)					✓					✓
20	*C. simplex* Giesbrecht	✓	✓			✓					
21	*C. truncata* (Dana)	✓	✓		✓	✓					

Table 3 (Continued)

No.	**Taxa**	**Gulf of Thailand**								**AS**	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
22	*Candacia* sp.			✓							
23	*Paracandacia truncata* (Dana)										✓
	Family Centropagidae										
24	*Centropages bradyi* Wheeler					✓					
25	*C. calaninus* (Dana)										✓
26	*C. dorsispiratus* Thompson&Scott					✓					✓
27	*C. elongatus* Giesbrecht										✓
28	*C. furcatus* (Dana)	✓	✓	✓	✓	✓	✓		✓	✓	✓
29	*C. gracilis* (Dana)	✓	✓			✓					✓
30	*C. orsinii* Giesbrecht	✓	✓	✓	✓	✓	✓		✓	✓	✓
31	*C. tenuiremis* Thompson&Scott	✓	✓			✓	✓		✓		✓
	Family Diaptomidae										
32	*Phyllodiaptomus praedictus* Apstein						✓				
33	*Mongolodiaptomus butulifer* Kiefer						✓				
34	*M. yangtsikiangensis* Mashiko						✓				
	Family Pontellidae										
35	*Calanopia aurivilli* Cleve					✓			✓	✓	✓
36	*C. australica* Badly&Greenwood									✓	
37	*C. elliptica* Cleve	✓	✓	✓	✓	✓			✓		✓
38	*C. minor* A.Scott	✓	✓			✓	✓				✓
39	*C. thompsoni* A.Scott		✓	✓		✓			✓		✓
40	*Labidocera acuta* (Dana)	✓	✓		✓	✓			✓		✓
41	*L. bengalensis* Khrishnawany								✓		✓
42	*L. bipinnata* Tabaka		✓			✓			✓		✓
43	*L. detruncata* (Dana)		✓			✓					
44	*L. japonica* Mori		✓			✓					
45	*L. kroyeri* (Brady)	✓	✓			✓			✓		
46	*L. laevidentata* (Brady)	✓	✓						✓		✓
47	*L. minuta* (Giesbrecht)	✓	✓			✓			✓	✓	✓
48	*L. pavo* Giesbrecht					✓	✓		✓	✓	✓
49	*L. pectinata* Thompson&Scott										✓
50	*L. rotunda* Mori						✓				✓
51	*Labidocera* sp. 1										✓

Table 3 (Continued)

No.	Taxa	Gulf of Thailand								AS	
		1	2	3	4	5	6	7	8	9	10
52	*Labidocera* sp. 2										✓
53	*Labidocera* sp. 3										✓
54	*Labidocera* spp.			✓							
55	*Pontella danae* Giesbrecht										✓
56	*P. diagonalis* Wilson										✓
57	*P. investigatoris* Sewell										✓
58	*P. fera* Dana								✓		✓
59	*P. forficula* A.Scott								✓	✓	✓
60	*P. latifurca* Chen&Zhang								✓		
61	*P. spinicauda* Mori		✓			✓	✓				
62	*P. spinipes* Giesbrecht								✓		✓
63	*P. tridactyla* Chen&Lee								✓		
64	*P. valida* Dana								✓		✓
65	*P. vervoorti* Mulyadi								✓		
66	*Pontella sp.* 1										✓
67	*Pontella* sp. 2										✓
68	*Pontella* sp. 3								✓		
69	*Pontellina plumata* (Dana)	✓	✓			✓					✓
70	*P. mori* Fleminger & Hulseman								✓		✓
71	*Pontellopsis armata* (Giesbrecht)										✓
72	*P. inflatodogitata* Chen&Shen								✓		✓
73	*P. krameri* (Giesbrecht)								✓		✓
74	*P. macronyx* A. Scott								✓		✓
75	*P. perspicax* (Dana)		✓			✓			✓		✓
76	*P. regalis* (Dana)					✓					
77	*P. scotii* Sewell								✓		✓
78	*P. yamadae* Mori		✓		✓	✓					
79	*Pontellopsis* sp.1										✓
80	*Pontellopsis* sp.2										✓
81	*Pontellopsis* sp.3								✓		
	Family Pseudodiaptomidae										
82	*Pseudodiaptomus annandalei* Sewell					✓	✓				✓
83	*P. aurivilli* Cleve		✓	✓		✓			✓		✓

Table 3 (Continued)

No.	Taxa	Gulf of Thailand								AS	
		1	2	3	4	5	6	7	8	9	10
84	*P. bispinosa* Walter						✓				
85	*P. bowmani* Walter									✓	
86	*P. clevi* A.Scott	✓	✓	✓		✓			✓	✓	✓
87	*Pseudodiaptomus* spp.				✓						
	Family Temoridae										
88	*Temora discaudata* Giesbrecht	✓	✓	✓	✓	✓			✓	✓	✓
89	*T. longicornis* (Muller)		✓								
90	*T. stylifera* (Dana)		✓			✓				✓	
91	*T. turbinata* (Dana)	✓	✓	✓	✓	✓				✓	✓
	Family Tortanidae										
92	*Tortanus barbotus* (Brady)									✓	✓
93	*T. forcipatus* (Giesbrecht)	✓	✓	✓	✓	✓	✓		✓	✓	✓
94	*T. gracilis* (Brady)					✓			✓	✓	✓
	Family Calanidae										
95	*Canthocalanus pauper* (Giesbrecht)	✓	✓	✓	✓	✓	✓		✓	✓	✓
96	*Cosmocalanus darwini* (Lubbock)										✓
97	*Nannocalanus minor* (Claus)	✓	✓			✓					✓
98	*Neocalanus tenuicornis* (Dana)		✓			✓					
99	*Undinula darwini* (Lubbock)		✓			✓					
100	*U. vulgaris* (Dana)	✓	✓	✓	✓	✓			✓		✓
	Family Paracalanidae										
101	*Acrocalanus gibber* Giesbrecht	✓	✓	✓		✓	✓		✓	✓	✓
102	*A. gracilis* Giesbrecht	✓	✓			✓					✓
103	*A. longicornis* Giesbrecht	✓	✓	✓	✓	✓					✓
104	*A. monachus* Giesbrecht			✓	✓	✓					✓
105	*A. similis* Sewell		✓	✓	✓	✓					
106	*Acrocalanus* spp.			✓							
107	*Bestiolina similis* Sewell						✓				
108	*Calocalanus pavo* (Dana)	✓	✓			✓					✓
109	*C. plumolosus* Giesbrecht	✓	✓			✓					✓
110	*C. styliremis* (Claus)	✓	✓			✓					
111	*Paracalanus aculeatus* Giesbrecht	✓	✓	✓		✓			✓		✓
112	*P. crassirostris* Dahl	✓	✓	✓		✓	✓				

Table 3 (Continued)

No.	Taxa	Gulf of Thailand								AS	
		1	2	3	4	5	6	7	8	9	10
113	*P. dentatus*	✓	✓								
114	*P. nanus*		✓								
115	*P. parvus* (Claus)	✓	✓	✓		✓					
116	*Paracalanus* spp.				✓						
	Family Eucalanidae										
117	*Eucalanus attenuatus* (Dana) (*Pareucalanus attenuatus*)		✓			✓					✓
118	*E. crassus* Giesbrecht *(Subeucalanus crassus)*	✓	✓			✓	✓				✓
119	*E. monachus* Giesbrecht		✓			✓					
120	*E. pileatus* Giesbrecht	✓	✓			✓					
121	*E. subcrassus* Giesbrecht (*Subeucalanus subcrassus*)		✓	✓	✓	✓				✓	✓
122	*Rhincalanus cornutus* Dana										✓
	Family Clausocalanidae										
123	*Clausocalanus arcuicornis* (Dana)		✓	✓		✓					✓
124	*C. arecornis*				✓						
125	*C. furcatus* (Brady)	✓	✓			✓					
	Family Euchaetidae										
126	*Eucaheta concinna* Dana	✓	✓		✓	✓					
127	*E. flava* Giesbrecht					✓					
128	*E. marina* (Prestandrea)		✓			✓					✓
129	*E. plana* Mori		✓		✓	✓					
130	*E. rimana* Bradford										✓
131	*E. wolfendeni* A. Scott										✓
132	*Euchaeta* spp.			✓							
	Family Scolecitrichidae										
133	*Scolecithricella longispinosa* Chen&Zhang					✓					✓
134	*S. tenuiserrata* (Giesbrecht)	✓	✓								
135	*Scolecithrix danae* (Lubbock)										✓
	Order Harpacticoida										
	Family Diosaccidae										

Table 3 (Continued)

No.	Taxa	Gulf of Thailand								AS	
		1	2	3	4	5	6	7	8	9	10
136	*Schizospera subterranea*		✓								
	Family Miraciidae										
137	*Macrosetella gracilis* (Dana)		✓			✓					
138	*Stella gracilis*			✓	✓						
	Family Ectinosomatidae										
139	*Microsetella atlantica*		✓								
140	*M. norvegica* (Boeck)		✓	✓		✓				✓	
141	*M. rosea* (Dana)		✓			✓					
142	*Microsetella* sp.						✓				
143	*Monops regalis*		✓								
144	*M. stennus*		✓								
	Family Clytemnestridae										
145	*Clytemnestra rostrata* (Brady)		✓			✓					
146	*C. scutellata* Dana			✓		✓					
147	*Corynura denticulata*		✓								
148	*C. recticuada*		✓								
	Family Euterpinidae										
149	*Euterpina acutifrons* (Dana)		✓		✓	✓	✓			✓	
	Family Metidae										
150	*Metis jousseaumei* (Richard)			✓		✓					
	Order Cyclopoida										
	Family Oithonidae										
151	*Oithona aruensis* Frucht						✓	✓			
152	*O. attenuata* Farren							✓			
153	*O. brevicornis* Giesbrecht		✓								
154	*O. dissimilis* Lindberg						✓	✓		✓	
155	*O. nana* Geisbrecht		✓			✓	✓	✓			
156	*O. oculata* Farren		✓			✓	✓				
157	*O. plumnifera* Baird		✓	✓	✓	✓	✓	✓		✓	
158	*O. pseudofrigida* Rosendorn						✓				
159	*O. rigida* Geisbrecht		✓	✓	✓	✓		✓			
160	*O. similis* Claus		✓			✓					
161	*O. simplex* Farren		✓			✓	✓	✓			

Table 3 (Continued)

No.	Taxa	Gulf of Thailand								AS	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
162	*Oithona* spp.			✓						✓	
	Family Cyclopidae										
163	*Mesocyclop aequatorialis* (Von der Velde)						✓				
	Order Poecilostomatoida										
	Family Oncaeidae										
164	*Oncaea conifera* Giesbrecht		✓			✓					
165	*O. media* Giesbrecht		✓			✓					
166	*O. venusta* Philippi		✓			✓				✓	
167	*Oncaea* spp.			✓	✓		✓				
	Family Corycaeidae										
168	*Corycaeus agilis* Dana		✓			✓					
169	*C. affinis* (McMurich)						✓				
170	*C. asiaticus* Dahl					✓				✓	
171	*C. andrewsi* Farren									✓	
172	*C. catus* Dahl		✓	✓		✓				✓	
173	*C. crassiusculus* Dana		✓			✓					
174	*C. concinnus* (Dana)		✓			✓					
175	*C. flaccus* Giesbrecht		✓			✓					
176	*C. gibbulus* Giesbrecht		✓		✓	✓					
177	*C. gracilicaudatus* Giesbrecht		✓			✓					
178	*C. latus* Dana		✓			✓					
179	*C. lautus* Dana		✓			✓					
180	*C. longistylis* Dana		✓			✓					
181	*C. ovalis* Claus		✓			✓					
182	*C. obtusus*		✓								
183	*C. robustus* Giesbrecht		✓								
184	*C. rostratus* (Claus)					✓					
185	*C. speciosus* Dana		✓			✓					
186	*C. trunkicus* Mori		✓			✓					
187	*Corycaeus* spp.			✓						✓	
	Family Sapphirinidae										
188	*Copilia mirabilis* Dana		✓		✓	✓					

Table 3 (Continued)

No.	Taxa	Gulf of Thailand								AS	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
189	*C. quadrata* Dana					✓					
190	*Sapphirina angusta* Dana		✓			✓					
191	*S. gastrica* Giesbrecht		✓			✓					
192	*S. gemma* Dana					✓					
193	*S. metallina* Dana		✓			✓					
194	*S. nigromaculata* Claus		✓			✓					
195	*S. ovatolanceolata* Dana					✓					
196	*S. scarlata* Giesbrecht		✓			✓					
197	*S. stellata* Giesbrecht		✓		✓	✓					
198	*S. vorax* Giesbrecht		✓			✓					
	Family Clausididae										
199	*Hemicyclops* sp.						✓				

Remarks: AS = Andaman Sea; [1]Fleminger (1963); [2] Suvapepun (1980); [3]Suwanrumpha (1980b); [4]Suwanrumpha (1984); [5] Suwanrumpha (1987); [6] Nishida (1985); [7] Pinkaew (2003) [8] Salakij (2009); [9] Punnarak (2004); [10] Phukham (2008)

Species composition of copepods in the upper Gulf of Thailand was investigated by Suwanrumpha (1980b) and 36 species were identified. The inshore copepod species are dominated by *Acrocalanus similis*, *Acartia spinicuada*, *Oithona plumifera*, *Paracalanus parvus*, *Microsetella norvegica*, *Corycaeus* spp., *Temora turbinata*, *Centropages orsinii*, *Labidocera* spp. and *Euterpina acutilifrons*. The offshore species compose of *Calanus pauper*, *Eucalanus subcrassus*, *Oithona plumnifera* and *Corycaeus* spp. (Suwanrumpha, 1980b).

The diversity indices were investigated in the western Gulf of Thailand that ranged from 0.55 to 8.39 (Suwanrumpha, 1984). The variation in zooplankton biomass and species numbers of copepods were found to be positively related to diversity index. Higher diversity indices were obtained during the post monsoon months from September to

October. The most abundant species in the western Gulf of Thailand are *Calanus pauper*, *Undinula vulgaris*, *Eucalanus subcrassus*, *Temora discaudata*, *Tortanus forcipatus*, *Acartia erythraea*, *Centropages furcatus*, *Candacia discaudata*, *Calanopia elliptica*, *Labidocera acuta* and *Acrocalanus longicornis.* While the most dominant species that frequently occurring throughout the year, compose of *Calanus pauper, Eucalanus subcrassus* and *Acartia erythraea* (Suwanrumpha, 1984). They are indicated suitable species for neritic and warm water preference.

The estuarine copepod species have been studied by Pinkaew (2003) in Bangpakong Estuary and Sri Racha Bay, eastern coast of the Gulf of Thailand. Thirty five species were identified and seven new recorded species in Thai waters were recorded. The new recorded species are *Labidocera rotunda*, *Pseudodiaptomus bispinosus*, *Oithona dissimilis*, *O. pseudofrigida*, *O. oruensis*, *Mesocyclops aequatoralis* and *Corycaeus affinis*.

Punnarak (2004) has studied species diversity of planktonic copepods in Pak Meng Canal Estuary, Andaman Sea. Order Calanoida is the most diverse group that composes with 22 species, followed by Order Poecilostomatoida, comprising 7 species. Less diverse groups are Order Harpacticoida and Order Cyclopoida, comprising 2 species in each order. The dominant species are *Acartia amboinensis*, *Canthocalanus puaper*, *Centropages orsinii* and *Labidocera pavo*.

Calanoid copepods were recently established in both the upper Gulf of Thailand and the Andaman Sea by Phukham (2008) and Salakij (2009). Phukham (2008) studied along the coastal Andaman Sea from Ranong Province to Satun Province. She found 80 species in 28 genera based on 330-µm in mesh size. In addition, 59 species were the new recorded in Thai waters. In 2009, Salakij presented 42 species in 15 genera based on 200 and 330-µm in mesh size. *Pontella* genus of four species were established in the new records in Thai waters.

B. Abundance and community of planktonic copepods

The quantitative plankton research is abundance and species identification that is the basis of community analysis. Community is defined as association of different populations co-existing in space and time. This association has specific properties such as composition, diversity, ratio of rare to common species, indicator species and biomass production (Postel *et al*., 2000). Pattern diversity is a kind of diversity that is resulted from zonation, stratification, periodicity, patchiness or food web (Odum and Barrett, 2005).

Abundance is a number of individuals per unit of water, expressed as number per m^3. Diversity measurement describe to a quality of a community, as either complex or simple. It depends on species numbers and a relative abundance of species (Postel *et al*., 2000). The relationship between diversity and number of species in two different samples is called evenness or equitability (Omari and Ikeda, 1984). Similarity and dissimilarity measurements are described to observed communities that differ in species composition or not, often as a result of environmental variations.

The seasonal variation in abundance of copepods showed fluctuation during the year from 12.5×10^5 to 112.5×10^5 ind. m^{-3} in the inner Gulf of Thailand (Suwanrumpha, 1980a). Maximum abundance of copepods was found during the Northeast monsoon months from December to March but the minimum density occurred during the inter-monsoons in April to October.

Jivaluk (1999) has investigated the abundance of copepods in the Gulf of Thailand and found the average abundance from 208 to 229 ind. m^{-3} or 43.9% to 55.99% of the total zooplankton. The higher density was found during the post-monsoons months from April to May. There was no significant difference between biomass in both periods.

Microzooplankton was studied by Chuchit *et al*., (2003) from June 2001 to May 2002 using the 60μm mesh size net in Si Racha Bay. Tintinnids was the dominant group that has highly occurred throughout the annual period with the average abundance of 40×10^4 ind. m^{-3}. The maximum value was recorded in June 2001 and the minimum value was showed in February 2002. Other groups of microzooplankton were polychaete larvae, rotifers, copepod nauplii, bivalve larvae and larvaceans. Average abundance of total microzooplankton was 101 x 10^4 ind. m^{-3}.

Chuchit *et al*., (2005) has investigated seasonal variation of copepods in Si Racha Bay, Chon Buri Province, and found Calanoida being the most abundant order, followed by Cyclopoida and Harpacticoida. Average abundance of calanoids, cyclopoids and harpactiocoids were 10,250, 1,920 and 330 ind. m^{-3}, respectively. The higher abundance of copepod was found in August to September and the lower abundance was found in February and June.

Panchote (2005) has investigated the abundance of zooplankton at Khram Island, Sattahip, Chon Buri Province. The abundance of zooplankton was higher during the Northeast Monsoon season and the lower period was during the Southwest monsoon season. The total average abundance was 14, 447 units l^{-1}; the maximum of 19,876 units l^{-1} in December and the minimum of 17,108 units l^{-1} in September. There was no significant variation in two seasonal abundance periods. The dominant group was copepods.

C. Horizontal and vertical migration

The distribution of copepods has been recognized as two types of the horizontal or spatial distribution and vertical distribution. The horizontal distribution has been used in terms of patch, aggregation, and swarm. The patches vary spatially on a scale of a few meters to hundred of kilometers and also vary in time such as daily, seasonally and annually. Various distributions occur throughout the coastal or brackish water to the oceans. An estuary has a low salinity and it has an endemic species such as *Acartia*, *Eurytemora* and *Gladioferus*. The restricted environments as fiords or coastal basins show the isolated population that live in the small habitats. However, a few species have been recognized as cosmopolitan species that have wide distribution ranges, for example, *Acrocalanus* species (Mauchline, 1998).

The widespread pattern of plankton distribution and abundance may be established broad communities or biota. It makes the plankton composition and their change in time (Figure 8). As a result of the oceanic circulation, the two largest gyres are the central gyre north and south of the equator in both of the Atlantic and Pacific oceans. They are largely warm-water tropical or subtropical systems. Between them, the tropical equatorial zone lays an area of water flowing east to west. A temperate subpolar gyre lays poleward from each central gyre. In addition, these gyre systems have characteristic associations of plankton species to show as biota or communities (Nybakken, 2001).

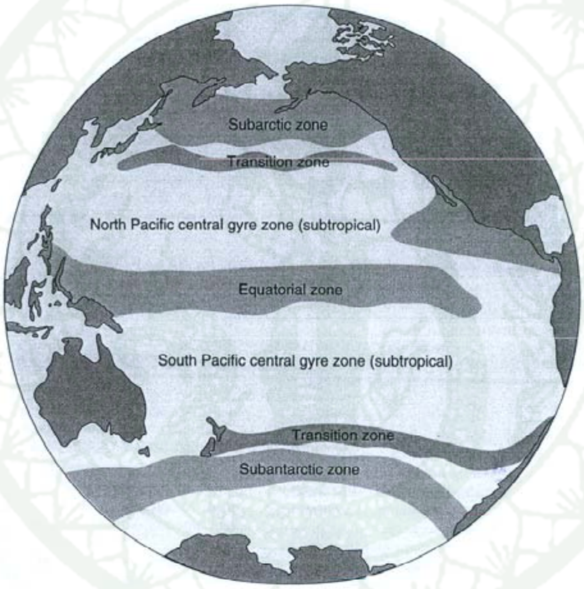


Figure 8 The main plankton biota provinces in the Pacific Oceans.

Source: Nybakken (2001)

The horizontal distribution of calanoid copepod in the coastal area was established by Mauchline (1998). Table 4 shows the species lists of calanoid copepods with their habitat in pelagic ecosystems that modified from Mauchline (1998).

Table 4 The copepod genera with the habitat in the horizontal and vertical distribution in worldwide.

Habitat	**Genera**			
1. Horizontal distribution				
A. Brackish water	*Acartia*	*Centropages*	*Eurytemora*	*Oithona*
	Paracalanus	*Parvocalanus*		
B. River plumes	*Acartia*	*Centropages*	*Eurytemora*	*Pseudocalanus*
	Temora			
C. Estuarine	*Acartia*	*Eurytemora*	*Eucalanus*	*Gladioferens*
D. Fjord	*Heterocalanus*	*Neocalanus*	*Paracalnus*	*Paraeuchaeta*
	Scaphocalanus	*Spinocalanus*	*Clausocalanus*	
E. Coastal and Shelf	*Acartia*	*Calanus*	*Candacia*	*Calocalanus*
	Ctenocalanus	*Calanoides*	*Centropages*	*Euchaeta*
	Eucalanus	*Labidocera*	*Metridia*	*Microcalanus*
	Neocalanus	*Paracalanus*	*Pseudocalanus*	*Temora*
	Tortanus			
F. Across-shelf	*Acartia*	*Calanoides*	*Calanus*	*Centropages*
	Eucalanus	*Neocalanus*	*Rhincalanus*	*Temora*
G. Upwelling	*Paracalanus*	*Pseudocalanus*	*Calanoides*	
2. Vertical distribution				
A. Epipelgic	*Acartia*	*Acrocalanus*	*Bestiolina*	*Calanus*
(0-200 m)	*Calocalanus*	*Candacia*	*Clausocalanus*	*Cosmocalanus*
	Eucalanus	*Eucaheta*	*Halotilus*	*Ischnocalanus*
	Labidocera	*Mecynocera*	*Neocalanus*	*Paracalanus*
	Phenna	*Pontella*	*Pontellopsis*	*Temora*
	Undinula			

Table 4 (Continued)

Habitat	Genera			
B. Mesopelagic	*Arietella*	*Chriridius*	*Chirundina*	*Euaetideus*
(200-275 m)	*Eucalanus*	*Euchaeta*	*Euchirella*	*Gaetanus*
	Heteromamma	*Rhincalanus*	*Scaphocalanus*	*Scottocalanus*
	Undeuchaeta			
C. Bathypelagic	*Amollothrix*	*Batheuchaeta*	*Bathypontia*	*Bradycalanus*
(750 – 3,000 m)	*Cephalophanes*	*Centraugaptilus*	*Chiridiella*	*Cornucalanus*
	Disco	*Disseta*	*Euaugaptilus*	*Euchirella*
	Gaussia	*Hemirhabdus*	*Heterorhabdus*	*Lophothrix*
	Lucicutia	*Megacalanus*	*Mesorhabdus*	*Metridia*
	Onchocalanus	*Pareuchaeta*	*Pseudoeuchaeta*	*Pseudochirella*
	Phyllopus	*Scaphocalanus*	*Scolecithricella*	*Scolecithrix*
	Spinocalanus	*Valdiviella*	*Xanthocalanus*	

Source: Mauchline (1998)

The patchiness may also exhibit in vertically. The vertical distribution composes of two types of diel vertical migration (DVM) and seasonally vertical migration. Among of 3 DVM patterns, the simplest is an ascent in the water column to maximum depth around sunset and descent in maximum depth around sunrise, termed as nocturnal or normal DVM. Another pattern, reverse DVM, shows an ascent to shallow depth at sunrise followed by a descent to deeper layer at sunset. The third pattern, twilight DVM, involves an ascent to the surface at sunset and a descent to deeper water around midnight, termed as midnight sink, and followed by a second ascent to surface and then descent to deeper water at sunrise (Atkinson *et al*., 1992; Cohen and Forward, 2005).

The seasonal vertical migration shows the decreasing of copepod density with depth through the water column. The bathymetric distribution is linked with the habitat of pelagic copepods may be divided into following:

1. Epipelagic copepods	0-200	m
2. Mesopelagic copepods	200-275	m

3. Bathypelagic copepods	750-3,000	m
4. Abyssal copepods	> 3,000	m

However, the vertical distributions of copepods show various differences in depth and time of the day, season, latitude and development stages. Additionally, the vertical distribution of copepods should probably not be restricted to these patterns. The pattern can vary between and within species, and under different environmental conditions (Mauchline, 1998).

The study on vertical migration and diurnal migration of planktonic copepods has been conducted in the western Gulf of Thailand (Suwanrumpha, 1978). Seven species exhibited the diurnal vertical migration by moving in sub seasurface at night time and settle down in day time. They are *Acartia erythraea*, *Temora discaudata*, *Candacia discaudata*, *Tortanus forcipatus*, *Euchaeata concinna*, *Acrocalanus longicornis* and *Centropages furcatus*. Two species, *Eucalanus subcrassus* and *Labidocera acuta*, showed the reversed pattern. They were found near seasurface at day time and in deep water at night time. No significant migration was observed in the most abundant species which is *Calanus pauper*.

The distribution is affected by the physical and chemical properties of the sea and also the physiological and behavioral of the copepods. The physical effects are major important factors that are generated the patchiness of zooplankton. Large – scale patchiness may be due to changes in the water column by resulting in nutrient availability. Another cause of patchiness is the movement of current systems that move the water mass rotating either clockwise and counter –clockwise. Physical processes include ocean eddies or ring, coastal fronts and Langmuir cells. These cells usually set up the plankton floating or sinking along the lines of convergence (Figure 9). Other factors contribute the patchiness including light intensity, nutrients and density gradients in the water column.

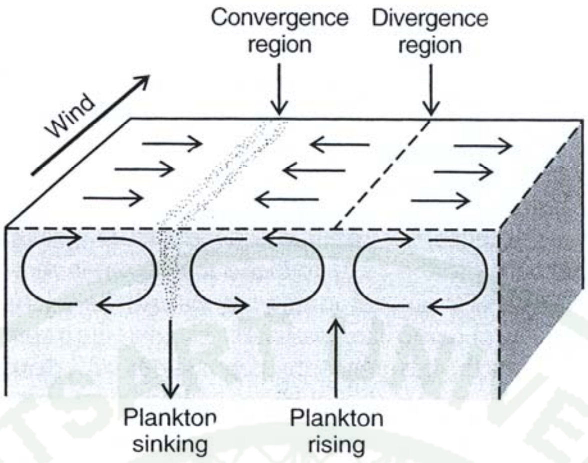


Figure 9 Langmuir convection cells induced by wind.

Source: Nybakken (2001)

Regarding to vertical migration, many hypotheses conclude that the primary stimulus is light and followed by other factors, such as temperature, avoidance of predator, avoidance of damaging ultraviolet light, increasing production or conserving energy. The following are explanations:

1. Light

Some copepods respond negatively to light intensity increase. In a typical pattern, they move to deep water as the light intensity increase and to surface water during the night.

2. Temperature

Temperature may also influence migration that modifies the light-regulated pattern. For example, some copepods are limited by temperature change in the depth such as the maximum depth to which they descend is set by temperature.

3. Predator

Many zooplankton moves to deeper water to avoid predation by visual predators. They may show reverse direction as response to avoid nocturnal surface predators or non-visual predators. Additionally, the explanations have been offered that the daytime depths of residence of many zooplankton still have sufficient light for visual predators to operate so other zooplankton migrate deeper layer than would be required by this hypothesis. Many of zooplankton use bioluminescent organs to counteract the effect of the darkness. Finally, many predators are also migratory.

4. Light – damaging avoidance

This hypothesis suggests that zooplankton organisms migrate to avoid damaging from solar radiation. In addition, the pigment, primarily carotenoids, can protect the zooplankton from light but it also makes the animal more visible to visual predators. It seems to assume that the pigmented zooplankton is response to both vertical migration and the absence of visual predators.

5. Production and energetic

It seems to explain two factors that zooplankton demonstrates that more energy is saved by remaining in deeper, cold water during the day than is expended in making migration. This hypothesis is fit with the overwintering of copepods at depths where phytoplankton is scare and the temperature differential between deeper and surface water such as in polar region.

In summary, it can be stated the vertical migration is a worldwide phenomenon of copepods and zooplankton. The primarily stimulus is light, also can modified by other factors, such as temperature. The other hypotheses deal with avoidance of predator, light-damaging and as a mechanism to increase production and conserve energy. It shows a multiple causes for vertical migration in different patterns.

D. Length –weight relationship

The length – weight regression equations of a simple measurable expression of size against dry weight and carbon- and nitrogen contents are powerful tools for estimation in biomass and production of marine calanoid copepods (Uye, 1982). The seasonal differences in body size among marine copepods express by body length that is inversely correlated with ambient temperature. Body weight is positively related to food availability (Durbin and Durbin, 1978). Weight losses caused by fixation are frequently as 30-40%, while cephalothorax length does not change significantly during preservation (Durbin and Durbin, 1978; Mauchline, 1998).

The isochronal development is found in some member of the *Acartia* species that whole stages are each passed in the same amount of time (Mauchline, 1998). Their duration of the stages must be closed to constant throughout the development after hatching of eggs. This growth pattern may be an alternate strategy for surviving in unfavorable conditions found in species in highly variable neritic and estuarine environments (Miller *et al*., 1977).

Life span of small copepods is generally short in eutrophic inshore waters where phytoplankton density is high throughout the year. The demonstrations of seasonal variation in dry weight and chemical composition may not be great because of changing in those are usually related to changes in food abundance (Uye, 1982).

The carbon contents approximate to a normal distribution with modal values of 40-46% dry weight. Surface – living copepod species in both low and medium latitudes have lower carbon contents while high latitude deep-living species tend to have the most carbon contents (Mauchline, 1998). Uye (1982) showed regression equations in length and weight of *Acartia clausi* and *A. tseunsis* from the Inland Sea of Japan that were highly significant correlation between prosome length and dry, carbon and nitrogen weight. Carbon and nitrogen contents expressed as percent of dry weight that were rather constant throughout the wide size range of copepod analyzed. Heinle (1966) examined a length-weight relationship of *Acartia tonsa* from preserved samples that was found to be linear on a semi-log plot.

There are a few studies on length and weight relationship of planktonic copepods; *Acrocalanus gibber* in the Andaman Sea (Poung-in, 1992), 4 calanoids, 2 poecilostomatoids and 2 harpacticoids (Satapoomin, 1999). Table 4 shows the regression equations of the length and weight of some planktonic copepods in the Andaman sea. Punnarak (2004) pooled the data of four dominant estuary species in Trang Province and presented in one correlation (Table 5).

Table 5 Regression equations of length and weight of planktonic copepods.

Species	**Equations**	**R^2**	**Author (S)**
Acrocalanus gibber	$\ln W = 2.26 \ln CL-13.85$	0.76	Satapoomin, 1999
Acrocalanus gibber	$W_f = 1.188 \times 10^{-9} L^{(3.359)}$	-	Poung-in, 1992
	$W_e = 0.139 (V) - 0.002$	-	Poung-in, 1992
Centropages furcatus	$\ln W = 3.82 \ln CL-24.58$	0.81	Satapoomin, 1999
Temora discaudata	$\ln W = 3.55 \ln CL-22.07$	0.92	Satapoomin, 1999
Euchaeta spp.	$\ln W = 3.82 \ln CL-25.19$	0.60	Satapoomin, 1999
Oncaea spp.	$\ln W = 2.90 \ln CL-17.50$	0.70	Satapoomin, 1999
Corycaeus spp.	$\ln W = 19.9 \ln CL-12.21$	0.64	Satapoomin, 1999
Macrosetella gracilis	$\ln W = 1.59 \ln CL-10.92$	0.51	Satapoomin, 1999
Microsetella spp.	$\ln W = 1.15 \ln CL-7.79$	0.26	Satapoomin, 1999
Acartia amboinensis, *Canthocalanus puaper*, *Centropages orsinii*, *Labidocera pavo*	$\ln C = 2.8304 \ln CL -14.857$	-	Punnarak, 2004

Remarks: CL = Cephalothorax length (μm); L = Total length (μm); C, W = Carbon weight (μg C); W_f = female weight (μg C); W_e = egg weight (μg C); V = egg volume (10^{-6} μ m^{-3}).

F. Egg production rate and weight specific growth rate

Growth is the process for determining the roles of copepods in the trophodynamics of marine ecosystems (Kiørboe and Sabatini, 1994; Uye *et al*., 2000; Hayashi and Uye, 2008). The functional responses of copepods are highly affected by changing in environmental variables, and vary with times as a function of the availability and characteristics of phytoplankton (Poulet *et al*., 1995; Hirst and Lampitt, 1998).

Rate of growth of copepods are strongly influenced by chlorophyll a concentration (Kimmerer and McKinnon, 1987), temperature (Huntley and Lopez, 1992; Sekigushi *et al*., 1980) and the combination of the effect of chlorophyll a, temperature, body size and development stages (Durbin *et al*., 1992; Hirst and Lampitt; 1998; Ara, 2001; Liu and Hopcroft, 2007).

The most expression of growth in calanoid copepods is a weight-specific growth rate (day^{-1}) (Mauchline, 1998). And egg production rate (EPR) is a measurement of population birth or recruitment rate, and also considered as the net production rate of the adult female copepods (Poulet *et al*., 1995). Growth can express as a number of eggs produced per female per day, for broadcast spawners (Runge and Roff, 2000).

G. Biomass and production

Production of copepod population is a major focus in marine ecological studies (Poulet *et al*., 1995; Uye *et al*., 2000; Peterson *et al*., 2002; Satapoomin *et al*., 2004; Miyashita *et al*., 2009). Production is a measurement of energy flow through a population and as an indicator of its physiological or nutritional state, as a rate averaged over a time interval. Production rate is redefined by Kimmerer (1987) as the instantaneous rate of production of biomass by a population. That is an integrated production during an interval is equal to the yield to consumers and decomposers, plus changing in biomass during the interval.

Measurement of the biomass of copepods is expressed in term of wet or dry body weight or body carbon weight per unit area or volume of the water column (Postel *et al*., 2000). Estimation of biomass is frequently made from counts of individuals through regression equations (Mauchline, 1998). Therefore, total biomass is determined as a sum of abundance times mean weight for each stage (Kimmerer and McKinnon, 1987). The error for estimation of biomass is general seasonal patchiness of distribution of individuals in both vertical and horizontal planes in coastal and shelf region (Mauchline, 1998).

The plankton biomass off the east coast of the Gulf of Thailand was generally lower than in the inner Gulf and the upper western coast (Suvapepun, 1977). There were two periods of monsoon affecting zooplankton abundance that the minimum density was occurred during the inter-monsoon months in April to October. In the inner Gulf of Thailand, the major factors influenced the distribution of zooplankton seem to be the nutrients loading (Sudara and Udomkit, 1984), primary productivity (Temiyavanich, 1984), salinity (Sribyatta, 1996) and minor factor was temperature (Suwanrumpha, 1978).

In calanoid copepods, specific production (P:B ratio or turnover rate) of population is a ratio of biomass produced during an interval to mean biomass during that interval. The turnover rate for a species is strongly influenced by environmental factors: temperature, population age, distribution and nutritional state (Kimmerer, 1983). There are many methods of determining turnover rate. The best estimation for calanoid copepods provided by McLaren and Corkett (1981) is based on Bêlehrádek's equations, when food is not limiting and development times are accurately known (Mauchline, 1988). It is assumed that copepods grow exponentially and the rate of production of eggs is the same rate of body growth of earlier copepodid stages (Kimmerer, 1983; Kimmerer and McKinnon, 1987; Kiørboe and Sabatini, 1995).

Poung-in (1992) studied the biomass and secondary production of *Acrocalanus gibber*, the most dominant species of meso-zooplankton in Andaman Sea. Estimated biomass of *Acrocalanus gibber* was 1,532 µg C m^{-2}, specific growth rate was 0.98 day^{-1} and estimated secondary production was 150.15 µg C m^{-2} d^{-1}. The length – weight relationship of *Acrocalanus gibber* is shows in Table 4. Average biomass of planktonic copepod was 381± 28 mg C m^{-2} in the Andaman Sea which calanoid copepods made up for half of the total biomass (Satapoomin *et al*., 2004).

6. Selective species: *Acartia erythraea* Giesbrecht

A. Description of Family Acartiidae Sars, 1900

Body typical small, clearly divided into prosome and slender urosome by gymnoplean articulation. Body gracile, with median eye on the antero-dorsal lateral angles; urosome three-segmented in the female, five- segmented in the male; right antennule of the male modified to form a grasping organ; the fifth leg uniramous, two or three segmented in the female; asymmetrical in the male, left leg three-segmented, right four-segmented. Genital apparatus of female with paired gonopores and copulatory pores situated in pair slits, typically located either adjacent to midline on ventral surface of genital double –somite; paired seminal receptacles usually present. Caudal rami often slightly asymmetrical armed with up to 6 setae; sometimes fused to anal somite. This family includes five genera: *Acartia* Dana, *Acartiella* Sewell, *Paracartia* T. Scott, *Paralabidocera* Wolfenden and *Pteriacartia* Belmonte (Boxshall and Halsey, 2004).

Genus *Acartia* Dana. Typically both sexes have slender bodies. Prosome fusiform, with or without a rostrum, caudal rami rather short. Anal somite without anal operculum, anus opens between the last 2 urosomal somites into dorsal groove on anal somite (Mulyadi, 2004). This genus belongs about 40 species (Mauchline, 1998).

Acartia erythraea female has length 1.15 mm. Posterolateral ends of 5th metasomoite produced into strong spiniform processes, with a pair of small spine a little dorsally and medially. First urosome is long and wide, twice length than the 2nd urosome, posterior margin with a pair of long spines dorsally; 2nd urosome also with sets 2-3 small spines on posterior dorsal margin. Caudal rami short with transverse row of setules on dorsal surface, caudal seta relatively long. Antennule reaches to distal end of caudal rami when fold backward, 1st segment with 2 strong spines produce distally from anterior distal margin, with smaller spine near base of these spines; segments 2,3 and 4 with 1,3 and 2 small spines, respectively. Terminal segment of P5 length twice times width; terminal spine slender and curved, with finely serrated membrane (Mulyadi, 2004).

Male is 1.08 mm in length. Cephalosome as in female, but spine on posterodorsal ends of 5th metasomite slender and inner spines of the same area larger than those of females. Posterolateral ends of 5th metasomite produced into strong spiniform processes, with small spine a little dorsally and medially. Urosome, 1st urosome short, with row of short hairs on lateral and posterior margins; 2nd urosome with tuft of hairs on anterior lateral surface, and a pair of strong spiniform processes. 3rd and 4th urosome each with a pair of very small spinules on posterior dorsal margin; caudal rami with transverse row of setules at base of inner dorsal seta. Fifth right swimming leg, 3rd segment with a long and large spine on its outer distal margin, the spine longer than the distal segment, 2nd segment with a protrusion on inner margin. Left leg, terminal segment slightly curved as long as 2/3 times of seta of 2nd segment, with 2 subequal terminal spines, stout spine present of mid-anterior surface (Mulyadi, 2004).

B. Species diversity in Thai waters

The genus *Acartia* is important consistent of the neritic zooplankton in Thai waters. Eight species were reported in the Gulf of Thailand and the Andaman Sea (Table 3). Among these, *A. erythraea* is a common dominant copepod in near-shore brackish waters that frequently occurring throughout the year.

C. Biology

Acartiids typically live in near-surface waters in estuarine and coastal habitats, especially embayments, and they occur from tropical to polar latitudes. Only two species *A. danae* Giesbrecht and *A. negligens* Dana, primarily inhabit open oceanic waters. Some species may occur in continental waters that are connected at least temporarily to marine waters. Three species of *Paralabidocera* occur in the low salinity waters of lakes in Anatarctica: *P. antarctica*, *P. grandispina* and *P. separabilis*. Several species of *Acartia* and *Acartiella* can be classified as invasive, having been translocated by ballast water in ship (Boxshall and Halsey, 2004).

Acartiids are often the dominant group in the neritic zooplankton, attaining high densities which normally occur in productive environment and high adaptive capacities, and they represent an important food source for larger planktonic animals and small fishes. Raptorial feeding by *A. tonsa* on ciliates was established and *Acartia* species is a primary omnivores feeding on phytoplankton and micro-zooplankton in high nutrient and low salinity water (Mauchline, 1998; Putland and Iverson, 2007).

The development stages of *Acartia* and *Paracartia* have the six nauplii and five copepodid stages. All species of *Acartia* is known produced resting eggs and may be typical for genus (Boxshall and Halsey, 2004). The external morphology of subitaneous eggs in acartiids that are spiny, smooth and bumped surface. Dormant stage of life cycle of some copepod species is most typical of temperate, coastal waters in which environmental fluctuations are greater than in tropical or ocean regions (Grice and Marcus, 1981).

The isochronal development is found in some member of the *Acartia* species that whole stages are each passed in the same amount of time (Mauchline, 1988). Their duration of the stages must be stable to constant time throughout the development after hatching of eggs. This growth pattern may be an alternate strategy for surviving in unfavorable conditions found in species in highly variable neritic and estuarine environments (Miller *et al*., 1977). Life span of small copepods is generally short in eutrophic inshore waters where phytoplankton density is high throughout the year (Uye, 1982).

MATERIALS AND METHODS

Materials

1. Field equipments

1. Plankton net with 20, 60, 200, 330 µm
2. Flow meter, TSK model
3. Plastic bottle sample
4. Buffered formaldehyde solution 4 %
5. pH meter, YSI 60
6. DO meter, YSI 550 A
7. Refractometer, Asahi
8. Depth sounder

2. Water analyses

1. Water bottle sample
2. GF/C filter
3. Spectrophotometer
4. Chemicals for nitrite – nitrogen analysis follow by Cadmium reduction method
5. Chemicals for ammonia – nitrogen analysis followed by Phenate method
6. Chemicals for orthophosphate – phosphorus followed by Ascorbic acid method
7. Chemicals for silicon – silicate followed by Molybdosilicate method
8. Chemicals for chlorophyll a analysis followed by Spectophotometric method

3. Identified species in laboratory

1. Sedgwick-Rafter counting slide
2. Inverted compound microscope with micrometer and camera lucida
3. Water - glyceraldehyde solution
4. Dissect needles

4. Production experiment

1. Incubation chambers
2. CHNS Element Analyzer, LECO CHN-932
3. Hot air oven, Binder
4. Electric microbalance
5. Desiccator

Methods

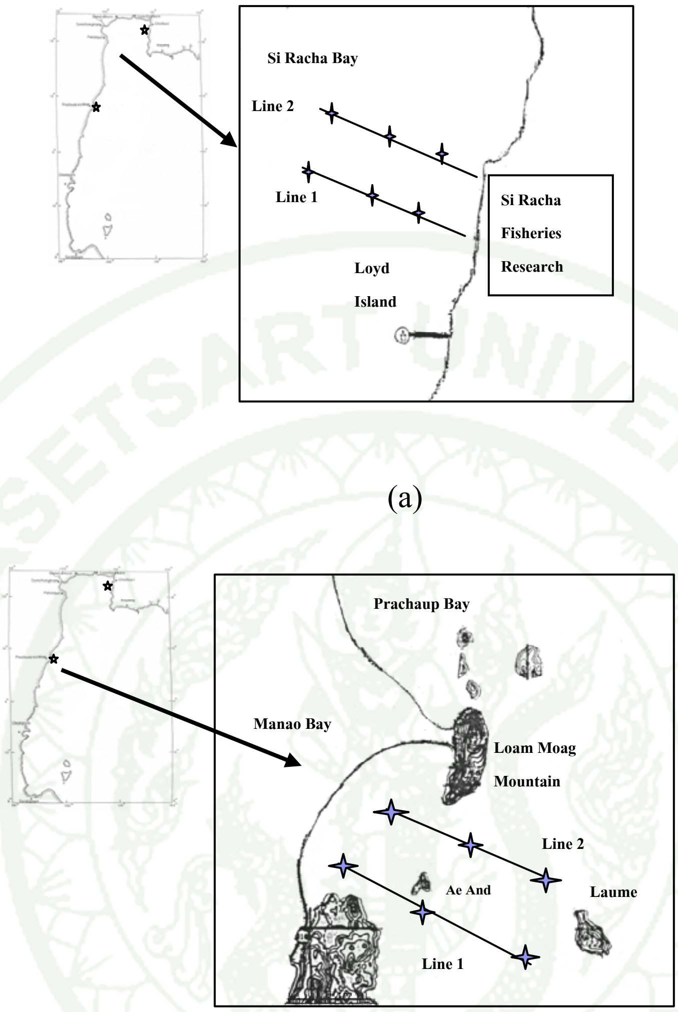
1. Hypothesis

The hypothesis is the community structure of planktonic copepods and production of *A. erythraea* in the Si Racha Bay is not equal to the production of *A. erythraea* in Manao Bay.

The hypothesis is based on the concept that the variation of quantity and quality of food available is the major factor affecting to growth rate and production of planktonic copepods in both adult and juvenile stages, associated with hydrographic parameters at two sampling sites.

2. Study area

The study areas in the upper Gulf of Thailand are characterized by a shallow basin with depths averaging 5-10 m along the shore and in averaging to approximately 40 m - 50 m in the middle of the upper Gulf of Thailand. Two sampling sites were selected representing two different exploited degree on natural resources: (i) the Si Racha Bay, Chon Buri Province (13°11′ N, 100°55′ E), a large shallow raft-cultured green mussel (with an area of 12 km^2) in the eastern coasts of the Gulf representing high nutrients load or polluted area and (ii) the Manao Bay, Prachuap Khiri Khan Province (11º 49′N, 99º 50′E) is a shallow protected bay (with an area of 15 km^2), located in the western upper Gulf of Thailand, representing an un-exploited natural coastal ecosystem (Figure 10).



(a)

(b)

Figure 10 Study areas in the upper Gulf of Thailand; A: Si Racha Bay, Chon Buri Province (the eastern coast); B: Manao Bay, Prachuap Khiri Khan Province (the western coast).

Circulation of coastal water is affected by tidal current, wind direction and river discharge. The upper gulf of Thailand, the tide is mixed type. Surface current (0-10m) is strongly influenced by prevailing monsoons and always moved downwind (Buranapratheprat *et al*., 2009). These areas are affected by two heavy monsoons; the Southwest monsoon from May to October and the Northeast monsoon from October to February. The surface vector field is northeastward in the Gulf of Thailand from the South China Sea during the Northeast monsoon and in the opposite direction in the Southwest monsoon (Robinson, 1963; Anongponyoskun and Bundismith, 1998; Snidvongs and Sojisuporn, 1999; Anongponyoskun, 2006; Buranapratheprat *et al*., 2009). The flow direction of circulation in the upper Gulf of Thailand at sea surface and 10 m depth were presented by Buranapratheprat *et al*. (2009) (Appendix Figures 1 and 2) and the circulation in the Si Racha coastal area was established by Buranapratheprat (2009) (Appendix Figures 3, 4 and 5). In May and July, the circulation of surface water was weak that were affected by the combinations of year-to-year variations of wind fields, the interaction of discharge and bottom topography (Buranapratheprat *et al*. 2009).

The sediment is silt-sand and slope of the coastal line is very low in Manao Bay. In Si Racha Bay, sediment is silt or sand and also mussel beds and macroalgae were on the bottom surface (Jansang *et al*., 1999).

3. Sampling designs

A total of 12 stations were set in the two study areas, with 6 stations each (Figure 10). In each site, two transect lines were set with 3 sampling stations on each line, representing inner station (average depth of 3 m), middle station (average depth of 7 m) and outer station (average depth of 10 m) from landward to seaward. Figure 10 presents the sampling stations in the two study areas. All samplings were done during daytime at high tide. Table 6 shows details of all sampling stations in UTM systems.

4. Sampling periods

Samplings were done from September 2006 to August 2008. In order to cover the temporal variation of copepod communities, samplings were scheduled twice a month for a period of 1 year, from September 2006 to August 2007. The sampling was alternated between two transect lines within a month. Sampling for length-weight analysis of *A. erythraea* was also done during September 2006 to August 2007 at Manao Bay only.

For egg production experiment and biomass determination, samples were taken from January to August 2008, twice a month. Abundance of development stages was studied from samples taken in January, March, May and August 2008.

Table 6 Sampling stations, depths and points in UTM system.

Station	Depth (m)	(X) N	(Y) E
Si Racha Bay			
SRL1-1	4	0708603	1458083
SRL1-2	7	0706964	1457799
SRL1-3	9	0706174	1457704
SRL2-1	4	0709183	1458911
SRL2-2	7	0707863	1458949
SRL2-3	9	0706534	1458843
Manao Bay			
AML1-1	4	0588031	1300916
AML1-2	7	0588942	1300743
AML1-3	9	0589625	1300197
AML2-1	4	0588366	1301328
AML2-2	7	0588508	1301145
AML2-3	9	0588887	1300171

5. Sampling techniques

A. Hydrographic parameters

Hydrographic parameters at each station were: water temperature and dissolved oxygen (using DO meter, YSI 550), salinity (refractometer, Asahi) and pH (pH meter, YSI 60). Data on monthly mean precipitations were obtained from the database of Thai Meteorological Department (http://www.tmd.go.th). For nutrient concentrations, water samples were collected from 30 centimeters depth from surface and analysed in the laboratory for nitrite, nitrate, ammonia, orthophosphate and silicate (APHA, AWWA and WEF, 1998).

B. Phytoplankton

Phytoplankton biomass was analysed in term of chlorophyll a concentration, which was classified into 3 size fractions: <10μm, 10-50 μm, and total). The analyses were done during the same period of egg production experiments, using spectrophotometric method (Parsons *et al*., 1984).

Phytoplankton community was studied using filtering technique. Twenty liters of sub-surface seawater from each station was filtered through of 20 μm mesh size nylon net. Filters were immediately fixed in 2.5% buffered formaldehyde solution, final concentration. Phytoplankton samples were later indentified to genera level and enumerated on a 1 ml Sedgewick-Rafter counting slide averaged from 3 replicated. Major reference for the identification is Wongrat (2001). Abundance of phytoplankton was expressed as number of cells per liter (Wongrat and Boonyapiwat, 2003).

C. Zooplankton

Zooplankton were collected using three types of plankton nets: 1) 0.3 m opening diameter with 60 μm mesh size for copepodid larval stage, 2) 0.6 m opening diameter with 200 μm mesh size for meso-zooplankton and 3) 0.6 m opening diameter with 330 μm mesh size for copepod adults and net zooplankton community. Duplicates of zooplankton samples were taken vertically at each station using all nets. Samples were immediately preserved in 5 % borax-buffered formaldehyde-seawater solution, final concentration. All nets were equipped with a flow meter (TSK) to calculate the filtered volume from each tow.

Zooplankton was identified to higher taxa and abundance was expressed as number of indviduls in one cubic meter (ind. m^{-3}). Major reference for identification is Wongrat (2000). Preserved copepod specimens were sorted out and identified to species level under a microscope in the laboratory. Abundance, frequency of occurrence and species composition were calculated following the methods of Postel *et al*. (2000). Adult copepods were separated into three pelagic orders: Calanoida, Cyclopoida, and Harpacticoida, following the works of Boxshall and Halsey (2004). Nauplii and copepodid stages were counted separately to determine the stage composition. The major identification keys are Kasturirangan (1963); Suwanrumpha (1987); Mulyadi (2002); Conway *et al*. (2003); Pinkaew (2003); Mulyadi (2004); Phukham (2008) and Salakij (2009).

In order to determine their trophic position that was studied from the secondary data, all observed copepod species were classified into 3 groups: carnivores, omnivores and herbivores, followed by the family lists that based on the methodology of their feeding apparatuses (Table 2). More information on their feeding behaviors was also obtained from Anraku & Omori (1963); Ohtsuka *et al*., (1996), Turner (2004) & Suwanrumpha (1980b).

6. Analysis of copepod community structure

A. Diversity index

Diversity index describes quality of a community, as either complex or simple. It depends on numbers of species and abundance of each species. The common indices based on proportional abundances (Postel *et al*., 2000). Shannon's diversity index (1949) can be calculated as followed:

$$H' = -\sum_{i=1}^{S} (P_i)(\ln P_i)$$

Where, H′ is Shannon's diversity index
S is observed number of species
P_i is proportional abundance of species i

B. Pielou's index of evenness

Calculation of diversity depends on sample size and number of species involved while relationship between diversity and number of species in two different samples is called evenness or equitability (Omari and Ikeda, 1984). Samples of different sizes with different diversity might have same evenness. Pielou's index of evenness can be calculated as followed:

$$J' = \frac{H'}{\ln(S)}$$

Where, J′ = Pielou’s index of evenness
H′ is Shannon’s diversity index
S is observed number of species

7. Length-weight measuring techniques

The length and weight relationship of *A. erythraea* was determined from the preserved specimens. *A. erythraea* were sorted out from the samples that were collected from September 2006 to August 2007. The prosome length of 60 preserved copepodid stages IV – V, males and females were measured using an ocular micrometer and classed to the same length group under a stereoscopic binocular microscope in each month. The prosome, total and width length of 180 copepods were measured in each developmental stage. And also, the live samples were determined the carbon weight of adult female and male in October 2008.

The average prosome length, width, dry weight and carbon weight were determined in adult male, female and copepodid stages IV and V. The specimens were randomly selected from the 200- and 330- µm net samples collected from September 2006 to August 2007 in Manao Bay.

The samples were quickly rinsed with distilled water to remove seawater and formaldehyde. A number of 150 –200 specimens of the same length group were dried on aluminum pans in an hot air oven at 60°C for 24 hours or until the weight was constant. After cooling down in a desiccator for 24 hours at room temperature, the specimens were weighed on an electric microbalance. Carbon weights of each length group were analysed with the Elemental analyzer (Leco CHNS-932). Weight losses during preservation are in a range of 30-40% (Mauchline, 1998; Postel *et al*. 2000) is also considered. This technique was modified from Durbin and Durbin (1978); Uye (1982).

8. Egg production experiment

Copepods were collected in the morning using a 0.6 diameter plankton net with 330 µm mesh size. Cod end samples were carefully diluted with surface seawater and transported to the laboratory within 15 minutes. Only healthy adult females of *A. erythraea* were sorted out and individually transferred into an incubation chamber filled with pre-filtered (on 50 µm screen) ambient seawater, with 30 replicates per station.

The polyethylene chambers composed of two parts: an upper female spawning part (55ml) with a 180 µm screen was fitted at the bottom that allowed food particles and eggs to pass into a lower chamber (15 ml). In this regards, egg cannibalism was minimized. The incubations were maintained in the laboratory at the same temperature as in the field under natural light conditions for 24 hours.

After the incubations, number of eggs and nauplii were counted and egg production rate is expressed as the number of egg produced per female per day. The incubation techniques are modified from Postel *et al*. (2000); Ara (2001); Jung *et al*. 2004); Pagano *et al*. (2004) and Putland and Iverson (2007) and the incubation chambers are modified from Hopcroft (pers.comm.).

9. Weight specific growth rate

Weight - specific growth rate (G_f) of copepod was calculated on a carbon basis and data on egg production rate as in the following equation:

$$G_f = (W_e / W_f)\,(24 / T)$$

Where, G_f is the weight - specific growth rate
W_e is the weight of eggs produced (µg C)
W_f is the weight of female (µg C)
T is the incubation time (h)

The carbon weight of egg was calculated from equation 0.14 x 10^{-6} µg C.µm^{-3} based on the egg diameter (Kiørboe *et al*., 1985; Huntley and Lopez, 1992). Weight of female copepod obtained from converting the prosome length of incubated female to weight in microgram carbon using the length-weight equation derived from this study.

10. Biomass

Measurement of the biomass of copepod was expressed in term of body carbon weight per unit area or volume of the water column (Postel *et al*., 2000). Therefore, biomass was determined as a sum of abundance times mean weight for each stage (Kimmerer and McKinnon, 1987). *A. erythraea* was sorted out and counted from the whole samples that collected from January to August 2008. Adult male, female and copepodid stages were counted by monthly and separately to determine the stage composition. The carbon weight was obtained from the Elemental analyzer (Leco CHNS-932). The *Acartia* biomass was expressed in terms of weight per unit volume (µg C m^{-3}) as followed:

$$B_i = N_i W_i$$

Where, B_i is biomass (µg C m^{-3})
N_i is number of individuals of stage i (individual.)
W_i is weight of individuals of stage i (µg C)

To determine the biomass of the total zooplankton per volume of the water (mg C m^{-3}), the 200-µm and 330-µm zooplankton samples were examined. The samples were filtered onto a 50 -µm in mesh sized net and then weighed in term of wet weight. The zooplankton sample was spitted ¼ of the total abundance and then were placed on aluminum pans in an oven at 60°C and dried for 24 hours until a constant weight was obtained. After desiccation at room temperature for 24 hours, weight measurements were done on an electric microbalance. Finally, carbon weights were determined with Elemental analyzer (Leco CHNS-932) about 2 mg per sample.

11. Secondary production

Secondary production rate was calculated simply as biomass of all *A. erythraea* (except adult males) times growth rate, assuming all stages grow at the same rate. For *Acartia* species development rate is nearly constant throughout their life time (Kimmerer and McKinnon, 1987). The growth rate does not vary much with stage, through assumed that adult females grow at the same rate as juveniles but generally expressed their growth as egg production (Miller *et al*., 1977; Sekigushi *et al*., 1980; Kimmerer and McKinnon, 1987). Secondary production was calculated according to Kimmerer (Kimmerer, 1987) as followed:

$$PR = \sum \{G_iB_i\} \text{ x } G_fB_f$$

Where, PR is secondary production rate (μg C m^{-3} d^{-1})
B is biomass (μg C m^{-3})
G_i is weight specific growth rate (d^{-1}) of stage i
G_f is egg production rate of females

To estimate P:B ratio or turnover rate of *A. erythraea*, P:B ratio is defined as the ratio of biomass increment produced during a time interval to mean biomass during that period of time (Kimmerer, 1983). There is simple correlation between P:B ratio and life span of marine organism that the long – life span is expressed as low P:B ratio for temperate region (Longhurst and Pauly, 1987). P:B ratio was calculated by least squares to log transformed biomass values over time and will be expressed as the slope of a line (Kimmerer, 1983).

12. Numerical analysis

Pearson correlation coefficient and regression analyses were used to correlate the effects of environmental parameters (temperature, salinity, chlorophyll a concentration) to egg production rate of *A. erythraea* (Legendre and Legendre, 1983). Two – way analysis of variance was performed to test the effects of time and sampling sites on the egg production rate of *A. erythraea*. All calculations were based on log – transformed data in order for the data to tend towards normal distributions (Pagano *et al*., 2004). One way ANOVA was calculated to test the differences between the 2 sampling sites and among months for all variables encountered in this study (Zar, 1974).

RESULTS AND DISCUSSION

In this study, the samples were collected in the filed and the experiments were set in laboratory and were divided into 9 parts which consisted of the planktonic copepods community structure, length-weight relationship, egg production rate, weight-specific growth rate, biomass and secondary production rate of *A. erythraea*, application, plankton community and hydrographic parameters and nutrients.

1. Planktonic copepods community structure

A. Species diversity

Overall, 46 copepod species in 27 genera were recorded in both sampling areas from September 2006 to August 2007 in the upper Gulf of Thailand. The combined data were pooled from 2 types of plankton nets: 200 and 330 µm in mesh sizes. The most diverse group was Order Calanoida comprising 27 species, followed by Order Cyclopoida (13 species) and Order Harpacticoida (6 species). Classification is referred to Boxshall and Halsey (2004) that poecilostomatioid copepods belong to Order Cyclopoida. The taxa are as followed:

Phylum Arthropoda
Subphylum Crustacea
Class Maxillopoda
Subclass Copepoda
Order Calanoida Milne-Edwards, 1840
Superfamily Calanoidea Dana, 1846
Family Calanidae Dana, 1846
Canthocalanus A.Scott, 1909
1 *Canthocalanus pauper* (Giesbrecht, 1888)
Family Paracalanidae Giesbrecht, 1893
Acrocalanus Giesbrecht, 1888
2 *Acrocalanus gibber* Giesbrecht, 1888
Paracalanus Boeck, 1865

- 3 *Paracalanus aculeatus* Giesbrecht, 1888

- Superfamily Clausocalanoidea Giesbrecht, 1893
  - Family Clausocalanidae Giesbrecht, 1893
    - *Clausocalanus* Giesbrecht, 1888
      - 4 *Clausocalanus furcatus* (Brady, 1883)

- Superfamily Diaptomidae Baird, 1850
  - Family Acartiidae Sars, 1900
    - *Acartia* Dana, 1846
      - 5 *Acartia erythraea* Giesbrecht, 1889
      - 6 *A. pacifica* Steuer, 1915
      - 7 *A. spinicauda* Giesbrecht, 1889
  - Family Candaciidae Giesbrecht, 1893
    - *Candacia* Dana, 1846
      - 8 *Candacia bradyi* A. Scott, 1902
      - 9 *C. catula* (Giesbrecht, 1889)
  - Family Centropagidae Giesbrecht, 1893
    - *Centropages* Krøyer, 1849
      - 10 *Centropages furcatus* (Dana, 1849)
      - 11 *C. orsinii* Giesbrecht, 1889
      - 12 *C. tenuiremis* Thompson &Scott, 1903
  - Family Pontellidae Dana, 1853
    - *Calanopia* Dana, 1853
      - 13 *Calanopia thompsoni* A. Scott, 1909
    - *Labidocera* Lubbock, 1853
      - 14 *Labidocera bataviae* A. Scott, 1909
      - 15 *L. bengalensis* Krishnaswamy, 1952
      - 16 *L. bipinnata* Tanaka, 1936
      - 17 *L. kroyeri* (Brady, 1883)
      - 18 *L. minuta* Giesbrecht, 1889
      - 19 *L. pectinata* Thompson &Scott, 1903

20 *Labidocera rotunda* Mori, 1929

Family Pseudodiaptomidae Sars, 1902

Pseudodiaptomus Herrick, 1884

21 *Pseudodiaptomus aurivilli* Cleve, 1901

22 *P. clevei* A. Scott, 1909

Family Temoridae Giesbrecht, 1893

Temora Baird, 1850

23 *Temora discaudata* Giesbrecht, 1889

Family Tortanidae Sars, 1902

Tortanus Giesbrecht&Schmeil, 1898

24 *Tortanus forcipatus* (Giesbrecht, 1889)

25 *T. gracilis* (Brady, 1883)

Superfamily Eucalanoidea Giesbrecht, 1893

Family Eucalanidae Giesbrecht, 1893

Subeucalanus Geletin, 1976

26 *S. subcrassus* (Dana, 1849)

Order Harpacticoida Sars, 1903

Family Clytemnestridae A. Scott, 1909

Clytemnestra Dana, 1848

27 *Clytemnestra scutellata* Dana, 1849

Family Ectinosomatidae Sars, 1903

Microsetella Brady&Robertson, 1873

28 *Microsetella norvegica* (Boeck, 1865)

29 *M. rosea* (Dana, 1848)

Family Euterpinidae Brian, 1921

Euterpina Norman, 1903

30 *Euterpina acutifrons* (Dana, 1849)

Family Longipediidae Sars, 1903

Longipedia Claus, 1862

31 *Longipedia* sp.

Family Miraciidae Dana, 1846

Macrosetella A. Scott, 1909

32 *Macrosetella gracilis* (Dana, 1847)

Order Cyclopoida Burmeister, 1834

Family Bomolochidae Sumpf, 1871*

Acantholocus Cressey, 1984

33 *Acantholocus* sp.

Family Caligidae Burmeister, 1935*

Caligus Müller, 1785

34 *Caligus* sp.

Family Corycaeidae Dana, 1852

Corycaeus Dana, 1846

35 *Corycaeus agilis* Dana, 1849

36 *C. asiaticus* Dahl, 1894

37 *C. catus* Dahl, 1894

38 *C. longistylis* Dana, 1894

39 *C. speciosus* Dana, 1849

40 *Corycaeus* sp.

Family Kelleriidae Humes&Boxshall, 1996

Kelleria Gurney, 1927

41 *Kelleria australica* Bayly, 1971

Family Oithonidae Dana, 1853

Oithona Baird, 1843

42 *Oithona plumnifera* Baird, 1843

43 *Oithona* sp 1.

44 *Oithona* sp 2.

Family Oncaeidae Giesbrecht, 1893

Oncaea Philippi, 1843

45 *Oncaea conifera* Giesbrecht, 1891

Family Sapphirinidae Thorell, 1860

Sapphirina J.V. Thompson, 1829

46 *Sapphirina stellata* Giesbrecht, 1891

The majority of total planktonic copepods are free-living forms. Two species of cyclopoid copepods are recognized to be ecto-parasitic copepod on pelagic fish (Boxshall and Halsey, 2004). They were *Acantholocus* sp. and *Caligus* sp. that were collected from plankton net. Also, they showed low frequency of occurrence during the sampling period.

B. Species richness

1. Manao Bay

The species richness values observed for 200-μm net were mostly higher than those values of 330-μm net throughout the period of study. The species richness of 200 μm-sample ranged from 12 species in September 2006 to 21 species in October 2006. The 330 μm- sample showed the minimum of 9 species in September 2006 to a maximum of 19 species in August 2007 (Figure 11).

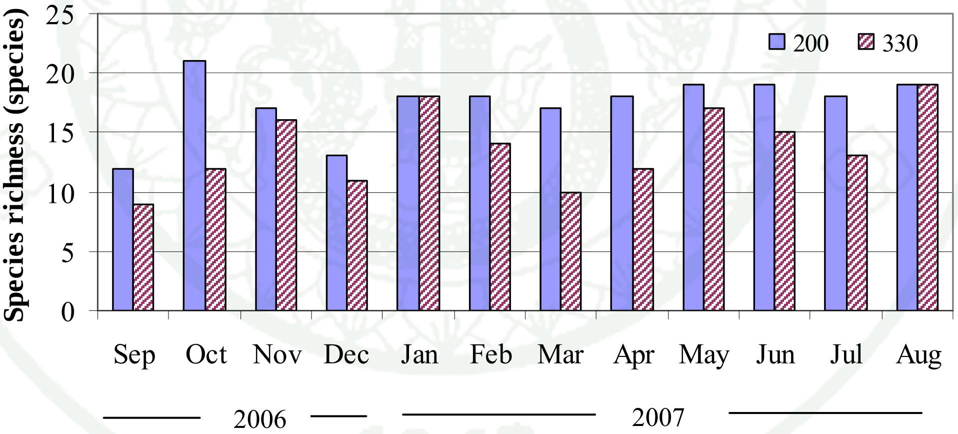


Figure 11 Species richness of planktonic copepods in Manao Bay, September 2006 to August 2007.

Overall, 35 species belonging to 21 genera were recorded in Manao Bay consisting of three orders: Order Calanoida, Order Harpactioida and Order Cyclopoida. Calanoids was the most diverse group, comprising 22 species, followed by cyclopoids (9 species) and harpacticoids (4 species). Among 28 species belonging to 19 genera were observed in total of 114 samples, collected by 200-μm of mesh size net. The 330 μm net captured 33 planktonic copepod species in 20 genera.

Table 7 shows the taxonomic lists with the abundance of planktonic copepod samples in 200 and 330 µm of mesh size nets. The raw data in term of temporal variation, including species lists, are available in Appendix (Tables 1 and 2).

Table 7 Planktonic copepods diversity with mean, maximum and minimum values of abundance (ind.m^{-3}), mean value for contribution (%) to total abundance of each taxon from September 2006 to August 2007 in Manao Bay, Prachaup Khiri Khan Province.

Taxa	**200 µm samples**				**330 µm samples**			
	Abundance (ind.m^{-3})			**Mean %**	**Abundance (ind.m^{-3})**			**Mean %**
	Mean	**Max**	**Min**		**Mean**	**Max**	**Min**	
ORDER CALANOIDA								
Acartia erythraea	291	559	52	7	318	422	92	32
Candacia catula	0	2	0	0	0	1	0	0
Centropages furcatus	38	103	8	1	31	87	1	3
C. orsinii	10	37	0	0	15	53	0	1
C. tenuiremis	4	24	0	0	5	42	0	1
Calanopia aurivilli	-	-	-	-	2	13	0	0
C. thompsoni	0	5	0	0	1	6	0	0
Labidocera bataviae	-	-	-	-	0	2	0	0
L. bipinnata	0	2	0	0	0	3	0	0
L. minuta	2	5	0	0	4	14	0	0
L. pectinata	1	9	0	0	1	10	0	0
L. rotunda	-	-	-	-	0	1	0	0
Pseudodiaptomus aurivilli	155	351	0	4	147	224	18	15
P. clevei	8	44	0	0	5	25	0	0
Temora discaudata	-	-	-	-	1	6	0	0
Tortanus forcipatus	5	29	0	0	5	13	0	0
T. gracilis	2	15	0	0	3	33	0	0
Canthocalanus puaper	2	11	0	0	4	31	0	0
Clausocalaus furcatus	-	-	-	-	7	43	0	1
Acrocalanus gibber	107	233	38	3	43	107	4	4

Table 7 (Continued)

Taxa	200 μm samples				330 μm samples			
	Abundance (ind.m^{-3})			Mean %	Abundance (ind.m^{-3})			Mean %
	Mean	Max	Min		Mean	Max	Min	
Paracalanus aculeatus	17	183	0	0	2	13	0	0
Subeucalanus subcrassus	10	48	0	0	24	93	2	2
ORDER HARPACTICOIDA								
Clytemnestra scutellata	19	75	0	0	0	4	0	0
Euterpina acutifrons	157	552	32	4	1	4	0	0
Macrosetella gracilis	9	75	0	0	-	-	-	-
Microsetella norvegica	1	5	0	0	1	7	0	0
ORDER CYCLOPOIDA								
Corycaeus agilis	-	-	-	-	10	23	1	1
C. asiaticus	190	557	48	5	14	27	2	1
C. catus	95	387	13	2	1	18	0	0
C. speciosus	37	67	9	1	1	10	0	0
Oithona plumnifera	25	70	3	1	4	28	0	0
Oithona sp.	126	303	19	3	3	9	0	0
Oncaea conifera	67	192	4	2	0	1	0	0
Sapphirina stellata	0	2	0	0	0	3	0	0
Nauplii	78	281	0	2	3	16	0	0
Copepodid larvae	2611	4333	1212	64	347	684	161	35

Remark: - not found

2. Si Racha Bay

Similar result was obtained for Si Racha Bay, the species richness values of 200 -μm net were higher than those of 330-μm except in May 2007. The species richness of 200-μm net sample varied from 5 species in July to 21 species in February 2007, whereas, the species richness of 330-μm net samples was determined from 3 species in July to 16 species in February 2007 (Figure 12).

Total of 34 species in 22 genera of planktonic copepods were recorded in Si Racha Bay from September 2006 to August 2007. The taxonomic data were pooled from 2 types of nets. The samples, collecting from 200 µm of mesh size, was identified to 33 species belonging 21 genera: 19 species were calanoid copepods, 6 harpactiocoid copepods and 8 cyclopoid copepods. Another 330 µm samples, were observed in a total of 114 samples. Among 24 species in 15 genera were recorded during the sampling period.

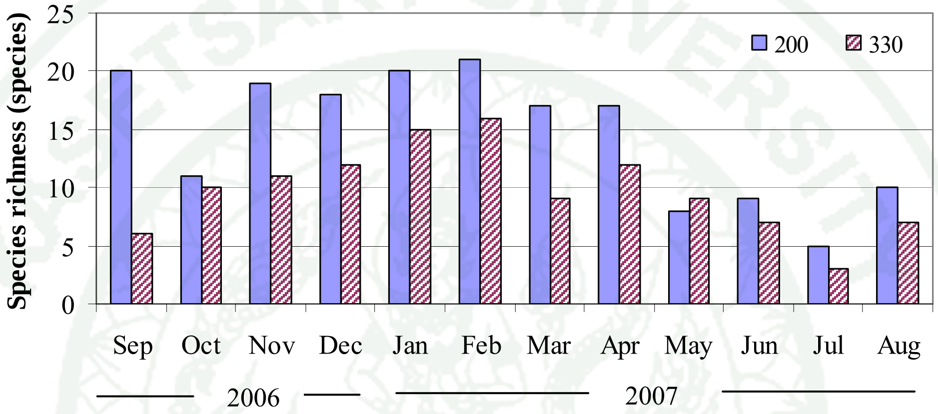


Figure 12 Species richness of planktonic copepods in Si Racha Bay, September 2006 to August 2007.

Table 8 shows abundance of the taxonomic lists with, collecting with 2 types of nets. In addition, the temporal variation in abundance is presented in Appendix (Tables 3 and 4).

Table 8 Planktonic copepods diversity with mean, maximum and minimum values of abundance (ind.m^{-3}), mean value for contribution (%) to total abundance of each taxon from September 2006 to August 2007 in Si Racha Bay, Chon Buri Province.

Taxa	**200 µm samples**				**330 µm samples**			
	Abundance (ind.m^{-3})			**Mean %**	**Abundance (ind.m^{-3})**			**Mean %**
	Mean	**Max**	**Min**		**Mean**	**Max**	**Min**	
ORDER CALANOIDA								
Acartia erythraea	278	1498	46	6	313	1158	23	38
A. pacifica	3	24	0	0	4	45	0	0

Table 8 (Continued)

Taxa	200 μm samples				330 μm samples			
	Abundance (ind.m^{-3})			Mean %	Abundance (ind.m^{-3})			Mean %
	Mean	Max	Min		Mean	Max	Min	
Acartia spinicuada	3	35	0	0	1	8	0	0
Candacia bradyi	0	2	0	0	-	-	-	-
Centropages furcatus	24	53	0	1	27	81	3	3
C. orsinii	5	16	0	0	7	29	0	1
C. tenuiremis	6	24	0	0	6	20	0	1
Labidocera bengalensis	0	3	0	0	1	4	0	0
L. kroyeri	1	7	0	0	0	2	0	0
L. minuta	0	3	0	0	-	-	-	-
L. pectinata	4	18	0	0	3	15	0	0
Pseudodiaptomus aurivilli	47	188	0	1	62	214	0	8
P. clevei	2	8	0	0	1	10	0	0
Temora discaudata	0	2	0	0	-	-	-	-
Tortanus forcipatus	11	31	0	0	8	27	0	1
Canthocalanus puaper	4	33	0	0	3	11	0	0
Clausocalanus furcatus	-	-	-	-	1	14	0	0
Acrocalanus gibber	21	161	0	0	11	48	0	1
Paracalanus aculeatus	30	165	0	1	5	29	0	1
Subeucalanus subcrassus	17	67	0	0	16	81	0	2
ORDER HARPACTICOIDA								
Clytemnestra scutellata	7	25	0	0	0	2	0	0
Euterpina acutifrons	84	328	19	2	1	13	0	0
Longipedia sp.	4	23	0	0	-	-	-	-
Macrosetella gracilis	3	16	0	0	-	-	-	-
Microsetella norvegica	0	2	0	0	-	-	-	-
M. rosea	0	10	0	0	-	-	-	-
ORDER CYCLOPOIDA								
Acantholocus sp.	0	5	0	0	-	-	-	-
Corycaeus asiaticus	56	143	0	1	9	41	0	1

Table 8 (Continued)

Taxa	**200 μm samples**				**330 μm samples**			
	Abundance (ind.m^{-3})			**Mean %**	**Abundance (ind.m^{-3})**			**Mean %**
	Mean	**Max**	**Min**		**Mean**	**Max**	**Min**	
Corycaeus longistylis	0	3	0	0	-	-	-	-
C. speciosus	16	77	0	0	0	3	0	0
Corycaeus sp.	2	17	0	0	1	4	0	0
Kelleria australica	1	13	0	0	0	0	0	0
Oithona spp.	96	269	11	2	6	19	0	1
Oncaea conifera	15	52	0	0	0	2	0	0
Nauplii	47	100	15	1	34	364	0	4
Copepodid larvae	3842	9631	916	83	299	453	34	36

Remark: - not found

The species diversity of planktonic copepods obtained for Manao Bay and Si Racha Bay during this study (46 species) was lower than those reported in the Gulf of Thailand (119 species) by Suwanrumpha (1987). The lower values recorded for this study area are probably due to the small collecting area restricted in a shallow bay (<10 m in depth) that did not include offshore areas. However, compared to the previous record of Pinkaew (2003) reported 35 species of planktonic copepods in Bangpakong Estuary and Sri racha coast, inner Gulf of Thailand. Salakij (2009) established 42 species of calanoid copepods based on 200- and 330 μm mesh size nets in the area of the inner Gulf of Thailand. Species lists were provided in Table 3.

At present, the proximate species diversity of epipelagic copepod is 176 species in the upper Gulf of Thailand. With the new record in Thai water is *Kelleria australica* Bayly, 1971 that belong to Order Cyclopoida and the two new records in the upper Gulf of Thailand were *Labidocera bataviae* A. Scott and *Labidocera pectinata* Thompson and Scott.

However, the new additional species were based on only a sample collected by 200- μm and 330- μm in mesh size. Different mesh sizes of sampling equipment undoubtedly influence the diversity, species composition and abundance of copepods (Hopcroft *et al*., 1998; Hopcroft and Roff, 1998; Miyashita *et al*., 2009). In this regards, the small copepods most commonly underestimated with refer to cyclopoid copepods (Böttger-Schnack *et al*., 2008).

The dominant species were almost the estuarine and neritic species that were *Acartia erythraea*, *Acrocalanus gibber*, *Centropages furcatus*, *C. orsinii*, *Euterpina acutifrons* and *Pseudodiaptomus aurivilli*. Moreover, five oceanic species were high in frequency of occurrences that were *Clytemnestra scutellata, Corycaeus asiaticus*, *Oithona* spp., *Oncaea conifera* and *Subeucalanus subcrassus*. These species are considered to be eurythermal and euryhaline species that are widely distributed in the Gulf of Thailand (Suwanrumpha, 1980b; 1984; 1987; Boxshall and Halsey, 2004).

The majority of planktonic copepods were sporadic presented during the sampling period. The taxonomic lists of planktonic copepods and their frequency of occurrences and habitats are presented in Appendix (Table 5). Their habitats were identified using the records by Suwanrumpha (1980b); Mulyadi (2002); Boxshall and Halsey (2004).

Boxshall and Halsey (2004) established the 9 families of planktonic copepods in terms of neritic and coastal water, 7 families for moderately abundance in frequency of occurrence and 10 groups in low probability in occurrences (Table 9). Our finding was similar with Boxshall and Halsey (2004). Eighteen families were recorded in the upper Gulf of Thailand during the study period that including in the Boxshall and Halsey’s lists.

In addition, the adult parasites were taken in plankton samples for examples; *Caligus* sp. and *Acantholocus* sp. It might be responsible to locating and infecting the appropriate host (Boxshall and Halsey, 2004).

Table 9 Probability of encounter of copepod families in coastal marine plankton.

High probability	**Moderate probability**	**Low probability**
Acartiidae*	Calanidae*	Pseudocyclopidae
Centropagidae*	Euterpinidae*	Pseudocyclopiidae
Clausocalanidae*	Corycaeidae*	Ridgewayiidae
Oithonidae*	Clytemnestridae*	Clausidiidae
Paracalanidae*	Ectosomatidae*	Thalestridae
Temoridae*	(*Microsetella*)	Miraciidae*
Pontellidae*	Oncaeidae*	Caligidae (larvae)*
Pseudodiaptomidae*	Stephidae	Pennellidae (larvae)
Tortanidae*		Sapphirinidae*
		Other marine families

Remark: * found in this study.

Source: Boxshall and Halsey (2004)

Table 10 shows the percentage of frequency of occurrence with the number of planktonic copepod species from the combined taxonomic in both sampling areas. The major group was the sporadic species (21 species), followed by the very frequent species (14 species), frequent species (5 species) and infrequent species (5 species). This result might indicate the resident species in two study areas and support the horizontal and vertical migration of the planktonic copepods. Data on species composition might be underestimated because the sampling time was only in the morning but the sampling technique was minimized underestimating by vertically haul from the bottom to surface water. Additionally the circulation in the coastal areas might be the potential parameter influencing the migration of planktonic copepods in the study areas (Hopcroft et al., 1998; Miyashita et al., 2009).

Table 10 The percentage of frequency of occurrence with the number of planktonic copepod species during the sampling period.

Categories	Classified	Number of species
> 75 %	Very frequent	14
74 % - 50 %	Frequent	5
49 % -25 %	Infrequent	5
< 24 %	Sporadic	21

C. Abundance

The abundance data of each area based on two different meshes sized distinctly showed that 200 - µm mesh size collected more copepods than those of 330 - µm mesh size. Composition of copepods in the temporal variations showed a different pattern between two areas for 330 - µm mesh size net, but showing a similar pattern for 200- µm mesh size net.

1. Manao Bay

The 200- and 330 - µm nets gave very different copepod community structure in term of abundance. Figure 13 shows a clear trend in temporal variation in abundance of 200- and 330 - µm net samples in Manao Bay. Total abundance of copepods, for 200- µm nets, varied from a minimum of 2,342 ind. m^{-3} in December 2006 to a maximum of 6,446 ind. m^{-3} in February 2007 (Figure 13). The mean abundance was 4,067 ± 1,334 ind. m^{-3}. The peak abundance was reached in February 2007, which coincided with the abundance of copepodid stage, *Corycaeus asiaticus*, *Pseudodiaptomus aurivilli*, *Acartia erythraea* , *Oithona* sp., nauplii and *Euterpina acutifrons* (Appendix Tables 1 and 2). Three minimum values were found in December 2006, July and August 2007. The trend lines showed the relatively difference in abundance between the 200-µm and 330 -µm samples. Average abundance of 200- µm net samples was significantly higher than 330- µm net abundance about 4 times.

The 330- µm net samples indicate that total abundance were recorded a minimum of 371 ind. m^{-3} in September 2006 to a maximum of 1,767 ind. m^{-3} in February 2007 (Figure 13). The mean abundance was 1,003 ± 391 ind. m^{-3}. Two peaks were reached in February and June 2007 whereas the lowest value was recorded in September 2006. Copepodid stage of *A. erythraea*, *P. aurivilli*, *A. gibber*, *C. furcatus* and *S. subcrassus* were the most abundant species in the 330- µm net samples during the sampling period.

According to seasonal pattern, the total abundance of copepods were analysed in three values: Southwest monsoon season, Northeast monsoon and summer. During the Southwest monsoon (May – October), the average abundance of 200- µm in mesh size samples was 3,580 ± 1,203 ind. m^{-3} while the average value of 4,301 ± 1,694 ind. m^{-3} was recorded during the Northeast monsoon (November –February) (Figure 14). The highest average abundance was 5,057 ± 355 ind. m^{-3} during summer period (March-April). No significant difference in seasonal abundance of copepods based on 200- µm in mesh sizes during the two monsoons was demonstrated in this study area.

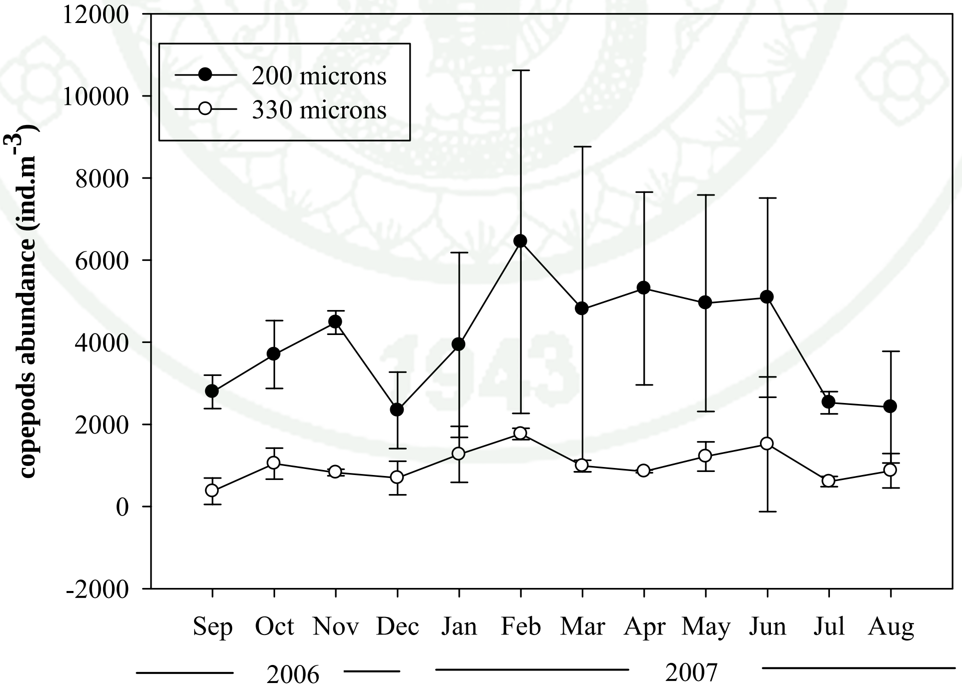


Figure 13 Total abundance of epipelagic copepods in Manao Bay as estimated by 200-µm and 330-µm net during the sampling period.

During the Southwest monsoon season, the average abundance of 330- μm net samples was 938 ± 414 ind. m^{-3} while the average of 1,140 ± 485 ind. m^{-3} was observed during the Northeast monsoon season. The lowest abundance was 922 ± 94 ind. m^{-3} during the summer period (Figure 14). No noticeable variation in seasonal abundance of copepods based on 330- μm in mesh sizes during the two monsoons was demonstrated in this study area.

The larval stages (copepodid) dominated over other stages, contributing 64 % to total abundance; the mean abundance was 2,611 ± 1035 ind. m^{-3}. Percentage and mean abundances of other groups in descending order were 16 % (652 ± 251 ind. m^{-3}) calanoids, 13 % (540 ± 256 ind. m^{-3}) cyclopoids and 5 % (186 ± 155 ind. m^{-3}) harpacticoids (Figure 15).

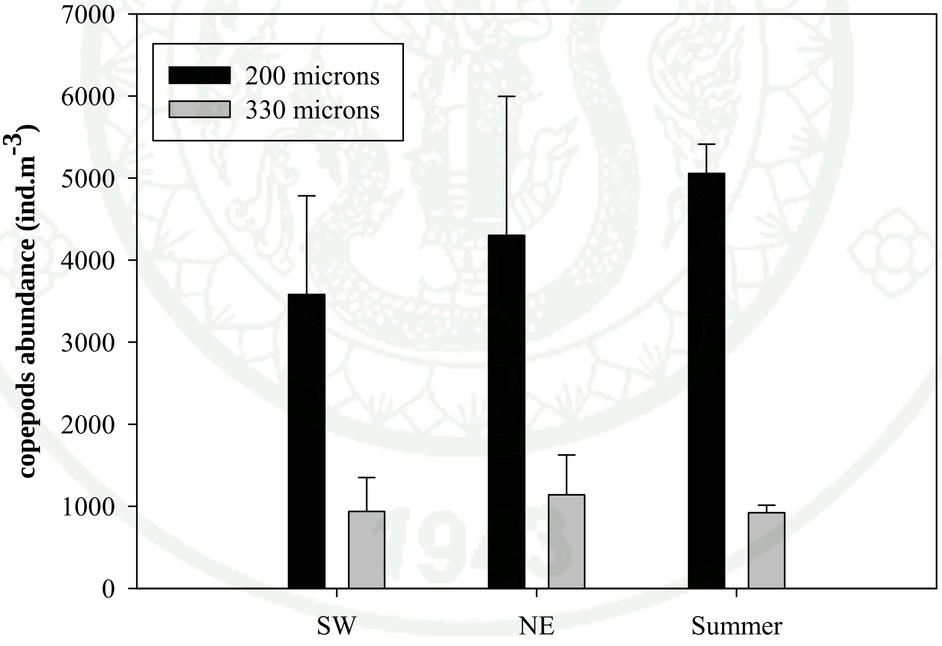


Figure 14 Average abundance of epipelgic copepods in Manao Bay, as estimated by 200-μm and 330-μm net during the sampling period.

In terms of percentage abundance the five dominant species were *Acartia erythraea* (7 %), *Corycaeus asiaticus* (5 %), *Pseudodiaptomus aurivilli* (4 %), *Oithona* spp. (4 %) and *Euterpina acutifrons* (4 %). Subdominant species were *Acrocalanus gibber* (3

%), *Corycaeus catus* (2 %) and *Oncaea conifera* (2 %). All frequently occurring species were present throughout the year.

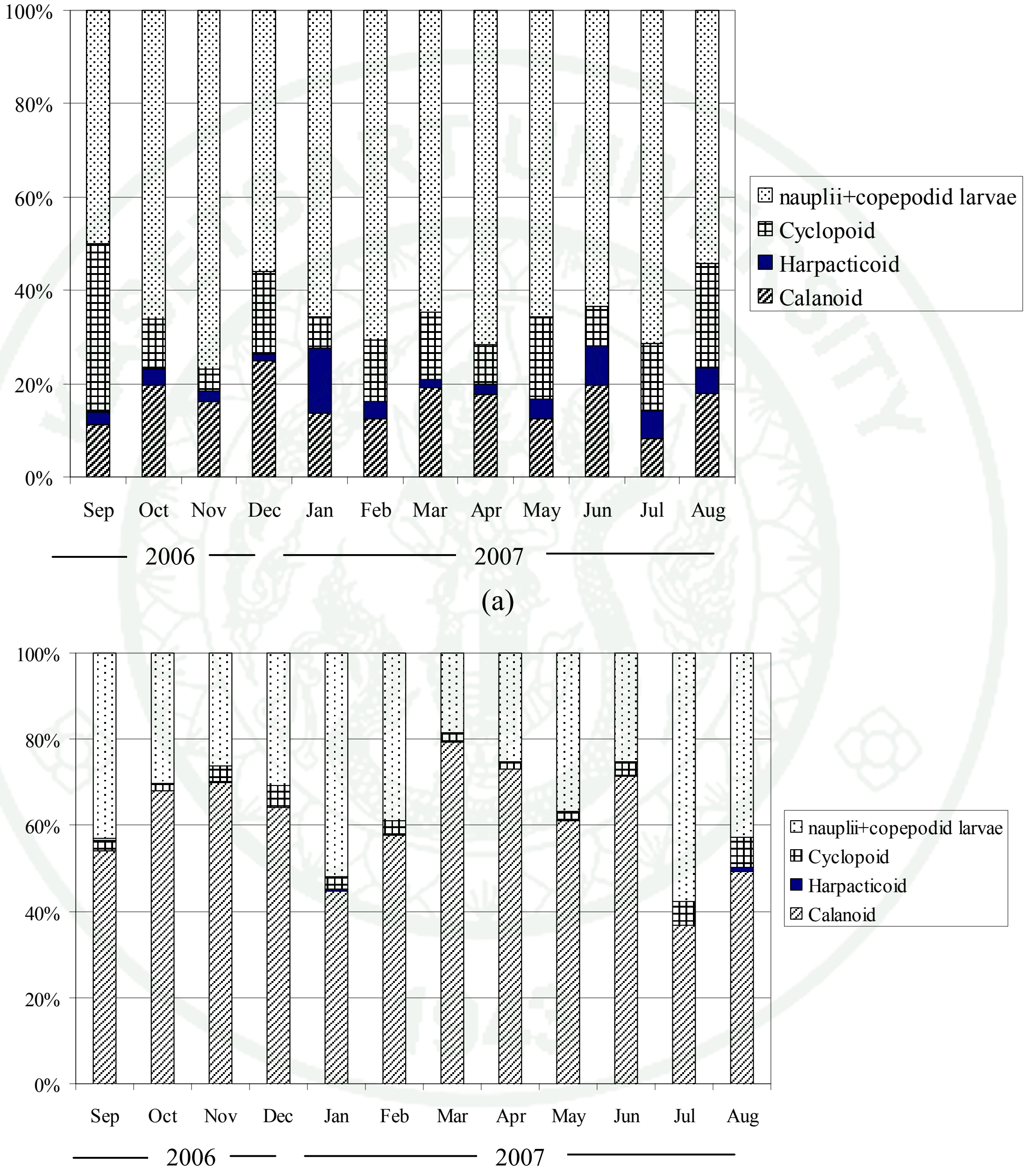
Copepodid stage in the 330-µm net samples was numerically dominant, representing one-thirds of the copepods sampled or 35 % (mean 347 ± 173 ind. m^{-3}) to the total abundance. *Acartia erythraea* was clearly the most important species, representing 32 % (mean 318 ± 166 ind. m^{-3}) of all copepod samples in Manao Bay. Subdominant species was *Pseudodiaptomus aurivilli*, contributing 15 % (mean 147 ± 114 ind. m^{-3}) to the total copepod abundance, followed by *Acrocalnus gibber* (4 %, 43 ± 30 ind. m^{-3}), *Centropages furcatus* (3 %, 31 ± 23 ind. m^{-3}) and *Subeucalanus subcrassus* (2 %, 24 ± 29 ind. m^{-3}), respectively.

The remaining species contributed less than 2% to total copepod abundance. Figure 15 shows the temporal relative abundance of dominant groups. Percentage and mean abundances of copepods in descending order were 62 % (618 ± 274 ind. m^{-3}) calanoids, 35% (351 ± 176 ind.m^{-3}) larval stage, 3 % (33 ± 17 ind. m^{-3}) cyclopoids and 0 % (2 ± 2 ind. m^{-3}) harpacticoids.

In conclusions, the abundance of epipelagic copepods between two different equipments (mesh size) showed distinct differences between mesh size and time (month) in Manao Bay. Within mesh size, the average seasonal abundance of copepods did not differ.

2. Si Racha Bay

Figure 16 shows the temporal variation of epipelagic copepods collecting by 200-µm and 330-µm nets. Average abundance of 200 - µm in mesh size samples was significantly higher than that of 330- µm net samples up to 5.6 times, and the values ranged from the minimum of 1,572 ind. m^{-3} in March to the maximum of 11,377 ind. m^{-3} in May (mean 4,629 ± 2,835 ind. m^{-3}). The 330-µm samples showed a minimum of 545 ind. m^{-3} in August 2007 and a maximum of 1,686 ind. m^{-3} in May 2007 with mean value was 821 ± 304 ind. m^{-3}. Figure 16 shows fairly variation in the temporal abundance of 330 -µm net, whereas the highest peak was reached in May and also low fluctuation during the sampling period.



(a)

(b)

Figure 15 Temporal contribution percentage of epipelagic copepods in Manao Bay, collecting with 200-µm net (a) and 330-µm net (b), September 2006 to August 2007.

As compared between seasons, the highest average abundance was recorded during the Southwest monsoon season (5,766 ± 3,059 ind. m$^{-3)}$, followed by the Northeast monsoon season (4,219 ± 2,538 ind. m^{-3}) and summer period (2,040 ± 661 ind. m^{-3}) (Figure 17). A dramatic decreasing in average abundance of the 200-µm samples and the significant differences were found between seasons within mesh size.

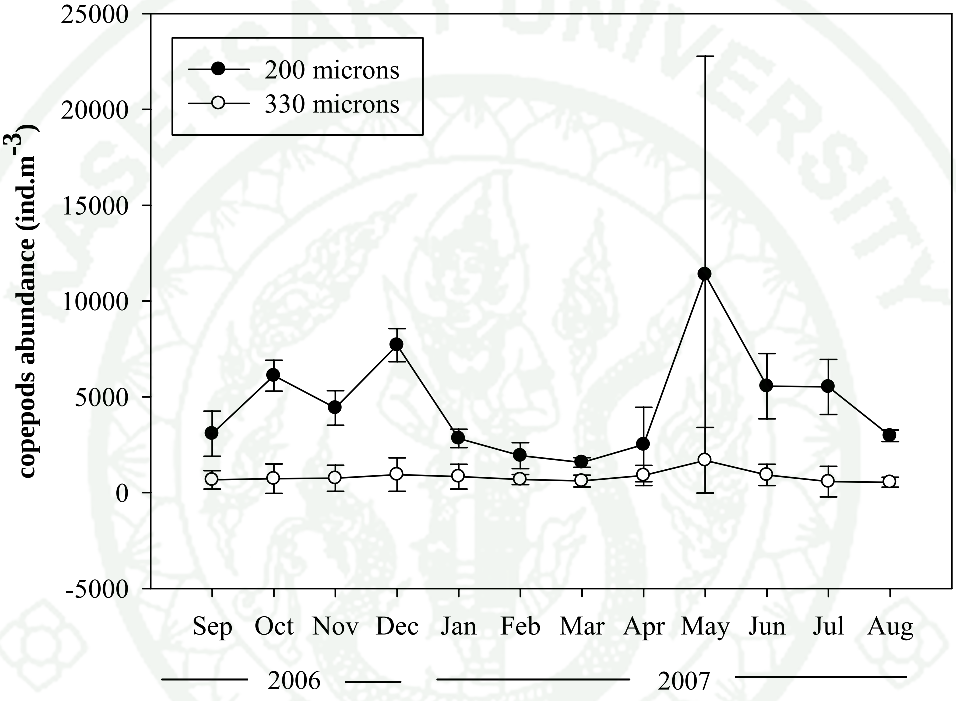


Figure 16 Total abundance of epipelagic copepods in Si Racha Bay as estimated by 200-µm and 330-µm net.

Seasonal patterns of the 330-µm samples showed no sharp fluctuation in Figure 17. The highest average abundance was 855 ± 429 ind. m^{-3} during the Southwest monsoon season, followed by an average of 803 ± 111 ind. m^{-3} in the Northeast monsoon season and the lowest value was 754 ± 208 ind. m^{-3} in summer period. In addition, no significant seasonal variation was demonstrated during the sampling period.

The majority contribution was copepodid larvae comprising 83 % (3,842 ± 2,606 ind. m^{-3}) to the total abundance in the 200 –µm samples (Appendix table 3). The dominant species was *Acartia erythraea*, comprising 6 % (mean 278 ± 398 ind. m^{-3}) and the subdominant was *Euterpina acutifrons* (2 %, mean 84 ± 98 ind. m^{-3}). The other species were measured less than 2% in contribution. Figure 18 shows the relative abundance of important groups of copepods during the sampling period. The highest component was copepod larvae (84%, 3,888 ± 2,620 ind. m^{-3}), followed by adults in decreasing order: calanoids (10 %, 455 ± 393 ind. m^{-3}), cyclopoids (4 %, 182 ± 141 ind. m^{-3}) and harpacticoids (2 %, 99 ± 101 ind. m^{-3}) (Figure 18).

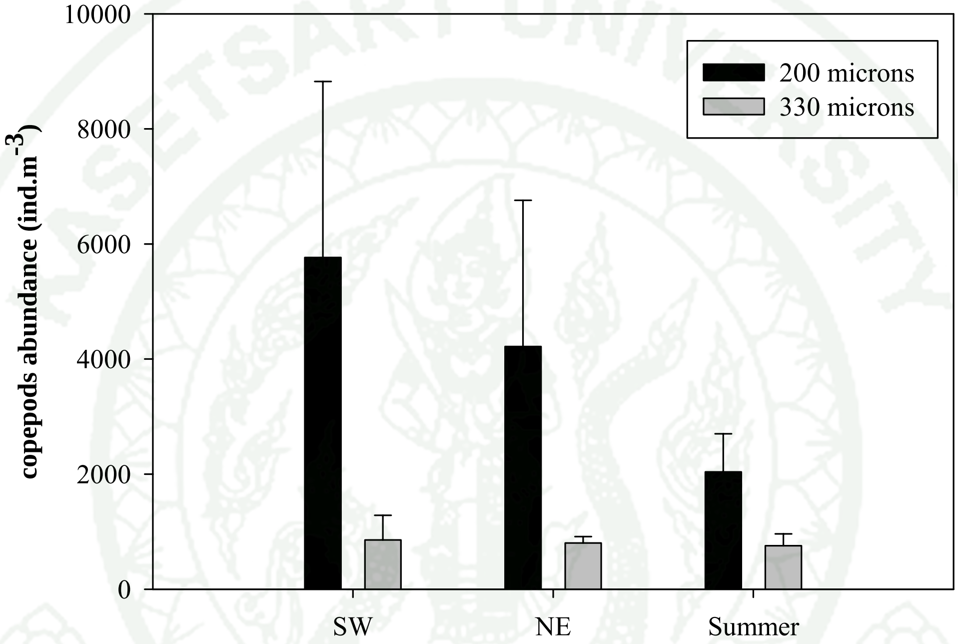


Figure 17 Seasonal average abundance of epipelagic copepods in Si Racha Bay, a comparison between 200-µm and 330 -µm samples.

Two important components in the 330-µm samples were *Acartia erythraea* and copepodid stage. They showed the percentage contribution and mean to the total abundance of copepods as followed: 38 % (313 ± 308 ind. m^{-3}) and 36 % (299 ± 131 ind. m^{-3}), respectively. Subdominant species were *Pseudodiatomus aurivilli* (8 %, mean 62 ± 73 ind. m^{-3}) and *Centropages furcatus* (3 %, mean 27 ± 25 ind. m^{-3}). The remaining species were the minor contribution that comprising less than 2 % to the total copepod abundance (Appendix Table 4).

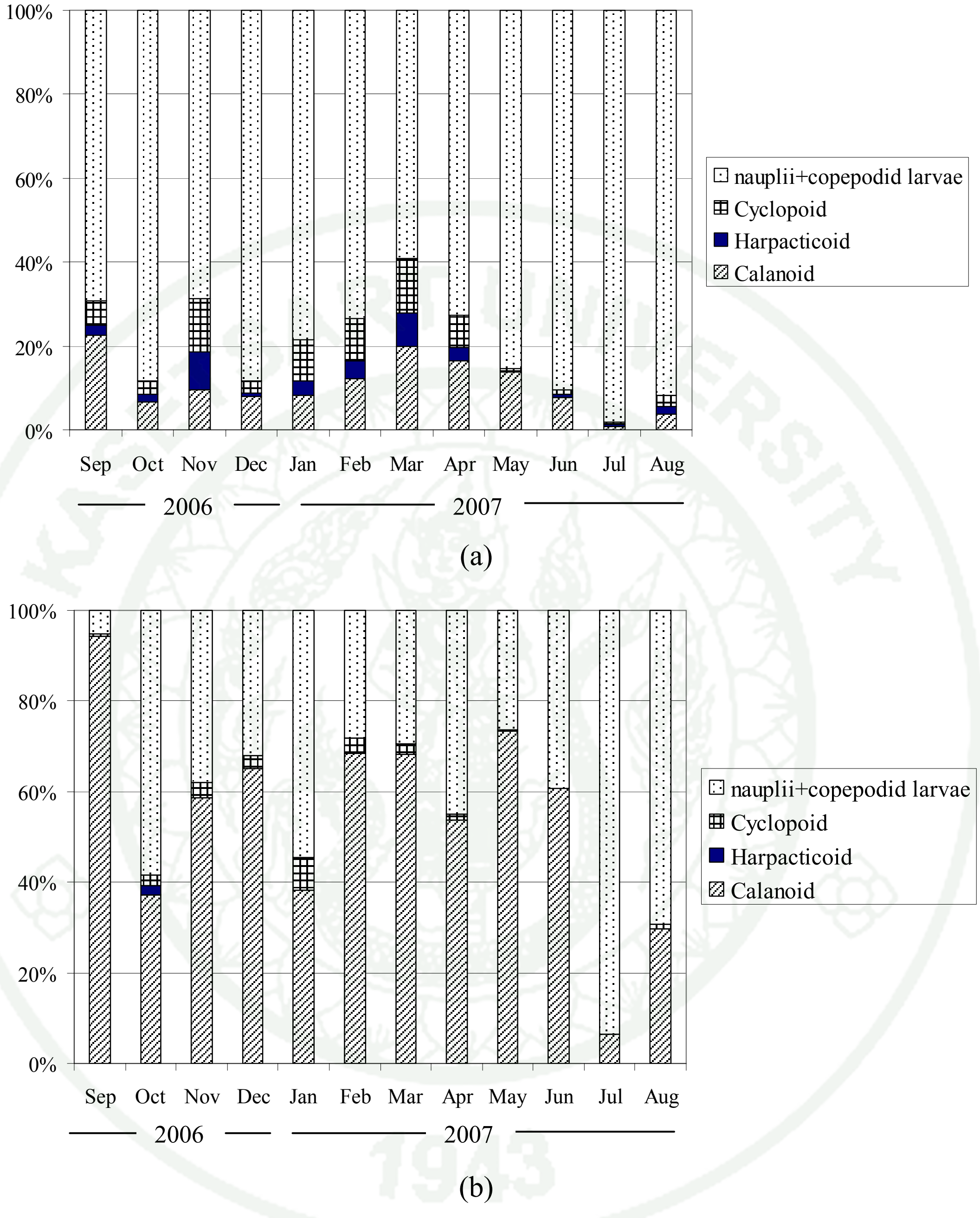


Figure 18 Temporal contribution percentage of epipelagic copepods in Si Racha Bay, from September 2006 to August 2007 collecting with 200-µm (a) and 330-µm net (b).

Regarding to total abundance, the major proportion could be in divided in three groups. The highest proportion were calanoids with 57 % (mean 470 ± 300 ind. m^{-3}) to the total abundance, followed by copepod larvae (41 %, 333 ± 142 ind. m^{-3}), cyclopoids (2 %, 16 ± 17 ind. m^{-3}) and harpacticoids (0%, 1 ± 4 ind. m^{-3}), respectively (Figure 18). The copepod larvae displayed the highest proportion in July to August 2007, but the lowest contribution in September 2006. Harpacticoids showed the small proportion in October 2006, and the cyclopoids or a minor proportion were absent in June to July 2007.

This result showed the clear composition and abundance of planktonic copepods based on 2 types of sampling nets. The abundance of 200- μm net sample was significant higher than that of the 330- μm net sample (ANOVA, $P<0.05$). In addition, the majority of planktonic copepods in the 200- μm net sample were copepod larvae (nauplii and copepodid) but the 330- μm net sample were adults of calanoids, especially *A. erythraea*.

In term of relative abundance, *Acartia erythraea*, *Pseudodiaptomus aurivilli*, and *Acrocalanus gibber* were dominated in 200-μm net samples. *Euterpina acutifrons* and *Corycaeus asiaticus* were dominanted only in 200-μm net whereas *Centropages furcatus* occurred only in 330- μm net sample. These copepods are important contributors to the total abundance in coastal waters (Suwanrumpha 1980b; 1984; Salakij, 2009).

According to quantitative study, the 200-μm net samples showed distinct seasonal fluctuation in both sampling areas, but the 330-μm net samples were relatively constant throughout both monsoon seasons. This pattern is in agreement with the previous study of Sribyatta (1996) in the Gulf of Thailand. She investigated the long term changing in abundance of zooplankton from 1976-1994. The mean abundance of zooplankton was slightly increased but the pattern of distribution was unchanged. The abundance of zooplankton in coastal areas (<50 m in depth) was higher densities than the offshore areas. Seasonal variation in abundance of zooplankton was not found the differences between two monsoon seasons. In addition, the water temperature is consistently throughout the annual cycle in tropical zone. Relationship between zooplankton abundance and water temperature were negatively correlated but positively correlated with salinity.

D. Trophic structure

The trophic structure of planktonic copepods were investigated in both sampling areas based on percentage of adult planktonic copepods in the samples. The carnivorous copepods are predominant throughout the annual cycle. Twenty-four species were classified to carnivores, followed by omnivores (14 species) and herbivores (5 species). The trophic categories of planktonic copepods in the upper Gulf of Thailand are as followed:

1. The carnivorous copepods are *Candacia*, *Corycaeus*, *Kelleria*, *Labidocera*, *Oithona*, *Oncaea*, *Pseudodiaptomus*, *Sapphirina*, *Temora* and *Tortanus*

2. The omnivorous copepods are *Acartia*, *Centropages*, *Clytemnestra*, *Euterpina*, *Macrosetella* ans *Microsetella*

3. The herbivorous copepods are *Acarocalanus*, *Clausocalanus*, *Paracalanus* and *Subeucalanus*

In Manao Bay, the sampling gears gave opposite results in term of dominant groups collected by each gears; carnivores dominated in the 200-µm net samples (713 ± 286 ind. m^{-3} or 52 %) whereas omnivores dominated in the 330-µm net samples (373±194 ind. m^{-3} or 57%). Herbivores were low in densities average 136 ± 92 ind. m^{-3} (or 10%) for the 200-µm net and 81 ± 60 ind. m^{-3} (or 13 %) for the 330-µm net (Figure 19).

Comparative similar results concerning the net used for Si Racha Bay, omnivores were dominant group in all samples, followed by carnivores and herbivores (Figure 20).

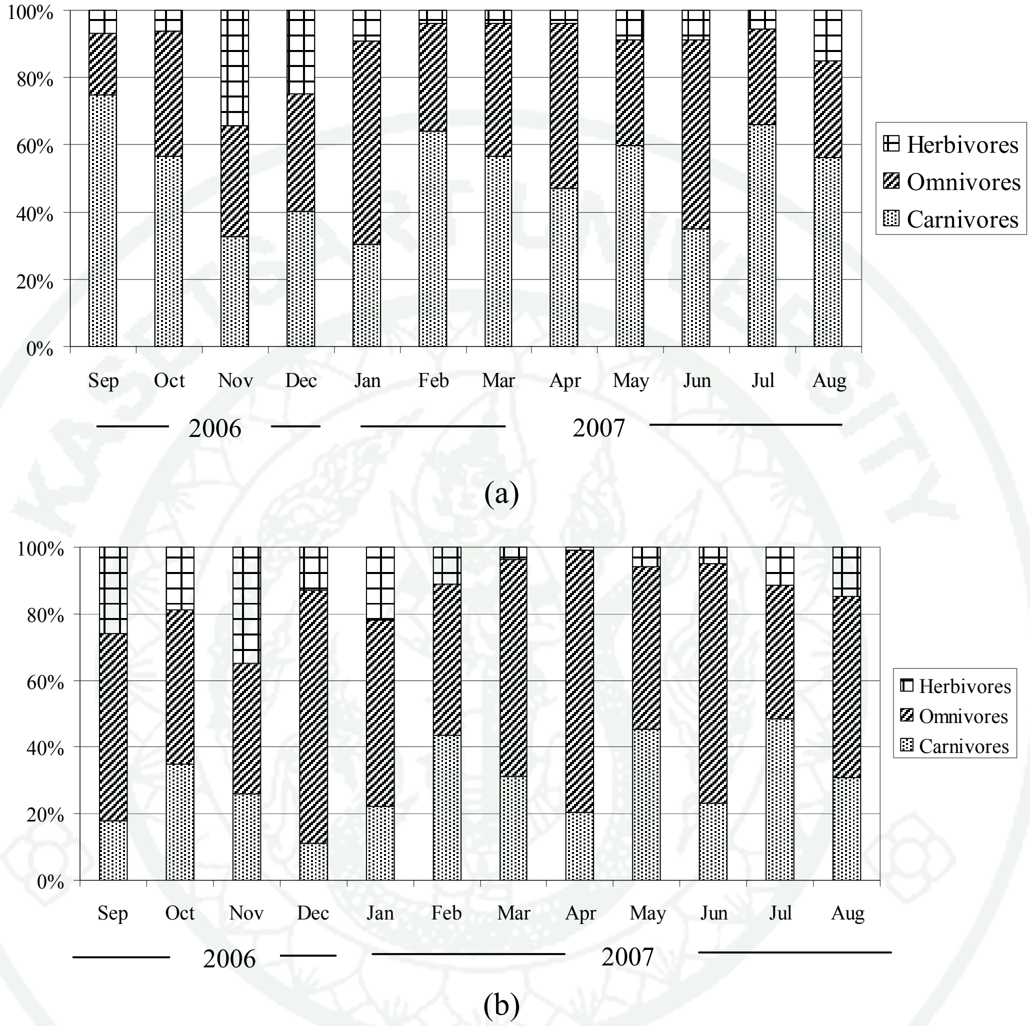


Figure 19 Percentage of composition of three categories of adult epipelagic copepods in Manao Bay, September 2006 to August 2007, collecting with 220 -µm (a) and 330-µm net (b).

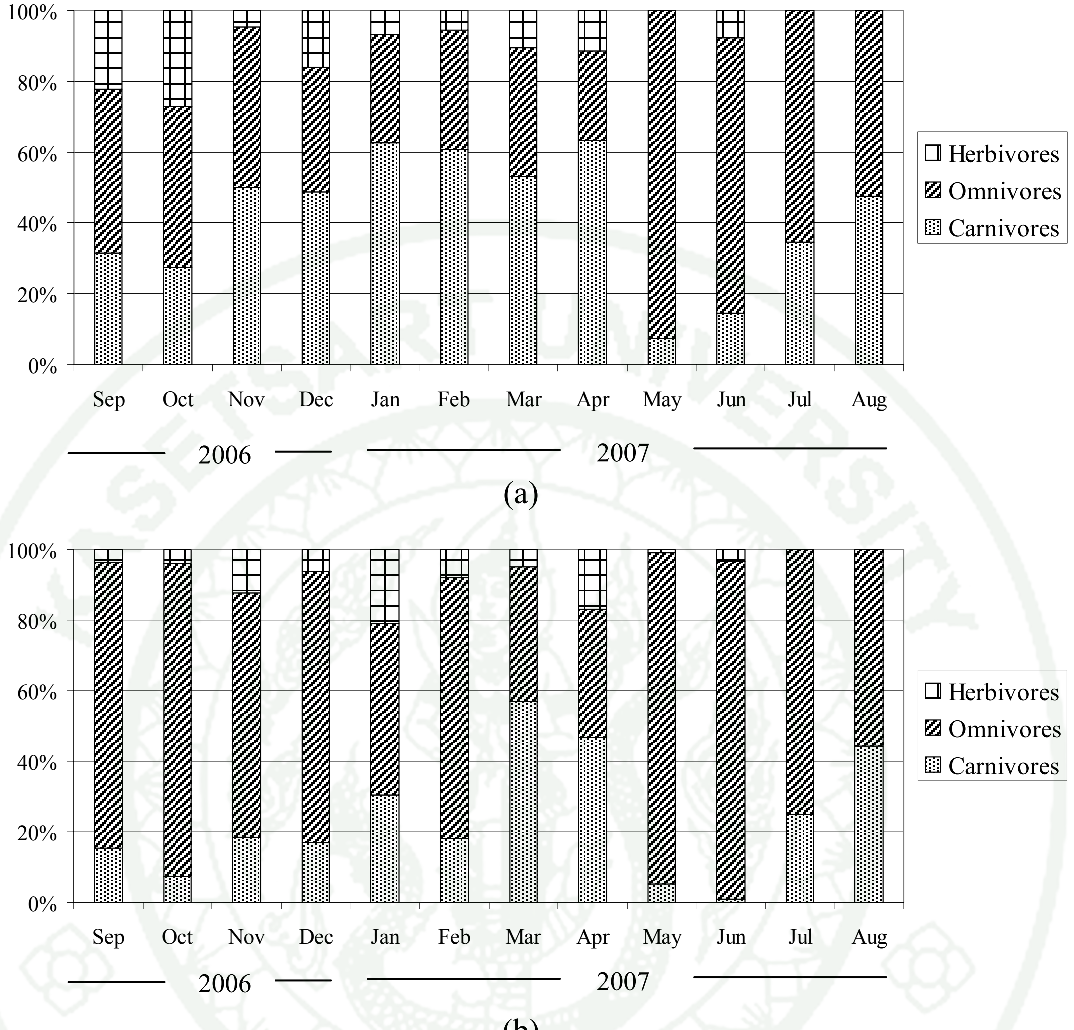


Figure 20 Percentage of composition of three trophic categories of copepods in Si Racha Bay, September 2006 to August 2007, collecting with 200-µm (a) and 330-µm net (b).

To compare between mesh sizes and sampling areas, Table 11 shows the maximum, minimum and average values in terms of three trophic categories and the contribution percentage of planktonic copepods in Manao Bay and Si Racha Bay. The herbivorous copepods contributed the lowest proportion to the total abundance of planktonic copepods in both type of nets and sampling areas. Some species of the following genera: *Canthocalanus*, *Acrocalanus*, *Paracalanus* and *Subeucalanu*s, distributing offshore in the inner Gulf of Thailand belonged to this trophic categories.

Table 11 The maximum, minimum and average values in term of three trophic categories and the contribution percentage of planktonic copepods, based on the 200 and 330-µm in mesh size in Manao Bay and Si Racha Bay.

Trophic category	**200µm**				**330µm**			
	min	**max**	**mean**	**%**	**min**	**max**	**mean**	**%**
Manao Bay								
Herbivores	40	354	136±92	10	6	214	81±60	13
Omnivores	207	1024	529±253	38	103	524	373±194	57
Carnivores	339	1212	713±286	52	38	469	198±125	30
Si Racha Bay								
Herbivores	0	210	72±73	10	0	84	32±29	7
Omnivores	64	1538	383±396	52	27	1166	360±304	74
Carnivores	34	690	286±188	39	5	243	96±76	20

Table 12 shows the comparison of trophic structure of planktonic copepods between this results and the study by Suwanrumpha (1980c). She found that herbivores in highest number (41.5%) throughout the year in the inner Gulf. On the other hand, the abundance of carnivores and omnivores were 36.85% and 21.5 %, respectively.

Table 12 Species lists of planktonic copepods in three trophic categories in the upper Gulf of Thailand.

Trophic categories/Species lists	**Suwanrumpha (1980c)**	**This study**
1. Herbivorous copepods		
Acrocalanus gibber	√	√
A. monachus	√	-
A. longicornis	√	-
A. similis	√	-
Acrocalanus spp.	√	-

Table 12 (Continued)

Trophic categories/Species lists	Suwanrumpha (1980c)	This study
Calanus pauper	√	√
(*Canthocalanus pauper*)		
Calanus vulgaris	√	-
(*Clausocalanus vulgaris*)		
Clausocalanus arecornis	√	-
Clausocalanus furcatus		√
Eucalanus subcrassus	√	√
(*Subeucalanus subcrassus*)		
Paracalanus parvus	√	-
P. crassiorostris	√	-
P. aculeatus	√	√
Metaclanus aurivilli	√	-
Temora discaudata	√	-
T. turbinata	√	-
2. Omnivorous copepods		
Acartia erythraea	√	√
A. spinicauda	√	√
A. pacifica	-	√
Calanopia aurivilli	-	√
C. elliptica	√	-
C. thompsoni	√	√
Centropages furcatus	√	√
C. orsinii	√	√
C. tenuiremis	-	√
Clytemnestra scutellata	√	√
Euterpina acutifrons	√	√
Microsetella norvegica	√	√
M. rosea	-	√

Table 12 (Continued)

Trophic categories/Species lists	Suwanrumpha (1980c)	This study
Longipedia sp.	-	√
Setella gracilis	√	√
(*Macrosetella gracilis*)		
3. Carnivorous copepods		
Candacia spp.	√	-
C. bradyi	-	√
C. catula	-	√
Corycaeus spp.	√	-
C. agilis	-	√
C. asiaticus	-	√
C. catus	-	√
C. longistylis	-	√
C. speciosus	-	√
Euchaeta spp.	√	-
Kelleria australica	-	√
Labidocera spp.	√	-
L. batavaie	-	√
L. bengalensis	-	√
L. bipinnata	-	√
L. kroyeri	-	√
L. minuta	-	√
L. pectinata	-	√
L. rotunda	-	√
Oncaea spp.	√	-
Oncaea conifera	-	√
Oithona plumnifera	√	-
O. rigida	√	-
Oithona spp.	√	√

Table 12 (Continued)

Trophic categories/Species lists	Suwanrumpha (1980c)	This study
Pseudodiaptomus aurivilli	√	√
P. clevei	√	√
Temora discaudata	-	√
Tortanus forcipatus	√	√
T. gracilis	-	√
Sapphirina stellata	-	√

Remark: () species in parentheses are new classified; - : not found

In coastal region, the omnivores seemed to be the most contributor of the planktonic copepod community in both type of nets. Those compositions were many neritic species of genera *Centropages*, *Acartia, Calanopia, Macrosetella*, *Microsetella*, *Clytemnestra* and *Euterpina*. They contributed in majority in the study areas because of the highly food supply. These areas were suitable condition for growing of phytoplankton including micro-zooplankton that is food of omnivorous copepods. The influences by the nutrients loading from land together with a strong turbulence in the littoral zone could be the factor affecting to available food for omnivores (Runge, 1988; Calbet and Landry, 2004; Calbet, 2008).

Carnivorous copepods (calanoids and cyclopoids) in the upper Gulf of Thailand belonged to the following families: Labidoceridae, Candaciidae, Tortanidae, Pseudodiaptomidae, Oithonidae, Oncaeidae, Sapphirinidae and Corycaeidae. Cyclopoids might be quantitatively underestimated because relatively large mesh sizes (200 and 330 µm) of the nets used.

The present finding can not be compared to previous study. The only available study reported by Suwanrumpha (1980c) was carried out offshore using a large mesh size net (330 µm). Consequently, small size cyclopoids such as *Oithona* and *Oncaea* were missing. The large mesh size net was reasonable gear as horizontal and vertical migration of calanoids being the focus of this investigation. She reported composition of offshore copepods that was different from the near shore community of this study.

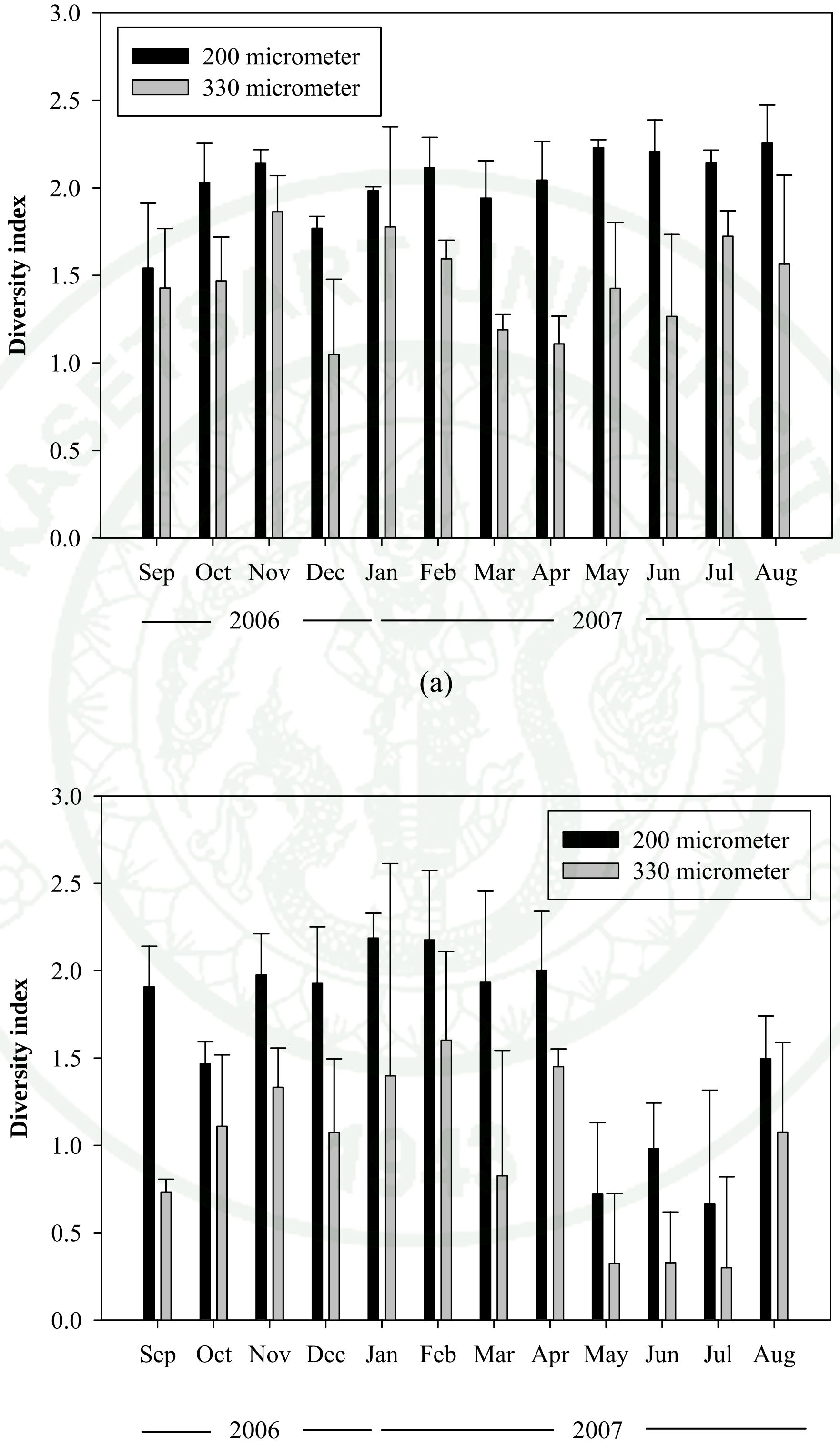
E. Shannon diversity index

The diversity of copepod community was studied based on two overall samples obtained by 200-µm and 330 -µm samples in two different areas. The samples were pooled in 6 stations in each mesh size net. The copepod diversity was calculated by means of Shannon diversity index (H´, natural logarithm). The significant differences were tested in Shannon diversity index between mesh size of nets, seasons and areas. Figure 21 shows the temporal variation in diversity index between 200-µm and 330 -µm samples in Manao Bay and Si Racha Bay.

In Manao Bay, diversity index of 200-µm samples exhibited the temporal fluctuations in the range between 1.66 and 2.49 for the most of the year (Figure 21a). The 330 -µm samples diversity index varied from 1.17 to 2.02. Though significant differences were found between 200-µm and 330 -µm samples (ANOVA, *P*<0.05) but the diversity showed similar values in September 2006 and January 2007.

Figure 21b shows diversity index recorded at Si Racha Bay for 200 µm net sample was higher than that of 330 µm net sample, but minimum and maximum values were observed relative same periods (months). The diversity index of 200 -µm samples varied from 0.47 – 2.47 while the values of 330 -µm samples ranged from 0.36 – 2.14. The significant differences between two groups of samples were also tested (ANOVA, *P*<0.05).

In comparison among three seasons, the most diverse period for 200-µm samples was the Southwest monsoon season (H´=2.38), followed by the Northeast monsoon season (H´=2.32) in Manao Bay. The diversity index of 200-µm samples exhibited higher values than 330 -µm samples (ANOVA, *P*<0.05). In contrast, the 330 -µm samples diversity index was H´=1.91 during the Northeast monsoon, followed by the Southwest monsoon season (H´=1.73). The lowest values were observed for both gears used: 2.18 and 1.27, respectively (Table 13).



(a)

(b)

Figure 21 Diversity index (H´) of epipelagic copepods in Manao Bay (a) and Si Racha Bay (b), September 2006 to August 2007.

In Si Racha Bay, the diversity of 200 -µm samples showed the highest average value was 2.39 in summer season, followed by a value of 2.38 in the Northeast monsoon season. The lowest value (H′= 1.68) was recorded in the Southwest monsoon season was recorded in Si Racha Bay (Table 13). Opposite results were shown for both mesh sizes net used for Manao Bay. The highest Shannon diversity index of 330 -µm samples (1.79) was recorded in the Northeast monsoon season, followed by 1.45 in summer season and the lowest value (0.86) in the Southwest monsoon. There was significant difference in diversity between the gears and among seasons (ANOVA, *P*<0.05).

To compare between two study areas, the monthly diversity index of planktonic copepods in Manao Bay in both sample nets were significantly higher than those of Si Racha Bay (*F-test*, *P*<0.05). Though, the species composition of copepods showed rather similar in both areas.

Table 13 Seasonal Shannon diversity index (H′) of epipelagic copepods in Manao Bay and Si Racha Bay, compared with 200-µm and 330 -µm samples.

Season	**Manao Bay**		**Si Racha Bay**	
	200 -µm	**330 -µm**	**200 -µm**	**330 -µm**
SW	2.38	1.73	1.68	0.86
NE	2.32	1.91	2.38	1.79
Summer	2.18	1.27	2.39	1.45

Remarks: SW: the Southwest monsoon season (May – October); NE: the Northeast monsoon season (November – February); summer (March-April).

The above results showed significant differences in species diversity index in both sampling mesh sizes and areas. The 200- µm net samples were higher diversity index than the 330-µm net index in both Manao Bay and Si Racha Bay, as the 200- µm mesh size could collect more small size copepods. A mostly adult of *A. erythraea* (32-38 % to the total copepod abundance) was collected by the 330µm net. Thus the diversity index value in the 330- µm mesh size collection was always low. The average seasonal diversity index of planktonic copepods was significant difference between two types of mesh sizes in both sampling areas.

F. Pearson correlation

The Pearson correlation was tested to determine the relationships between chemical and physical properties to copepod abundance in both areas. All parameters showed no correlation to copepod abundance in both study areas (Table 14). Because of the special characteristics in brackish animals that are highly adaptive to the environmental variations showed the minimal affects to copepods abundance in coastal waters. Moreover, the sufficient natural food supply also supported the abundance of copepods and maintained the community structure (Saiz and Calbet, 2007; Calbet 2008).

High abundance of copepods was accompanied by a low diversity index in Si Racha Bay (May 2007). Also, the Pearson correlation analysis showed that no correlation between abundance and physical parameters. It can be assumed that majority of copepod community was restricted to this area and was not affected by monsoon season or coastal currents. Therefore, the species composition did not vary with monsoon seasons and they were described to the euryhaline and eurythermal species in the upper Gulf of Thailand. This result agrees with the previous study of Suwanrumpha (1984). She also indicated that the epipelegic copepod community composed of more brackish water species in the upper Gulf of Thailand.

2. Length-weight relationship of *A. erythraea*

As resulted in the abundance of planktonic copepods community, *A. erythraea* showed a highest contribution of total abundance, 7 % to the total 200-µm sample, and 32 % to the total 330 -µm samples, in Manao Bay (Tables 7 and 8). In Si Racha Bay, the highest contribution was recorded 6 % and 38 % to the total abundance of 200-µm and 330 -µm samples, respectively.

Table 14 Correlation coefficients (r) in relationships between copepods abundance, environmental parameters and nutrients during the sampling period; * P<0.05.

Parameter	**copepods abundance (ind. m^{-3})**			
	Manao Bay		**Si Racha Bay**	
	200-µm	**330-µm**	**200-µm**	**330-µm**
Water temperature (°C)	0.00	-0.28	0.31	0.19
Salinity (psu)	-0.12	-0.21	-0.40	0.00
Dissolved oxygen (mg l^{-1})	0.09	0.47	-0.27	-0.30
pH	0.27	0.39	0.31	0.07
Rainfall (mm)	-0.06	-0.11	0.23	0.03
Chlorophyll a concentration (mg m^{-3})	0.37	0.31	0.24	0.14

Temporal variation in average abundance of *A. erythraea* in Manao Bay and Si Racha Bay were pooled data from two mesh sizes. Figure 22 shows *Acartia* abundance that varied from 145 ind. m^{-3} in January 2007 to 512 ind. m^{-3} in October 2006, an average of 305 ± 119 ind. m^{-3}. In Si Racha Bay, average abundance of *Acartia* varied from 34 ind. m^{-3} in July 2007 to 1,328 ind. m^{-3} in May 2007, with an average of 295 ± 349 ind. m^{-3}. The temporal variation of *Acartia* were tested in both study areas that showed no difference.

Average abundance in seasonal variations of *A. erythraea* is presented in both study areas in Figure 23. The distinct variations are shown in summer period (393 ± 45 ind. m^{-3}) in Manao Bay and the Southwest monsoon season (410 ± 437 ind. m^{-3}) in Si Racha Bay that *Acartia* expressed the highest abundance.

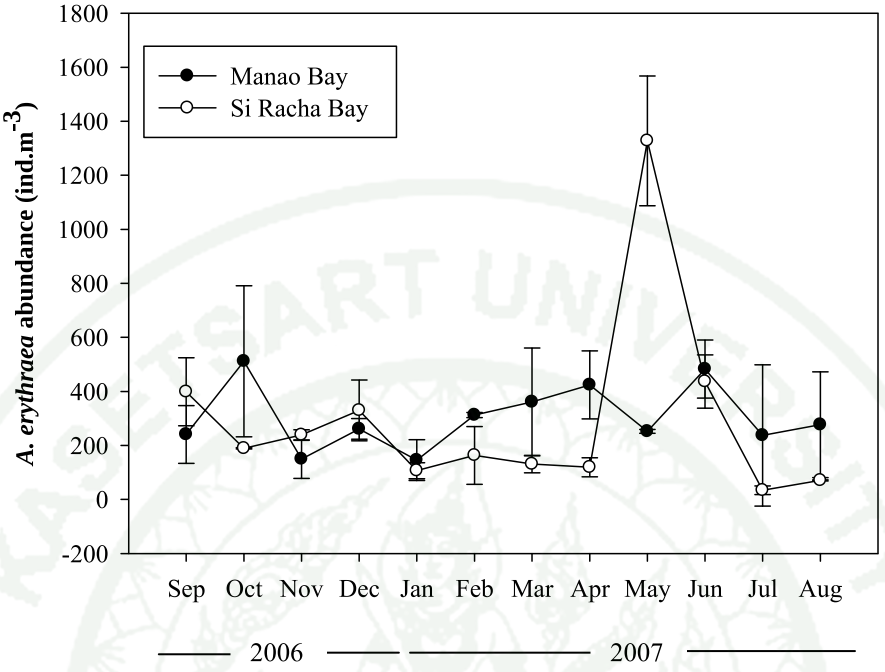


Figure 22 Average abundance of *A. erythraea* in Manao Bay and Si Racha Bay, from September 2006 to August 2007.

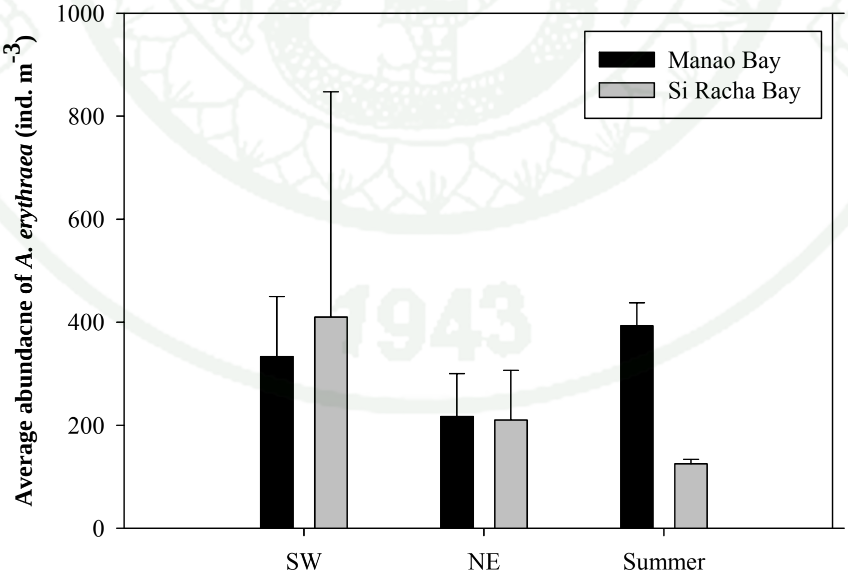


Figure 23 Seasonal average abundance in of *A. erythraea* in Manao Bay and Si Racha Bay, from September 2006 to August 2007.

Prosome lengths of *A.erythraea* male and female from September 2006 to August 2007, are presented in Figure 24. The male prosome length varied from 920 µm in September 2006 to 980 µm in January and May 2007, with an average of 951 ± 20 µm (*n* = 2,137). Female prosome length varied from 1,010 µm in October 2006 to 1,110 µm in January 2007, with an average of 1,055 ± 31 µm (*n* = 2,205). There was no difference of prosome length of male and female. Average width of male and female were 316 ± 12 µm and 330 ± 21 µm (*n* = 200), respectively. The raw data are available in Appendix Table 6.

Dry weight of male *A. erythraea* varied from 6.0 µg in June 2007 to 7.93 µg in December 2006 (Figure 25), with an average of 7.15 ± 0.58 µg (*n* = 2,137). Female dry weight ranged from 6.94 µg in June 2007 to 8.99 µg in December 2006, with an average of 8.04 ± 0.66 µg (*n* = 2,205). Temporal variation of dry weight showed fluctuation during the sampling period in both sexes.

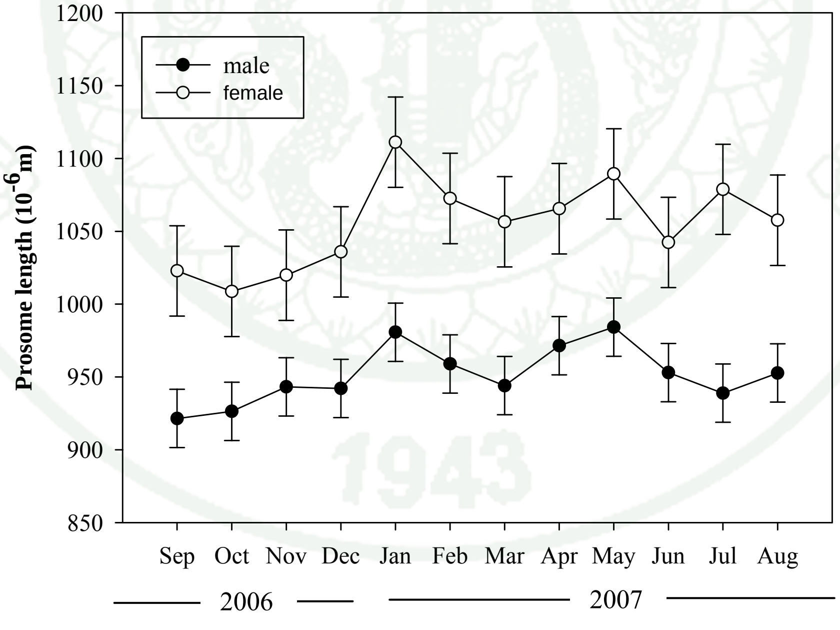


Figure 24 Temporal variation on mean prosome length (µm) of *A. erythraea* in both male and female in Manao Bay, September 2006 to August 2007.

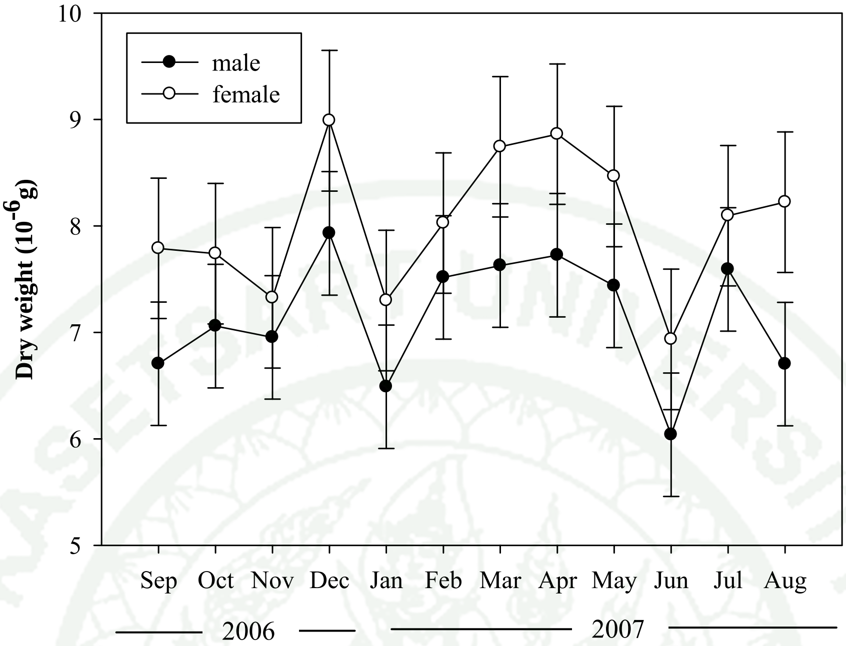


Figure 25 Temporal variation of mean dry weight (μg) of *A. erythraea* in both male (920 – 980 μm in length) and female (1,010-1,110 μm in length) in Manao Bay, September 2006 to August 2007.

Carbon weight was obtained from the same specimens examined for dry weight and length. Carbon weight of male varied from 2.9 μg in June 2007 to 3.74 μg in December 2006, with and average of 3.38 ± 0.25 μg (*n* = 2,137). Carbon weight of female ranged from 3.28 μg in June 2007 to 4.3 μg in December 2006, with an average of 3.78 ± 0.29 μg (*n* = 2,205). Figure 26 shows variation of carbon weight in both male and female over the study period, which established the same pattern, except from September to October 2006, and from July to August 2007.

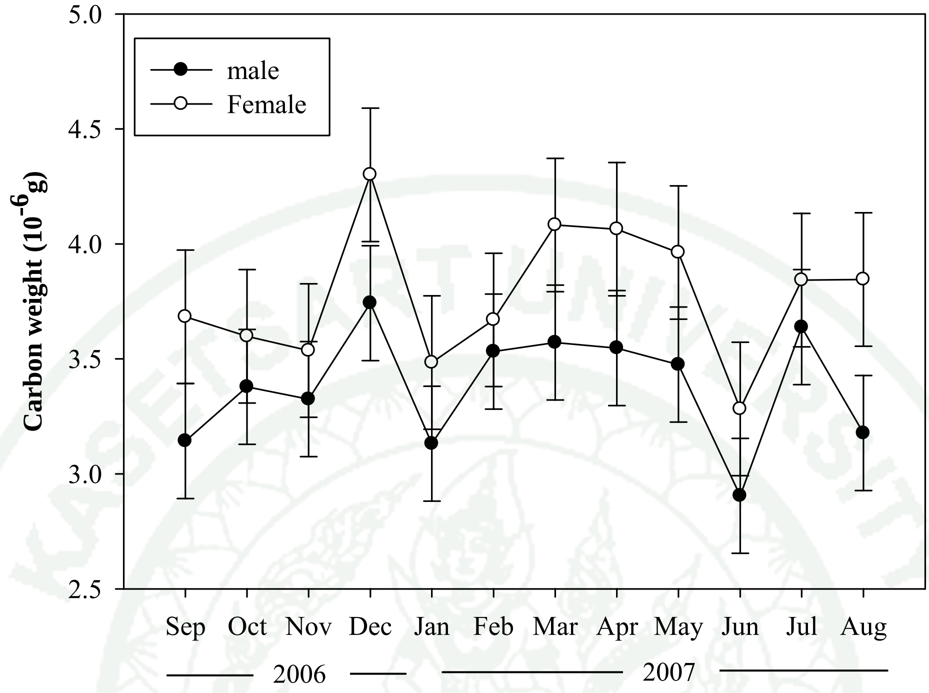


Figure 26 Temporal variation of mean carbon weight (μg) of *A. erythraea* in both male (920 – 980 μm in length) and female (1,010-1,110 μm in length) in Manao Bay, September 2006 to August 2007.

Average prosome lengths, dry weights, and carbon weights of copepodid stage 4 (CIV) and 5 (CV) were determined to pooled data from the total net samples. The prosome lengths of CIV ranged from 640 – 848 μm and average were 724 ± 41 μm (*n* = 504). The prosome length of CV ranged from 832 – 928 μm with average of 878 ± 26 μm (*n* = 601), respectively. Average dry weight and carbon weight of the C IV were average of 2.4 μg and 1.67 μg C, respectively. Average dry weight and carbon weight of CV were 3.7 μg and 2.56 μg C. Figure 27 shows the average carbon weight in each development stages (CIV, CV, male and female).

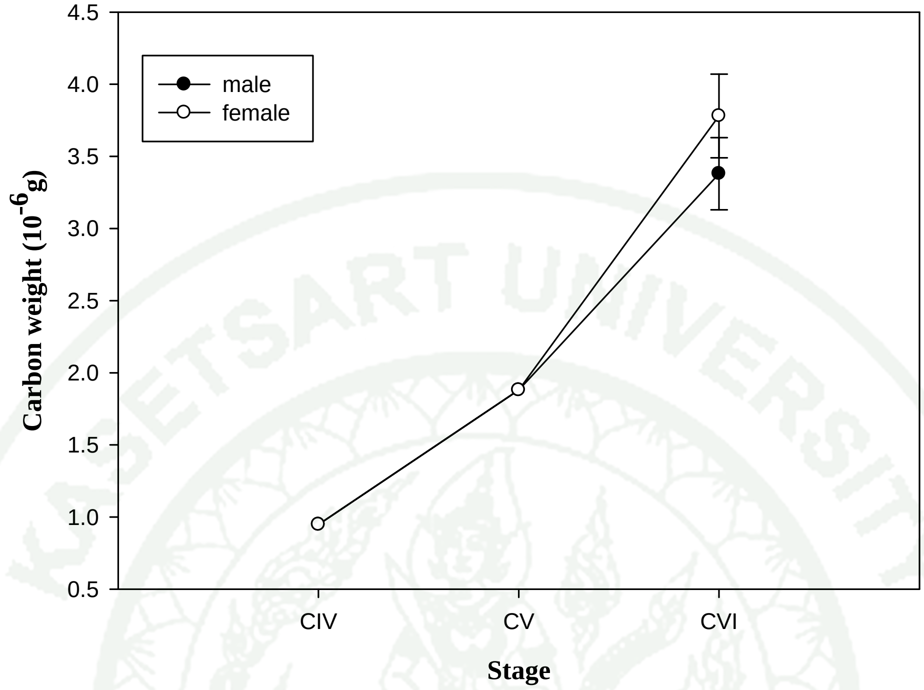


Figure 27 The average carbon weight of development stages of *A. erythraea* in Manao Bay; CIV (copepodid 4, 640-848 µm in length), CV (copepodid 5, 832-928 µm in length), CVI (adult: male, 920 – 980 µm in length and female, 1,010-1,110 µm in length).

The length and weight relationship of *A. erythraea* was determined based on size-classes. Adult male and female specimens were randomly separated, measured for their prosome length, and classified into the same length groups (Appendix Table 7). Dry weight and carbon weight of the same length group were analysed. Male were classified to 10 length groups: 724, 878, 880, 912, 928, 944, 960, 976, 992 and 1008 mm. and those of 12 length groups of female were 724, 878, 960, 992, 1008, 1024, 1040, 1056, 1072, 1088, 1120 and 1152 mm. All data were normal-log transformed, prior to the calculation. The length – carbon weight regressions were derived for copepodite stage 4 (CIV), copepodite stage 5 (CV), male, female, and adults (Table 15). Regressions coefficients (R^2) of the equations for male, female, and total adult were 0.83, 0.89 and 0.74, respectively. While the length and dry weight regression, the coefficients of determination (R^2) of male, female and total adult were 0.86, 0.94 and 0.75, respectively.

Table 15 Length-weight regressions for male, female and combined adults of *Acartia erythraea* in Manao Bay. *CW*: carbon weight (µg); *DW*: dry weight (µg); *L*: prosome length (µm); *n* = number of observations; int: intercept; *RMS*: residual mean square of the regression; P < 0.05.

Sex	Regression	*n*	SE int	SE slope	RMS	R^2
Male	$\ln CW = 3.64 \ln L - 23.9$	10	4.04	0.59	0.03	0.82
	$\ln DW = 4.02 \ln L - 25.66$	10	3.86	0.56	0.03	0.86
Female	$\ln CW = 2.96 \ln L - 19.38$	13	2.13	0.31	0.02	0.89
	$\ln DW = 3.19 \ln L - 20.22$	13	1.60	0.23	0.01	0.94
Total	$\ln CW = 2.48 \ln L - 16.1$	21	2.33	0.34	0.02	0.74
	$\ln DW = 2.66 \ln L - 16.5$	21	2.38	0.34	0.02	0.75

The average dry weight and carbon weight were calculated by random measuring in annual cycle to assume the conversion index. The average carbon weight was not equal to the average dry weight. The pooled data of the combined sex showed that the average carbon weight was lower than the average dry weight as 47% (*n* = 24). Figure 28 shows the average dry weights plotted against carbon weights of *A. erythraea* in Manao Bay. The scattered plots of both dry and carbon weight expressed the equation of carbon and dry weight was $CW = 0.471\ DW$. The carbon weight of copepod was lost about 53 % during the one year preservation in the formaldehyde – seawater buffered solution at 10 % of the final concentration.

The annual average length of males and females showed no seasonal variation. The prosome length of female was longer than male length by a factor of 1.11. Annual dry weight showed slightly fluctuation between male and female. But the carbon contents demonstrated the slightly variation with the exception in June 2007. The decreasing trends of male and female carbon weights might be that the early matured weights were examined. They might be lost the reserved food in terms of the lack of the quality food condition. The highly chlorophyll a concentration tend to be lower consumed by copepods in the coastal areas and estuarine (Calbet, 2001; Irigoien *et al.*, 2005). The chlorophyll a concentration showed the highest value (2.67 mg m^{-3}) in June 2007 may be the increasing of the short-lived nano- and pico- phytoplankton bloom (Kiørboe, 1993). Moreover, the turbulent condition interrupted the feeding habits (Siaz *et al.*, 1992; Kiørboe *et al.*, 1996).

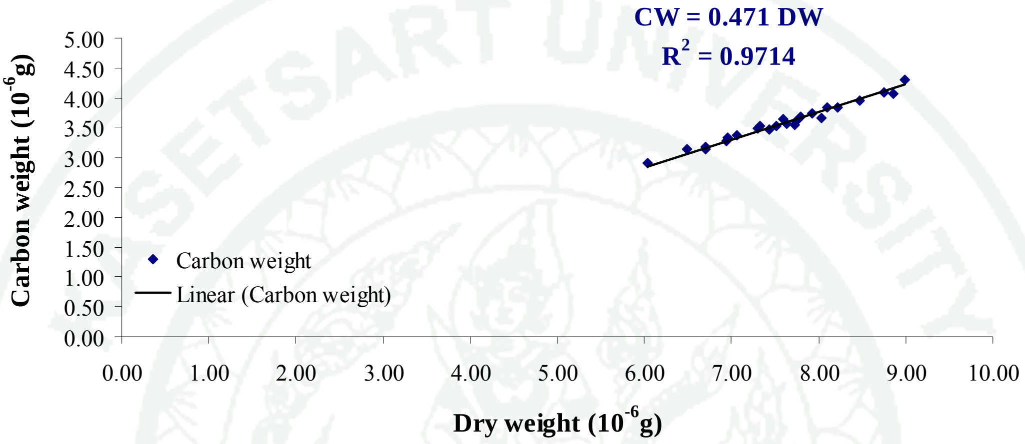


Figure 28 The scatter plot between dry weight (µg) and carbon weight (µg) of *A. erythraea* in Manao Bay, September 2006 to August 2007.

The measurement in prosome length and width were obtained from using eyepiece micrometer that might be the errors of determination. Weighing error might be due to the small specimens used. The dry and carbon weight of female *A. erythraea* was established by Liu *et al.* (2010) were about 5.2 ±0.2 µg and 3.03 ± 0.26 µg during summer in Hong Kong waters, respectively. The values were lower than those of this study and also showed the conversion factor for carbon weight as 57 % of its dry weight. However, Uye (1982) established the prosome female length of *A. erythraea* (1,109 µm) dry weight (11.5 µg) and carbon weight (4.97 µg) in Inland Sea of Japan were higher values than those of *A. erythraea* in the coastal areas of the upper Gulf of Thailand (Manao Bay). The larger body size and weight in temperate area that might be the effects of temperature and food available had influenced on copepods body weight and also reserved food in terms of oil sac in temperate animal (Durbin and Durbin, 1992). In addition, copepods in tropical areas had highly ingestion rate and short life span that expressed in their small size than those in the temperate zone (Kleppel and Hazzard, 2000; Calliari *et al.*, 2009; Liu *et al.*, 2010).

In the present study, the regression was compared with other observations of *Acartia* species in different areas (Table 16). For example, *Acartia* spp. off Lime Cay, Jamaica (Chisholm and Roff, 1990); *A. clausi* and *A. tsuensis* in Inland Sea, Japan (Uye, 1982). The length – dry weight equation was similar with the finding of Chisholm and Roff (1990) but the coefficient value was lower than their values.

Table 16 Regression equation of dry weight (*DW*, μg), carbon weight (*CW*, μg) and prosome length (*L*, μm).

Species	Equation	R^2	Author(s)
Acartia spp.	$\ln DW = 3.09 \ln L - 19.19$	0.92	Chisholm & Roff (1990)
A. clausi	$\log DW = 3.06 \log L - 8.12$	0.97	Uye (1982)
	$\log CW = 3.08 \log L - 8.51$	0.98	
A. tsuensis	$\log DW = 3.27 \log L - 8.88$	0.98	Uye (1982)
	$\log CW = 3.03 \log L - 8.52$	0.97	
A. erythraea	$\ln DW = 3.26 \ln L - 20.36$	0.69	This study
	$\ln CW = 2.79 \ln L - 17.34$	0.77	

The approximate dry weight of *Acartia* can be applied to the regression equation. The estimated scatter plots using various empirical equations for fitted the linear lines was shown in Figure 29 to compare length and weight regression. Though *Acartia* species do not differ in shape, their weights may fluctuate due to locations and slightly seasonal variation (Durbin and Durbin, 1992; Putland and Iverson, 2007).

The forecast lines of *Acartia* spp. for Chisholm-Roff equation and *A.erythraea* in this study showed similar pattern of length and dry weight. This result was remarkably similar with the empirical equations of Chisholm and Roff (1990) because both study areas are in tropical water. Uye's equations differed from this study because his study area was in the temperate zone (Inland Sea of Japan).

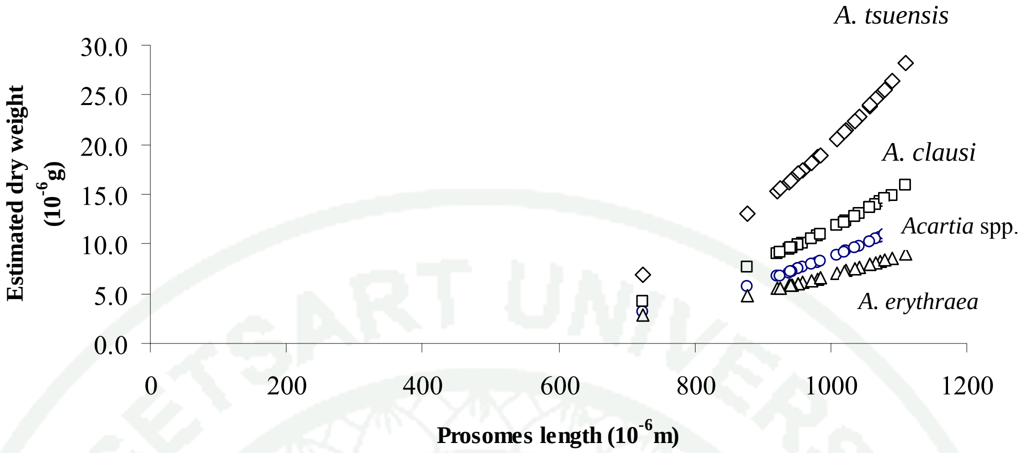


Figure 29 Comparison between the prosome length (µm) plot against the estimated dry weight (µg) using empirical equation.

3. Egg production rate of *A. erythraea*

Egg production rate (EPR) experiments of *A. erythraea* were carried out in both study areas: Manao Bay, Prachaup Khiri Khan Province and Si Racha Bay, Chon Buri Province. Water temperature, salinity, and fractionated chlorophyll *a* concentration were determined to correlate with the egg production rates. In addition, the *A. erythraea* communities were studied in January, March, May and August 2008 to provide data on copepod biomass in the same period as egg production studies. The experiments were carried out in the Southwest monsoon (May and August), the Northeast monsoon (January) and summer (March) in 2008.

A. Temperature, salinity, and fractionated chlorophyll *a* concentration

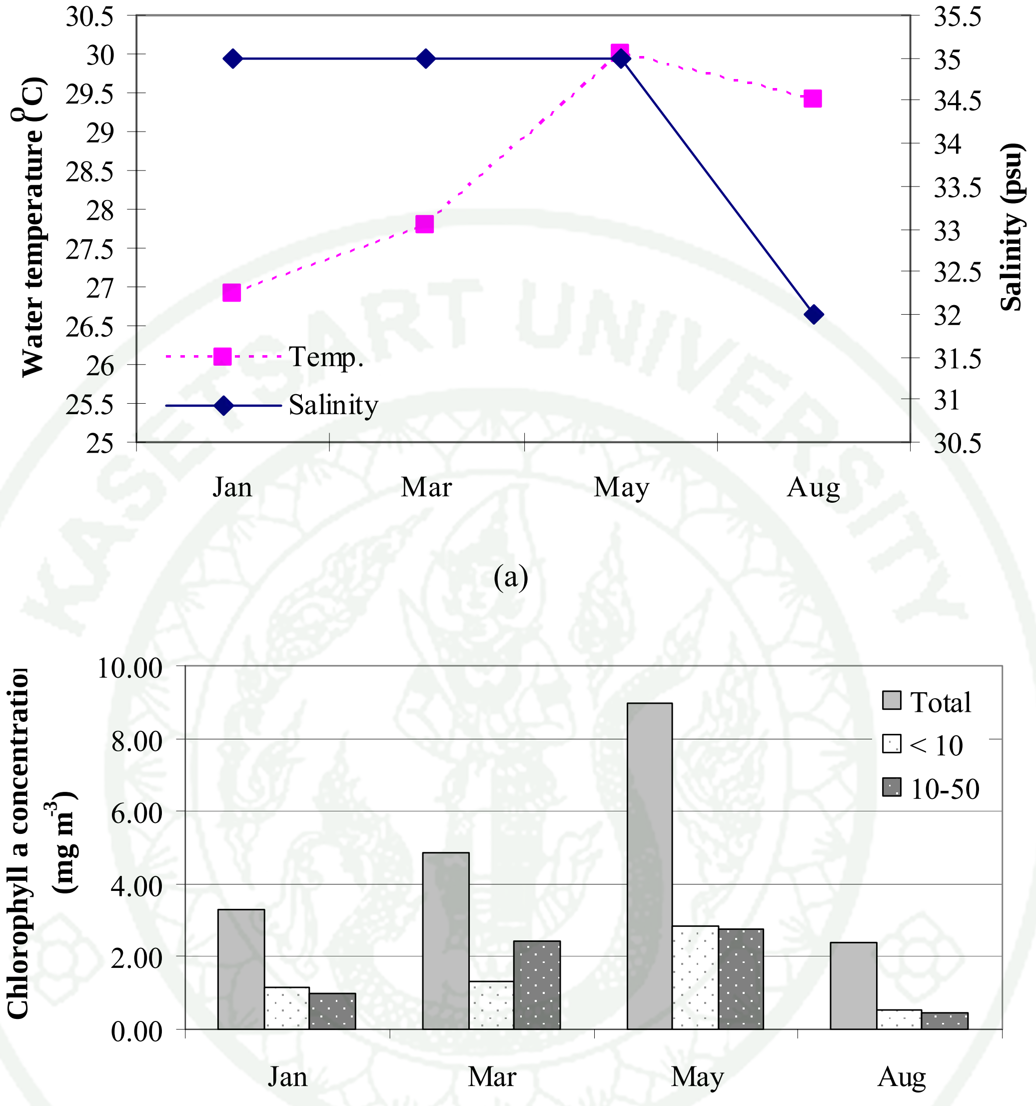
In the Manao Bay, water temperature ranged from 26.9°C in January to 30 °C in May 2008 (Figure 30), while salinity varied from 32 psu in August to 35 psu in January - May. Total chlorophyll *a* concentration fluctuated from 2.41 mg m^{-3} in August to 8.99 mg m^{-3} in May. Chlorophyll *a* of < 10 µm fraction contributed 22 – 34.78% (0.53-2.85 mg m^{-3}) of the total chlorophyll in the ambient seawater (Figure 30). Chlorophyll a 10-50 µm fraction contained 18.7 – 49.9 % (0.45 – 2.76 mg m^{-3}) of the total chlorophyll a concentration. Noticeable variation in chlorophyll a concentration was explained by dinoflagellates bloom (*Noctiluca scintillans* (Macartney) Kofoid &Swezy) in May 2008.

Variation of water temperature and salinity in Si Racha Bay was demonstrated in Figure 31. Temperature ranged from 27°C in May to 29.5 °C in August 2008. Salinity varied from 33 psu in May to August to 35 psu in March. Total chlorophyll *a* concentration fluctuated from 1.61 mg m^{-3} in May to 2.49 mg m^{-3} in January. Also, chlorophyll a of < 10 µm fraction contained 52.2 - 57.2 % (0.98-1.42 mg m^{-3}) of the total chlorophyll a concentration in the ambient seawater (Figure 31). Chlorophyll a 10-50 µm fraction contained 14.3 – 30.4 % (0.36 – 0.61 mg m^{-3}) of the total chlorophyll a concentration.

During the sampling period, the two study areas consistently showed high salinity (> 32 psu) but the value slightly decreased during the Southwest monsoon season. Water temperature fluctuated within a narrow ranged and it showed a slightly low value in January. The average monthly precipitation showed clear pattern following the two monsoon seasons.

B. Stage composition and abundance of *A. erythraea*

A. erythraea occurred in the zooplankton samples throughout the study period. Figure 32 presented total abundance from 200-µm mesh size samples during January and August 2008. In Manao Bay, total abundance of *A. erythraea* was rather low, ranged from 2 ind. m^{-3} in May to 41 ind. m^{-3} in January (average of 16±17 ind. m^{-3}), with one peak observed in January. Copepodid stages were the major component of *A. erythraea* abundance in this area (Figure 33). It composed of 86.5 % to the total abundance in January to 100 % in May. Percentage of adult stage to the total abundance of *A. erythraea* varied from 0 % in May to 13.5 % in January. Also, adult female was absent in January to May but reappeared in August with low abundance (0.2 ind. m^{-3}). Sex ratio (females/males) varied from 0-0.16 and adult male was absent in May. The raw data of abundance are presented in Appendix (Table 8). The pictures of *Acartia* in copepodid stage and adults are presented in Appendix (Figures 6-9).



(a)

(b)

Figure 30 Water temperature (°C) and salinity (psu) (a) and total chlorophyll a concentration, < 10 µm fraction and 10-50 µm fraction (mg m^{-3}) (b) in Manao Bay from January to August 2008.

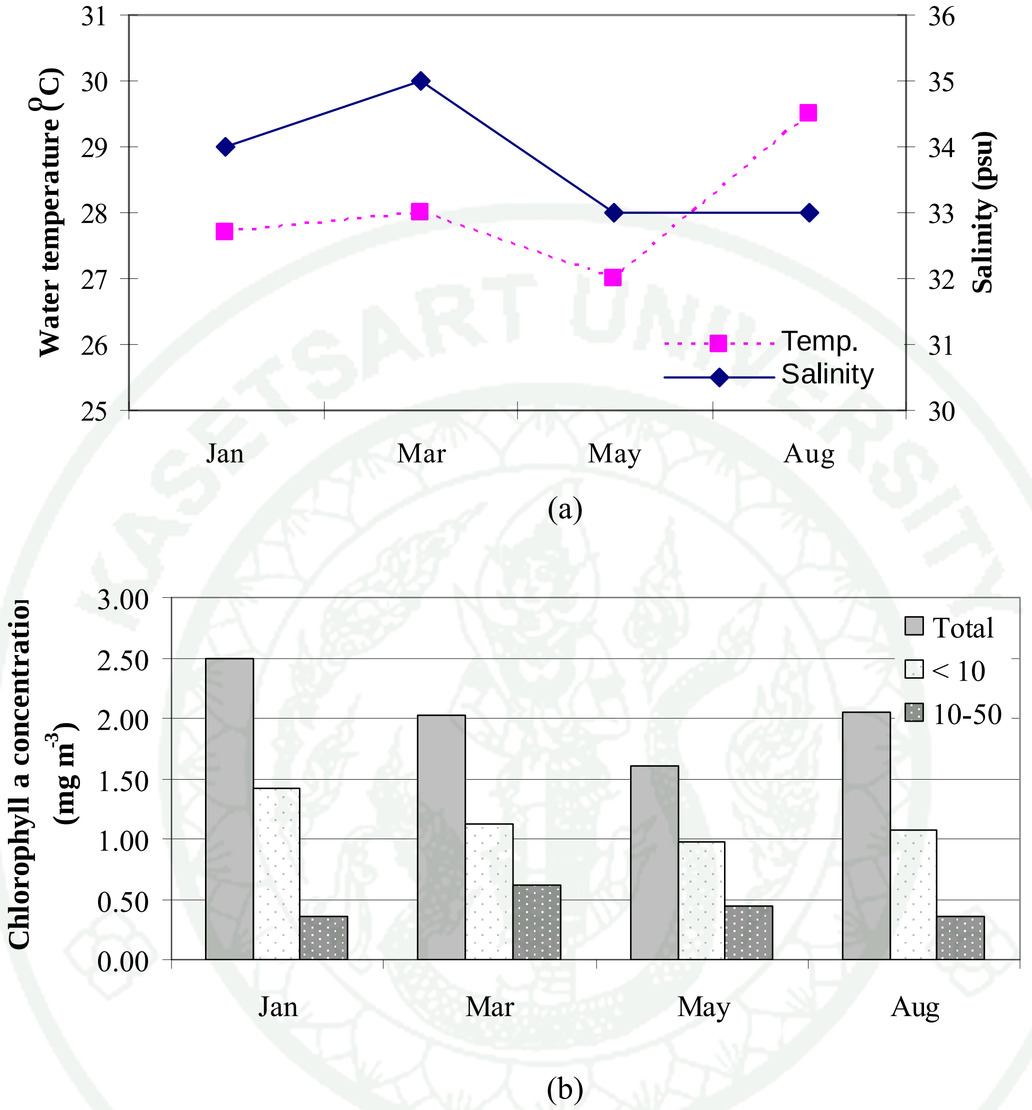


Figure 31 Water temperature (°C) and salinity (psu) (a) and total chlorophyll a concentration, < 10 μm fraction and 10-50 μm fraction (mg m^{-3}) (b) in Si Racha Bay from January to August 2008.

In Si Racha Bay station, total abundance of *A. erythraea* ranged from 2 ind. m^{-3} in January to 95 ind. m^{-3} in August (average of 34±43 ind. m^{-3}), with one peak in August 2008. The temporal abundance cycle was characterized by a sharp increasing from May to August (Figure 32). Abundance of copepodid stages varied from 44.4 % in March to 76.2 % in August 2008. Also, adults composed of 23.8 % to the total abundance of *A. erythraea* in August to 56.6 % in March. Moreover, sex ratio (females /males) varied from 0.46 – 1.8 and the composition of adult male were twice of female during January – August 2008 (Figure 33).

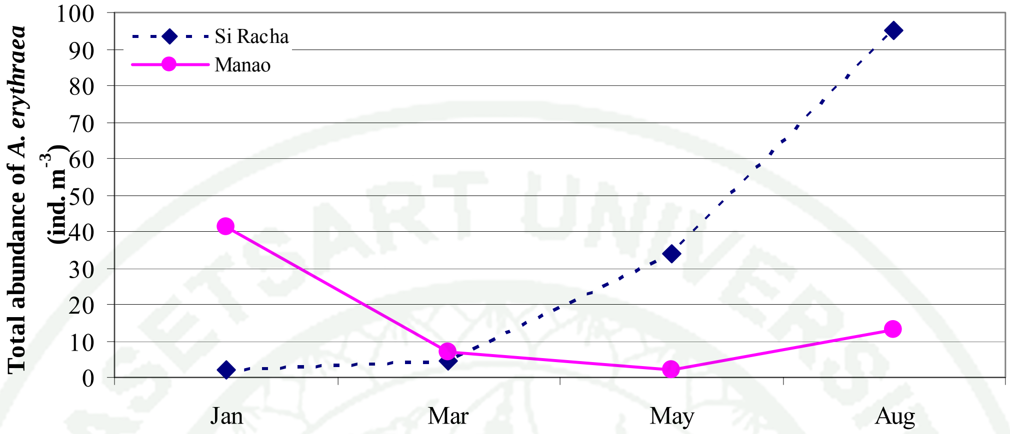
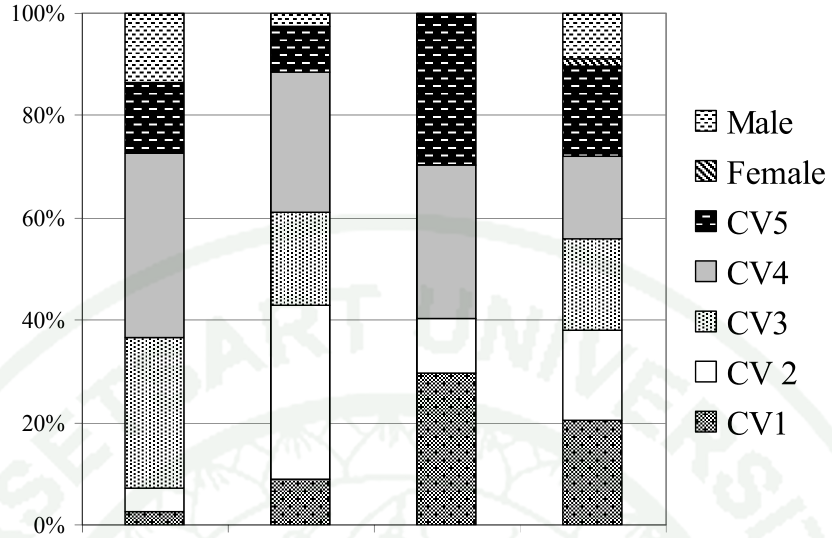


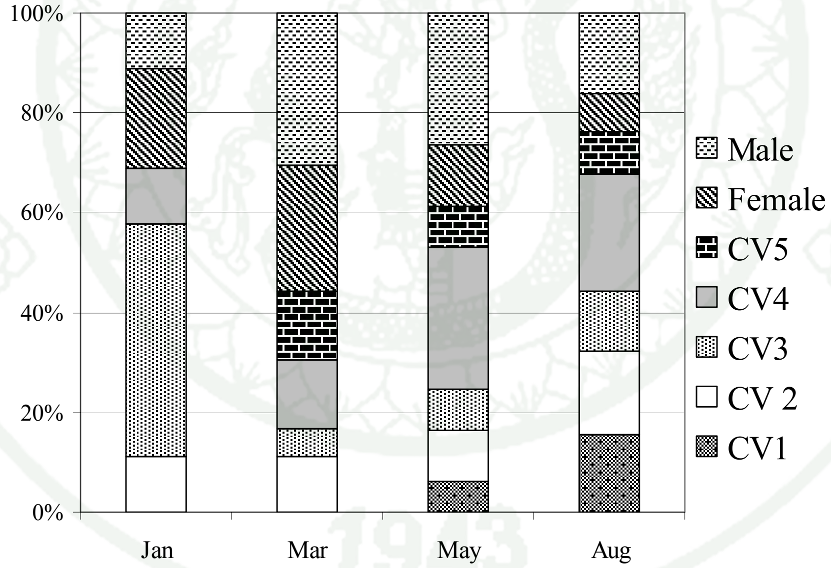
Figure 32 Total abundance of *A. erythraea* (ind. m^{-3}) in Manao Bay and Si Racha Bay, January to August 2008.

These results were compared with the previous studies. The frequently occurrence of *A. erythraea* were reported in the Gulf of Thailand by Fleminger (1963), Suwanrumpha (1980b; 1984), Pinkaew (2003) and Salakij (2009). It was a common neritic species widely distributed along the eastern and western coasts of the Gulf of Thailand. The average abundance value of *A. erythraea* was low in two study areas. The larvae, mostly copepodid stages, presented throughout the study period. They comprised up to 44.4 - 76.2 % of the total population in Si Racha Bay, and 86.5 –100% in Manao Bay.

This finding was similar with those reported by others for the inner Gulf of Thailand (Suwanrumpha, 1980; 1984; Jivaluk, 1999). The coastal water or neritic water is a nursing ground of marine organisms including copepods. Many studies establish that copepod nauplii and copepodid stages are the major components in the zooplankton population i.e. in the area of Mae Klong Estuaries (Boondao, 2006), Kham Islands (Panchote, 2005), the eastern coast of the Gulf (Srinui, 2007) and the Gulf of Thailand (Suwanrumpha, 1980b; 1984; Sribyatta, 1996; Jivaluk, 1999; Salakij, 2009).



(a)



(b)

Figure 33 Temporal contribution percentage of five stages and adult male and female in Manao Bay (a) and Si Racha Bay (b), based on 60 µm, January to August 2008.

The seasonal variation and species composition did not show any differences between the two monsoon seasons (Sribyatta, 1996; Jivaluk, 1999; Chuchit *et al*., 2005). Moreover, the temporal abundance of zooplankton including copepods showed high values during the Southwest and the Northeast monsoons. In this regard, the trend is similar with these study findings that the abundance of *A. erythraea* was high value during the monsoon seasons and decreased in March to May or summer.

The low relative abundance of *A. erythraea* and absence of adult male and female in some months (January – August 2008) might be due to the length of life span and impact of environmental parameters, particularly, strong tidal current. This result was similar with the study of *A. steueri* in Ilkwang Bay, Korea (Jung *et al*., 2004). Also an absence of pelagic copepods could be because of sampling equipments related to (mesh size of plankton net) patchy distribution of copepods (Dagg, 1977; Hopcroft and Roff, 1998; Hopcroft *et al*., 1998). Moreover, the high predation pressure by hydrozoans and ctenophores might be the result to rather low abundance of copepods. Many studies account the predation affecting to variability in zooplankton abundance (Burrell and Van Engel, 1976; Purcell, 1989; Purcell, 1992; Mills, 1995).

The higher abundance of adult male to that of female adult was in contrast to the study in *A. tsuensis* by Takahashi and Ohno (1996). Nevertheless, the adult male was mostly high abundant than adult female. They found high female sex ratio (average 75.2%) in the rearing experiments. Also, Corkett and McLaren (1978) reported that males of *Pseudocalanus* did not feed so they had also short life span. In this regards, the low sex ratio (female/male) and relative abundance could explain relatively low population of the *A. erythraea* in this study period. The low abundance of female is probably due to the regulation of the population to avoidance the unfavoured condition (Rodríguez *et al*., 1995).

C. Egg production rate

Daily egg production rate (EPR) of *A. erythraea* is shown in Table 17. Mean EPR ranged from 0 eggs female^{-1} d^{-1} in January to a maximum of 1.41 eggs female^{-1} d^{-1} in May 2008 in Manao Bay, with an average of 0.75 ± 0.77 eggs female^{-1} d^{-1}. The average EPR at Si Racha Bay was higher, 1.28 ± 1.06 eggs female^{-1} d^{-1}. Mean EPR varied between 0.02 eggs female^{-1} d^{-1} in January to a maximum of 2.49 eggs female^{-1} d^{-1} in March 2008 in Si Racha Bay. The average egg diameter was 80 μm. The raw data of EPR are presented in Appendix (Table 9).

Table 17 Daily egg production rate (EPR, eggs female^{-1} d^{-1}) of *A. erythraea* with minimum and maximum EPR, mean EPR, total number of female incubated, water temperature (Temp., °C) and Chlorophyll a concentration (Chl a, mg m^{-3}). in Manao Bay and Si Racha Bay.

Station/date	**EPR (eggs f^{-1} d^{-1})**	**Mean EPR ±SD (eggs f^{-1} d^{-1})**	**Total number of females incubated**	**Temp. (°C)**	**Chl a (mg m^{-3})**
Manao Bay					
26 Jan. 08	0	0	67	26.9	3.28
8 Mar. 08	0-4	0.47±0.25	45	27.8	4.87
10 May 08	0-12	1.41±0.62	43	30.0	8.99
23 Aug. 08	0-9	1.14±1.11	37	29.4	2.41
Average		**0.75 ± 0.77**			
Si Racha Bay					
18 Jan. 08	0-1	0.02±0.03	57	27.7	2.49
1 Mar. 08	0-7	2.49±0.52	47	28.0	2.02
4 May 08	0-4	0.74± 0.20	54	27.0	1.61
30 Aug. 08	0-10	1.87± 0.44	26	29.5	2.05
Average		**1.28 ± 1.06**			

Several tests were conducted to see if there were significant differences between EPR, months and study areas. The results showed that no different EPR between months (time) and study areas (Si Racha and Manao Bay) (*F test*, $P<0.05$). In this regards, all data were pooled and calculated to average EPR was 1.02 ± 0.94 eggs female^{-1} d^{-1} in the coastal areas of the upper Gulf of Thailand.

Pearson correlation showed positively significant between mean EPR to water temperature ($r = 0.99$, $P<0.05$) and total chlorophyll a concentration ($r = 0.53$, $P<0.05$) but mean EPR was unrelated to chlorophyll a concentration in any sized fraction in Manao Bay (Table 18). In Si Racha Bay, the correlation showed positively significant between mean EPR to water temperature ($r = 0.51$, $P<0.05$) and chlorophyll a 10-50 μm fraction ($r = 0.65$,

$P<0.05$) and negatively correlation between mean EPR and chlorophyll a <10 μm fraction (r = - 0.52, $P<0.05$).

Table 18 The Pearson correlation between mean EPR (eggs female^{-1} d^{-1}) and water temperature (°C) and fraction chlorophyll a concentration (Chl a con, mg m^{-3}) in Manao Bay and Si Racha Bay from January to August 2008 *$P<0.05$).

Parameters	**Mean EPR (eggs f^{-1} d^{-1})**	
	Manao Bay	**Si Racha Bay**
Water temperature (°C)	**0.99***	**0.51***
Total Chl a con (mg m^{-3})	**0.53***	-0.29
< 10 μm Chl a con	0.45	**-0.52***
10-50 μm Chl a con	0.23	**0.65***

Measurement of reproduction in planktonic copepod has not been determined in the coastal areas of the Gulf of Thailand. Few copepod studies have mostly focused on pelagic species in term of carbon contents, biomass and production in the Andaman Sea, western coast of Thailand (Satapoomin, 1999; Satapoomin *et al*., 2004). This study was the first report to determine the egg production rate of *A. erythraea* in the upper Gulf of Thailand. Mean EPR in this study (1.02 ± 0.94 eggs female^{-1} d^{-1}) was lower than the value of (13 eggs female^{-1} d^{-1}) by Checkley *et al*., (1992) in the Inland Sea of Japan. But the maximum EPR increased to 12 eggs female^{-1} d^{-1} at Manao bay in May 2008.

There are differences in EPR also may be regional or temporal differences. Table 19 show the mean EPR of *A. erythraea* in this study which was lower than other species of *Acartia*: *A.australis* in the Andaman Sea (Satapoomin *et al*., 2004), *A. clausi* in Gulf of Marseilles, France (Gaudy, 1971); Jakle's lagoon, USA (Landry, 1978); Onagawa Bay, Japan (Uye, 1981); Gulf of Naples, Italy (Ianora and Buttino, 1990); Barcelona Harbor, Spain (Saiz *et al*., 1992); Bahia Magdalena, Mexico (Gómez-Gutiérrez *et al*., 1999); the South of Côte d'Ivoire (Pagano *et al*., 2004), *A. grani* in Barcelona Harbor, Spain (Saiz *et al*., 1992); Málaga harbor, Spain (Rodríguez *et al*., 1995), *A. lilljeborgi* in Jamaica waters (Hopcroft and Roff, 1988); Bahía Magdalena, Mexico (Gómez-Gutiérrez *et al*., 1999); São

Paulo, Brazil (Ara, 2001), *A. longiremis* in Oregon, USA. (Gómez-Gutiérrez and Peterson, 1999), *A. omorii* in the Inland sea of Japan (Liang and Uye, 1996), *A. pacifica* in the Inland sea of Japan (Checkley *et al*., 1992), *A.steueri* in Onagawa Bay, Japan (Uye, 1981); Ilkwang Bay, Korea (Jung *et al*., 2004), *A. tranteri* in Westernport Bay, Australia (Kimmerer and McKinnon, 1987) and *A. tonsa* in Narragansett Bay, USA (Durbin *et al*., 1983); Long Island Sound, USA (Dagg, 1977); East Lagoon, USA (Ambler, 1985); Long Island Sound, USA (Peterson and Bellantoni (1987); Hunt's Bay, Jamaica (Hopcroft and Roff, 1988); La Habana Bay, Cuba (Zaballa and Gaudy, 1996); Florida Bay, USA (Kleppel & Hazzard, 2000); Laguna de Rocha, Uruguay (Calliari *et al*., 2009).

The estimation of *A. erythraea* egg production rate in the upper Gulf of Thailand showed relatively low egg production (0-2.49 eggs female $^{-1}$ d^{-1}) (Table 19). The analyses showed positively correlation between EPR of *A. erythraea* and water temperature and total chlorophyll a concentration in Manao Bay. But the correlation showed positively correlated with water temperature and negatively relationship to <10 μm chlorophyll a concentration fraction in Si Racha Bay.

In comparison with previous studies on other species of *Acartia* in coastal areas, the low EPR of *A. erythraea* was similar to EPR of *A. hudsonica* and *A. longiremis* (< 5 eggs female $^{-1}$ d^{-1}) off the Oregon coast, USA (Peterson *et al*., 2002). Additionally, the study by Kleppel and Hazzard (2000) mentioned the consistently low EPR of *A. tonsa* (Rankin Key: 3-16 eggs female $^{-1}$ d^{-1}; Duck Key: 1-12 eggs female $^{-1}$ d^{-1}) in Florida Bay.

Table 19 Daily egg production rate (EPR, eggs female^{-1} d^{-1}) of *Acartia* species with mean EPR, maximum EPR and Temperature (Temp., °C) in various regions.

Species	Mean EPR	Max. EPR	Temp.	Region	Author (s)
Acartia australis	1.3-2.1	36.9	28-30	Andaman Sea	Satapoomin *et al*., (2004)
A. clausi	0.6-31	75	17	France	Gaudy (1971)
A. clausi	7-25	70	20	Jakle's Lagoon, USA	Landry (1978)
A. clausi	ND	56	21.7	Onagawa, Japan	Uye (1981)
A. clausi	5-25	30	14	Gulf of Naples, Italy	Ianora&Buttino (1990)

Table 19 (Continiued)

Species	Mean EPR	Max. EPR	Temp.	Region	Author (s)
Acartia clausi	ND	75	17.5	Barcelona Harbor, Spain	Saiz *et al*., (1992)
A. clausi	10-60	ND	25-31	South of Côte d'Ivoire	Pagano *et al*., (2004)
A. erythraea	13	ND	26	Inland Sea of Japan	Checkley *et al*., (1992)
A. erythraea	**0-2.49**	**12**	**26.9 - 30**	**Upper Gulf of Thailand**	**This study**
A. grani	ND	48	17.5	Barcelona Harbor, Spain	Saiz *et al*., (1992)
A. grani	<5-79	115	18	Málaga bay, Spain	Rodríguez *et al*., (1995)
A.lilljeborgi	10.4-88	88	28	Kingston Bay, Jamaica	Hopcroft & Roff (1988)
A. lilljeborgi	2-13	18	19.8	Bahía Magdalena, Mexico	Gómez-Gutiérrez *et al*., (1999)
A.lilljeborgi	13.8-66.8	96	25.5	São Paulo, Brazil	Ara (2001)
A. longiremis	0-18	ND	ND	off Newport, USA.	Gómez-Gutiérrez & Peterson (1999)
A. omorii	26-60	ND	8.9-28.2	Inland sea of Japan	Liang and Uye (1996)
A. pacifica	9	ND	22	Inland sea of Japan	Checkley *et al*., (1992)
A.steueri	ND	56	21	Onagawa, Japan	Uye (1981)
A. steueri	3.9-10.1	ND	11.5-25.6	Ilkwang Bay, Korea	Jung *et al*., (2004)
A. tranteri	ND	12	20	Westernport Bay, Australia	Kimmerer &McKinnon, (1987)
A. tonsa	25.3	51.6	20	Narransansett Bay, USA	Durbin *et al*., (1983)
A. tonsa	10-50	50	15	Long Island Sound, USA	Dagg (1977)
A. tonsa	56	105	28	East Lagoon, USA	Ambler (1985)
A. tonsa	ND	81	19	Long Island Sound, USA	Peterson&Bellantoni (1987)
A. tonsa	69.8	99	28	Hunt's Bay, Jamaica	Hopcroft & Roff (1988)
A. tonsa	0.6-120	ND	22-31	La Habana Bay, Cuba	Zaballa & Gaudy (1996)
A. tonsa	11	ND	20-30	Florida Bay, USA	Kleppel&Hazzard (2000)
A. tonsa	38	83	13.8-26.1	Laguna de Rocha, Uruguay	Calliari *et al*., (2009)

The impact of environmental factors on EPR of *Acartia* species were also reported in temperate regions i.e. effect of temperature on *A . tonsa* (Durbin *et al*., 1983; Kiørboe *et al*., 1988); *A. clausi* and *A. steueri* (Uye, 1981); *A. longiremis* (Gómez-Gutiérrez and Peterson, 1999). On the contrary, Zaballa and Gaudy (1996) showed no correlation between EPR of *A. tonsa* and temperature, salinity and chlorophyll a concentration in La Habana Bay, Cuba.

Rates of egg production by female are influenced by a number of factors, the principle one being the availability of food (Mauchline, 1998). The low EPR are probably related to various factors, such as phytoplankton sizes (Peterson and Bellantoni, 1987), species composition and biochemical composition and the availability of microzooplankton (Irigoien *et al*., 2000a). Low chlorophyll a concentration or low available of food, and the quality of food might affect on the physiological process of female maturation e.g. the maturation of oocytes (Kiørboe *et al*., 1988; Zaballa and Gaudy, 1996).

Additionally, the proportion of edible size of phytoplankton cell should also be considered. Berggreen *et al.* (1988) establish the optimum particle sizes of food are 7-14 µm and 14-70 µm for *A. tonsa* nauplii and adult, respectively. Liu *et al*., (2010) has proposed the optimal food size for *A. erythraea* that was about 10 µm and also the dinoflagellate, *Prorocentrum minimum* was a good food for it. Another study by Wiadnyana and Rassoulzadegan (1989) showed their results that the preference of *A. clausi* selected on ciliated (*Strombidium sulcatum*) over diatom (*Thalassiosira weissflogii*) and dinoflagellate (*P. micans*) in mixture food. Similar with the study by Bollens and Penry (2003) mentioned that estuary heterotrophic prey contributed 50-60% of *Acartia* spp. diet in San Francisco. Those researches supported the predatory behaviour of omnivorous copepods that related to detecting the movement of prey (Kiørboe *et al*., 1996; Mauchline, 1998) and also the selective feeding of copepods on microzooplankton in most types of ecosystems (Calbet and Saiz, 2005).

The correlation between mean EPR and chlorophyll a concentration was difficult to prove in practice, though this result, the relationship between mean EPR and chlorophyll a concentration showed significantly correlated in both study areas. *Acartia* species were defined to be an omnivorous feeder (Landry, 1798; Anraku and Omori, 1963; Ohtsuka *et al*., 1996; Turner, 2004). They may prefer metazoans or microzooplankton to phytoplankton. Many study mentioned that they might be switched from suspension feeding in calm condition to carnivorous feeding on ciliates in turbulent conditions (Saiz *et al*., 1992; Kiørboe and Saiz, 1995). Evidently this result can not assume that chlorophyll a concentration was only related to mean EPR of copepods but the composition, quality and size of food are each important factors (Dagg, 1978; Peterson *et al*., 2002). Additionally, the ciliate protozoan and microzooplankton were also considered.

Mean EPR of *A. erythraea* in Si Racha Bay (1.28 eggs female $^{-1}$ d^{-1}) expressed higher value than that of *Acartia* in Manao Bay (0.75 eggs female $^{-1}$ d^{-1}). It might be the influene of food in term of ciliate protozoan than phytoplankton in the field because of the comparison between chlorophyll a concentration (total, <10 and 10-50 μm size fraction) in Si Racha Bay showed lower values than those in Manao Bay (Figures 30 and 31). Moreover, many researches show the EPR of copepods feeding on ciliates was significantly higher than that of copepods feeding on algae (Stoecker and Egloff, 1987; Wiadnyana and Rassoulzadegan, 1989; Kleppel and Hazzard, 2000; Miyashita *et al*., 2009). In addition, stusied the microzooplankton in Si Racha Bay based on the 60 μm mesh size. Chuchit *et al*. (2003) reported that tintinnids were the highest contribution of the total microzooplankton abundance and highly occurred throughout the annual period. Panchote (2005) also reported the highly diversity of tintinnids in Khram Island, the eastern coats of the upper Gulf of Thailand. Unfortunately, no record on microzooplankton was established in Manao bay and also in the adjacent areas.

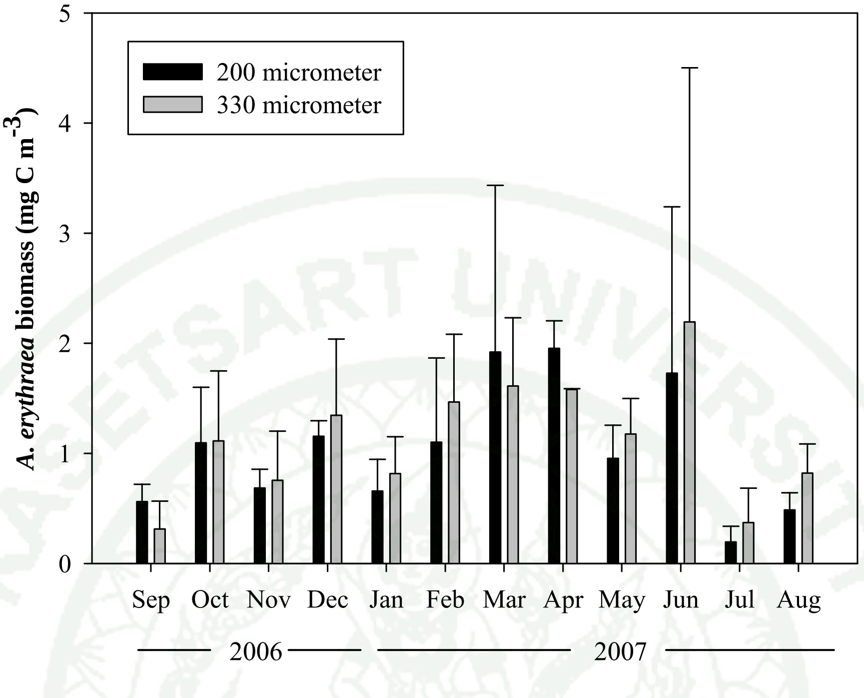
Noctiluca bloom observed in May at Manao Bay did not affect or inhibit on copepod egg production. On the other hand, the diatom bloom might be affect copepod reproduction in terms of aldehyde production or producing toxin (Paffenhöffer *et al*, 2005). Conversely, EPR may be affected by food availability in some species and not in others. Some laboratory studies suggested that high concentration of diatoms can lead to lower EPR and hatching rate (Kang and Poulet, 2000) but not in the incubation of *Calanus helgolandicus* that was observed during the diatom blooms (Irigoien *et al*., 2000b).

The small incubation chamber could stress on the female spawning (Ara, 2001). Consequently, *A. erythraea* was expressed as low EPR in the filtered seawater incubation. The results demonstrated that *A. erythraea* produced low eggs and established to low recruitment rate or production rate in the upper Gulf of Thailand. Seasonal variation did not change in reproductive rate of *A. erythraea* that might not induce variations in population with relationship between body length and weight (Chisholm and Roff, 1990). In neritic water, primary production is generally high so that *Acartia* may continuously produce eggs but in low rate (Hopcroft *et al*., 1998; Hopcroft and Roff, 1998; Miyashita *et al*., 2009).

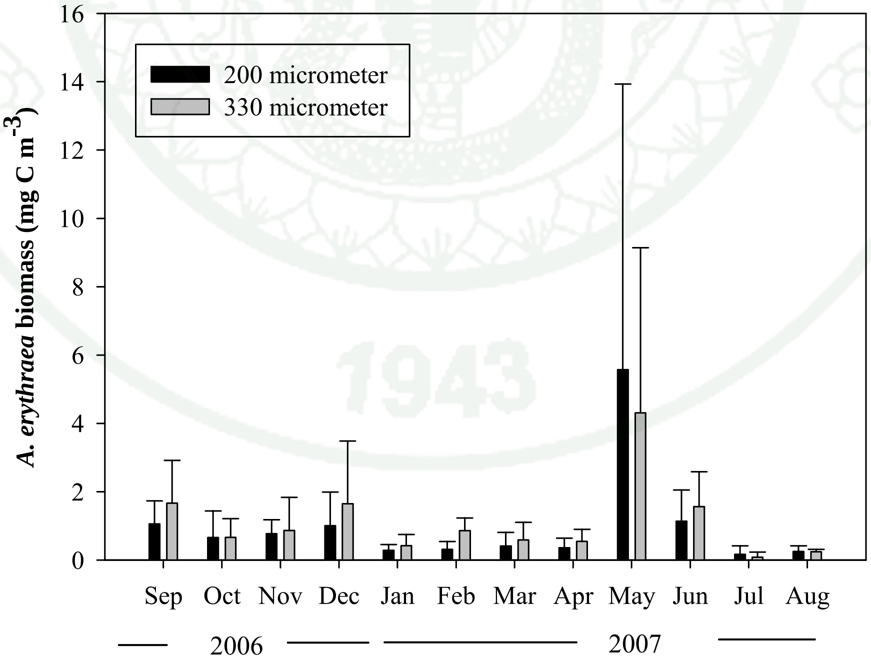
4. Biomass of *A. erythraea*

Measurement of the biomass of copepods per unit volume of water column in terms of dry body weight or carbon weight is useful in studies of biological production. The biomass of *A. erythraea* was determined in Manao Bay and Si Racha Bay from September 2006 to August 2007. Figure 34 shows the variation of *A. erythraea* biomass to total copepod community with comparison between two mesh size net samples in Manao Bay. The 200- µm net sample biomass varied 0.2 mg C m^{-3} in July 2007 to 1.95 mg C m^{-3} in April 2007. While the 330- µm net sample biomass distributed from 0.31 mg C m^{-3} in September 2007 to 2.19 mg C m^{-3} in June 2006. The average biomass of 330- µm net sample (1.13 ± 0.55 mg C m^{-3}) was higher than the biomass of 200- µm net sample (1.04 ± 0.57 mg C m^{-3}). The biomass showed homogeneously to abundance of *A. erythraea* over the sampling period. In conclusion, the average biomass of *A. erythraea* was equal to 7 % and 32 % of the total copepods abundance based on the 200- and 330- µm net sample, respectively.

The biomass of *A. erythraea* to total copepod community in Si Racha Bay was determined from September 2006 to August 2007 with two mesh size net samples (Figure 34). The biomass of the 200- µm net sample ranged from 0.17 mg C m^{-3} in July to 5.57 mg C m^{-3} in May 2007. The average was 1.0 ± 1.48 mg C m^{-3}. While the biomass of the 330- µm net sample varied from 0.09 mg C m^{-3} in July to 4.31 mg C m^{-3} in May 2007. The average was 1.12 ± 1.14 mg C m^{-3}. Also the average biomass of the 330- µm net sample was higher than the 200- µm net sample. In addition, the average biomass excluding the



(a)



(b)

Figure 34 Temporal biomass of *A. erythraea* (mg C m^{-3}) in Manao bay (a) and Si Racha Bay (b) with the comparison of two net samples, September 2006 to August 2007.

highest values in May, the average biomass of the 200- μm and 330- μm net sample were 0.68 ± 0.42 mg C m^{-3} and 0.88 ± 0.52 mg C m^{-3}, respectively. In conclusion, the average of *A. erythraea* abundance was equal to 6 % and 38 % of the total copepods abundance based on the 200- and 330- μm net sample, respectively.

Table 20 shows the seasonal variation of the average biomass of *A. erythraea* in Manao Bay and Si Racha bay. The biomass of *A. erythraea* changed seasonally in both areas. In Manao Bay, the average biomass of the 200- μm net sample was highest in summer period (1.94 ± 0.02 mg C m^{-3}), value decreased to 0.9 ± 0.26 mg C m^{-3} in the Northeast monsoon season and the values reduced to 0.84 ± 0.54 mg C m^{-3} in the Southwest monsoon season. On the contrary, biomass of the 330 - μm net sample showed the highest value in the Southwest monsoon season (1.28 ± 0.29 mg C m^{-3}), and decreased to 1.06 ± 0.98 mg C m^{-3} by the summer period and the lowest value (1.03 ± 0.27 mg C m^{-3}) was found during the Northeast monsoon season.

Table 20 The seasonal average biomass (mg C m^{-3}) of *A. erythraea* in Manao Bay and Si Racha bay, September 2006 to August 2007, * $P<0.05$.

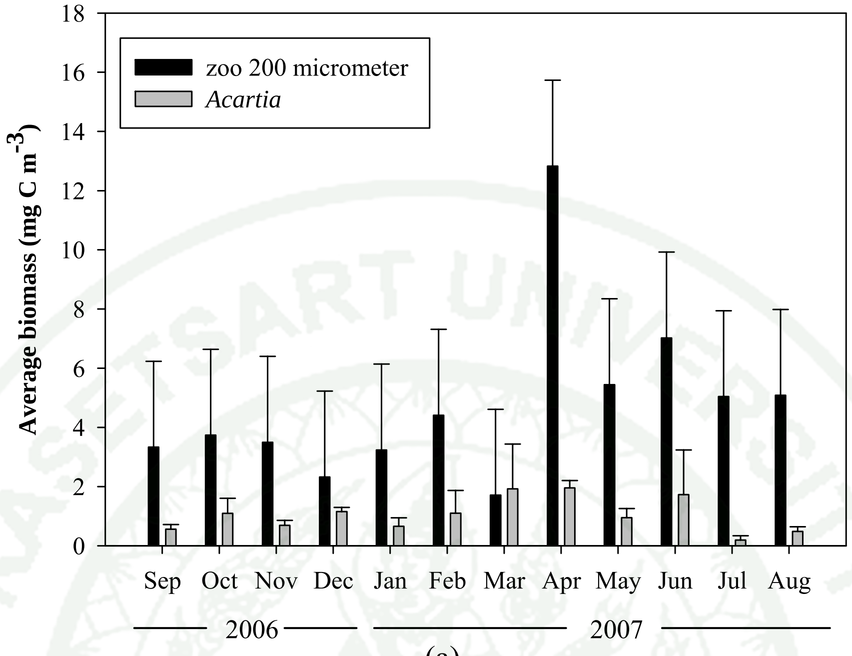
Areas	The 200- μm net sample			The 330- μm net sample		
	SW	NE	Summer	SW	NE	Summer
Manao Bay	0.84±0.54	0.90±0.26	1.94±0.02	1.28±0.29	1.06±0.98	1.03±0.27
Si Racha Bay	1.47±2.05	0.59±0.35	0.39±0.04	1.42±1.56	0.59±0.51	0.57±0.03

Remarks: SW: the Southwest monsoon season (May – October); NE: the Northeast monsoon season (November – February); summer (March-April).

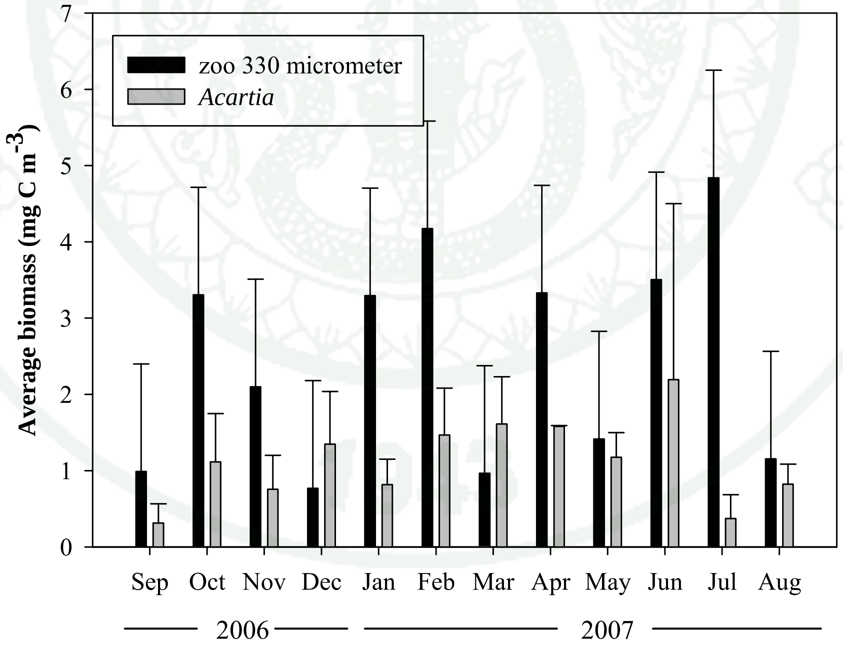
In Si Racha Bay, the seasonal variation of *A. erythraea* biomass showed high fluctuation that is presented in Table 20. The highest biomass of the 200- μm net sample was recorded during the Southwest monsoon season (1.47 ± 2.05 mg C m^{-3}), followed by the Northeast monsoon season (0.59 ± 0.35 mg C m^{-3}) and the summer period (0.39 ± 0.04 mg C m^{-3}), respectively. While the 330- µm net sample showed highest biomass in the Southwest monsoon season (1.42 ± 1.56 mg C m^{-3}), followed by the Northeast monsoon season (0.95 ± 0.51 mg C m^{-3}) and the summer period (0.57 ± 0.03 mg C m^{-3}), respectively. Interestingly, there were no differences between monsoon season and biomass of *A. erythraea* in both sampling areas.

In comparison with the total zooplankton biomass, the average biomass of 200-µm net zooplankton was 4.81 ± 2.91 mg C m^{-3}, with the minimum of 1.71 mg C m^{-3} in March 2007 to a maximum of 12.83 mg C m^{-3} in April 2007 in Manao Bay (Figure 35). The 330-µm net zooplankton biomass varied from 0.77 mg C m^{-3} in December 2006 to 4.84 mg C m^{-3} in July 2007, with an average of 2.49 ± 1.41 mg C m^{-3} (Figure 35). The average of *A. erythraea* biomass was equal to 21.43 % and 46.33 % of the total zooplankton biomass based on the 200- and 330- µm net sample, respectively. Figure 35 shows the comparison between the biomass of total zooplankton and *A. erythraea* during the sampling period. The raw data are available in Appendix (Table 10).

Figure 36 shows the total 200- µm net zooplankton biomass in Si Racha Bay which varied from 1.75 mg C m^{-3} in February to 11.76 mg C m^{-3} in July 2007. The average biomass was 5.65 ± 3.55 mg C m^{-3} in Si Racha Bay. Higher biomass values of net zooplankton were observed over the whole period of study. While the 330- µm net zooplankton biomass fluctuated from 0.48 mg C m^{-3} in November 2006 to 7.23 mg C m^{-3} in August 2007, with an average of 2.61 ± 1.98 mg C m^{-3} (Figure 36). Also the average of *A. erythraea* biomass was equal to 17.69 % and 43.05 % to the total biomass of the 200- and 330- µm net zooplankton in Si Racha Bay, respectively. The raw data are available in Appendix (Table 10).



(a)



(b)

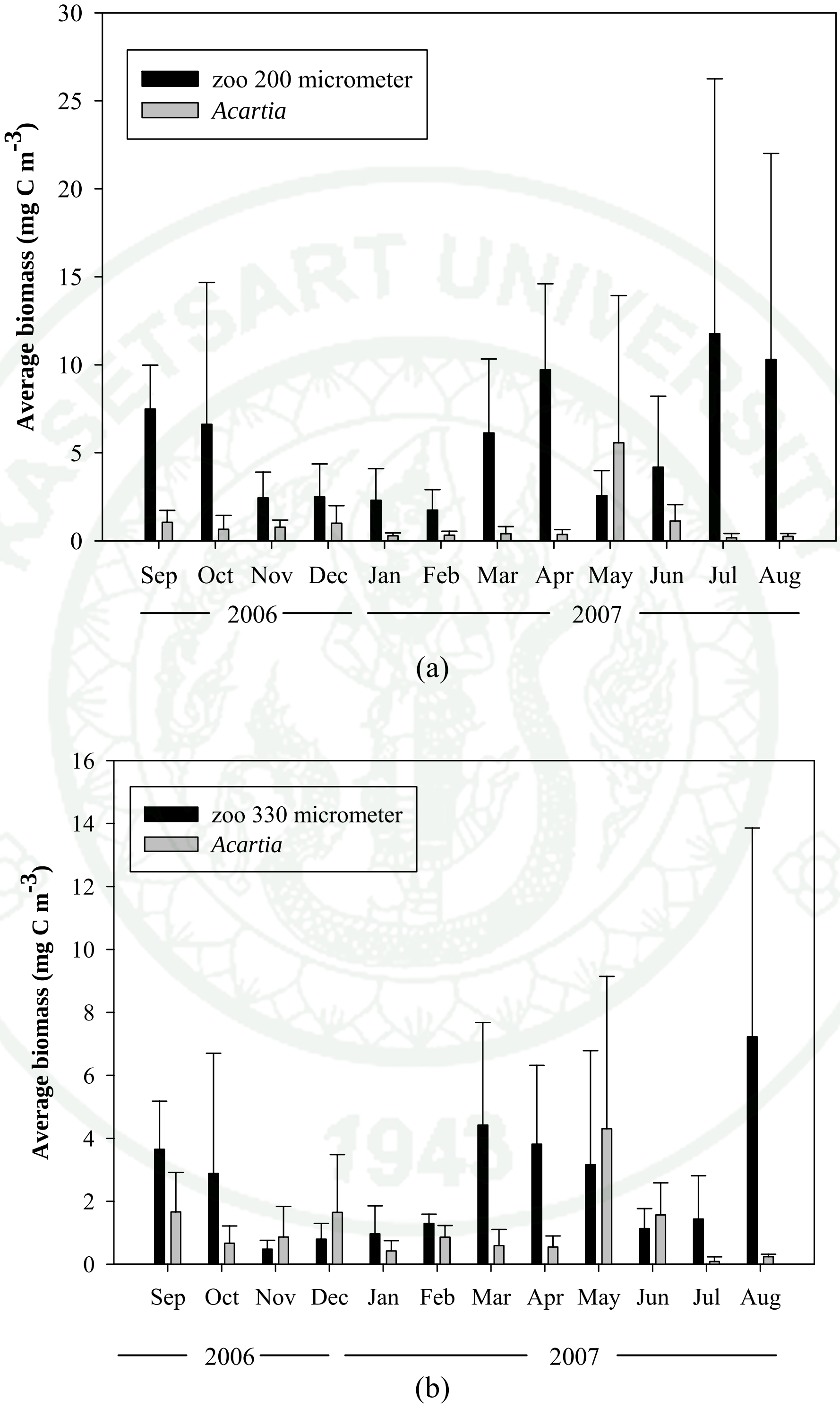
Figure 35 The variation in biomass (mg C m^{-3}) of the total 200 (a) and 330 (b) µm net zooplankton and *A. erythraea* in Manao Bay, September 2006 to August 2007.

Table 21 presents the comparisons of the total zooplankton and *A. erythraea* biomass and phytoplankton biomass with the two mesh size net samples in both sampling areas. The variation in biomass of the total zooplankton and *A. erythraea* showed no differences between mesh sizes. The carbon content of phytoplankton was determined from chlorophyll a concentration using a conversion factor of 40 (Parsons *et al*., 1984). The average chlorophyll a concentration was converted to phytoplankton carbon biomass (52 mg C m^{-3}) in Manao Bay. The average biomass of 200- and 330-µm nets *A. erythraea* equal to 2.0 % and 2.17 % of the total phytoplankton standing stock in Manao Bay, respectively. Moreover, the zooplankton biomass of 200- and 330- µm net equal to 9.25 % and 4.79 % to the total phytoplankton biomass, respectively. The biomass of total plankton community was 66.04 mg C m^{-3} in Manao Bay.

In Si Racha Bay, average chlorophyll a concentration was converted to phytoplankton carbon biomass equal 104 mg C m^{-3} also the 200- and 330- µm net of *A. erythraea* biomass equal to 0.96 % and 1.08 % of the total phytoplankton standing stock, respectively. While the total zooplankton biomass of 200- and 330- µm nets were equal to 5.43 % and 2.51 % to the total phytoplankton biomass, respectively. In addition, the total biomass of plankton community was 112.26 mg C m^{-3} in Si Racha Bay.

The value of total plankton community biomass was underestimated because small micro-zooplankton, such as small cyclopoid copepods and ciliated protozoans, can not be collected by 200 -µm plankton net. The phytoplankton and zooplankton biomass in Si Racha Bay showed significantly higher values than that of biomass in Manao Bay (*F-test*, *P*<0.05).

However, the biomass of *A. erythraea* was similar values in both study areas and two mesh size nets used. Average biomass of *A. erythraea* (1.0 mg C m^{-3}) based on the 200-µm net in this study was much higher than the biomass of *A. hudsonica* (0.004 mg C m^{-3}) and *A. longiremis* (0.03 mg C m^{-3}) in the Oregon coast, USA (Peterson *et al*., 2002). The tropical coastal water might expressed the highly metabolic rate in terms of ingestion rate and short life span of small copepods but contributes in the large abundance and biomass (Miyashita *et al*., 2009).



(a)

(b)

Figure 36 The variation in biomass (mg C m^{-3}) of the total 200 (a) and 330 (b) μm net zooplankton and *A. erythraea* in Si Racha Bay, September 2006 to August 2007.

Table 21 Annual average biomass (mg C m^{-3}) of phytoplankton, zooplankton and *A. erythraea*, September 2006 to August 2007.

Areas	**Phytoplankton biomass (mg C m^{-3})**	**Zooplankton biomass (mg C m^{-3})**		***Acartia erythraea*** **biomass(mg C m^{-3})**	
		200µm	**330µm**	**200µm**	**330µm**
Manao Bay	52±27.2	4.81±2.91	2.49±1.41	1.04±0.57	1.13±0.55
Si Racha Bay	104±93.2	5.65±3.55	2.61±1.98	1.0±1.48	1.12±1.14

5. Weight - specific growth rates of *A. erythraea*

The weight-specific growth rate of adult female *A. erythraea* was determined in laboratory from January to August 2008. The calculation was based on the carbon weight of eggs and adult female that were studied in Manao Bay. The carbon weight of eggs was predicted from direct measurement of egg diameters assuming a density of 0.14 µg C. µm^{-3} from Kiørboe *et al*. (1985). The average diameter of *A. erythraea* in this study was 80 µm, so the calculated egg carbon weight was 0.0375 µg C. The carbon weight of eggs could be calculated from the equation of Laing *et al*. (1994) based on the relationship of egg diameter and egg carbon weight. The latter carbon weight of eggs calculated from the equation: $C_E = 10^{-7.27} \times D^{3.04}$ was 0.03276 µg C. which was comparable value to the former one (0.0375 µg C). The weight-specific growth rate of *A. erythraea* ranged from 0.00 d^{-1} in January to 0.0133 d^{-1} in May 2008 in Manao Bay (Table 22). The average growth rate was 0.0072 ± 0.0061 d^{-1}. While the growth rate of *A. erythraea* in Si Racha Bay varied from 0.0002 d^{-1} in January to 0.0229 d^{-1} in March 2008 (average was 0.0121 ± 0.0103 d^{-1}).

For this result, the carbon weight was rather constant throughout the sampling period. As the EPR was strongly affected to the weight specific growth rate hence low egg production rate lead to low growth rate.

Table 22 Body weight of female (μg C), egg production (eggs f^{-1} d^{-1}) and weight specific growth rate (d^{-1}) of *A. erythraea* in Manao Bay and Si Racha Bay in 2008.

Area/Date	**Body weight of female (μg C)**	**Egg production rate (μg C f^{-1} d^{-1})**	**Weight specific growth rate (d^{-1})**
Manao Bay			
January	3.48	0	0
March	4.08	0.465	0.0043
May	3.96	1.41	0.0133
August	3.85	1.14	0.0111
			0.0072 ±0.0061
Si Racha Bay			
January	3.48	0.02	0.0002
March	4.08	2.49	0.0229
May	3.96	0.74	0.007
August	3.85	1.87	0.0182
			0.0121±0.0103

The comparison of female growth rate was considered from the published empirical equations for copepod growth rate proposed by Hirst and Lampitt (1998) for broadcast spawners as follows:

$$\mathrm{Log}_{10}\, g = 0.0087\ (T°C) - 0.4902\ (\log_{10} BW) - 0.7568$$

The estimated growth rate (average 28.5°C water temperature) showed an overestimated (0.11 d^{-1}) value which was more than 32 % in Manao Bay and 20 % in Si Racha Bay. In addition, the estimated CIV and CV copepodid stages using the Hirst-Lampitt model established the high values of growth rate for copepodid stages. The growth rate of CIV and CV copepodid stages were estimated to 0.38 and 0.31 d^{-1}, respectively. In general, the development stages (CI-CV) express the higher growth rate than the adult female. Therefore, the overestimated growth rate using the empirical model should not be accurate results when the water temperature is not likely to correlate with growth, body weight and reproductive rate of the small tropical planktonic copepods (Kiørboe and Sabatini, 1995; Hirst and Lampitt, 1998; Peterson *et al*., 2002; Miyashita *et al*., 2009).

Table 23 shows the weight specific growth rate of 6 species within genus *Acartia*. The weight specific growth rate of *A. erythraea* in this study was much lower than 5 other species: *A. lilljoborgi* and *A. tonsa* (Hopcroft and Roff, 1998); *A. longiremis* (Peterson *et al*., 1991; Gómez-Gutiérrez and Peterson, 1999); *A. hudsonica* and *A. longiremis* (Peterson *et al*., 2002) and *A. steueri* (Kang and Kang, 1998; Jung *et al*., 2004).

The pattern of positively relation of growth rate to body weight was found in this study. But this pattern did not agree with the findings of Kiørboe and Sabatini (1995) and Hopcroft and Roff (1998) that the growth rates were negatively related to female weight but positively related to chlorophyll a in the > 2 μm size fraction.

Table 23 Comparison of weight specific growth rate (d^{-1}) among *Acartia* species.

Species	**Temperature (°C)**	**weight specific growth rate (d^{-1})**	**Authors**
Acartia hudsonica	7	0.03	Peterson *et al*., 2002
A. lilljoborgi	28	0.14-0.82	Hopcroft and Roff, 1998
A. longiremis	10-13	0.01-0.02	Gómez-Gutiérrez and Peterson, 1999
A. longiremis	7-16	0.03-0.13	Peterson *et al*., 1991
A. longiremis	11-12	0.01-0.09	Peterson *et al*., 2002
A. steueri	11-25.4	0.064	Kang and Kang, 1998
A. steueri	11.5-25.6	0.047	Jung *et al*., 2004
A. tonsa	28	0.87	Hopcroft and Roff, 1998
A. erythraea	**28.5**	**0.0072-0.0121**	**This study**

6. Secondary production of *A. erythraea*

The secondary production of *A. erythraea* was estimated from growth rate and biomass from January to August 2008. The average secondary production was 0.014 ± 0.025 mg C m^{-3} d^{-1} in Manao bay and 0.503 ± 0.646 mg C m^{-3} d^{-1} in Si Racha Bay. Table 24 shows the variation in secondary production between two study areas that varied in sampling times. The values varied from 0 – 0.052 mg C m^{-3} d^{-1} in Manao Bay. In Si Racha bay, the secondary production ranged from 0.0005 – 1.448 mg C m^{-3} d^{-1}. The secondary production of *A. erythraea* in Si Racha Bay was significantly higher than that value in Manao Bay (*F test*, $P<0.001$).

The turnover rate (P/B ratio) of *A. erythraea* was calculated from the secondary production rate and biomass in both study areas. Table 24 shows the variation in turnover rate of *A. erythraea* in Manao Bay and Si Racha Bay. The values varied from 0 – 0.011 d^{-1}, average with 0.005 ± 0.006 d^{-1} and ranged from 0 – 0.023 d^{-1}, with average of 0.0121 ± 0.01 d^{-1}, respectively.

Table 24 Secondary production (mg C m^{-3} d^{-1}) and turnover rate (d^{-1}) of *A. erythraea* in Manao Bay and Si Racha Bay in 2008.

Date	**Manao Bay**		**Si Racha Bay**	
	Secondary production (mg C m^{-3} d^{-1})	**Turnover rate** (d^{-1})	**Secondary production** (mg C m^{-3} d^{-1})	**Turnover rate** (d^{-1})
January	0	0	0	0.00022
March	0.000003	0.0043	0.00022	0.023
May	0	0	0.000343	0.007
August	0.000052	0.0111	0.001448	0.018
Average	**0.000014**	**0.005**	**0.000503**	**0.0121**
SD	0.000025	0.006	0.000646	0.0103

In conclusions, table 25 shows the comparison in the biomass (mg C m^{-3}), weight specific growth rate (d^{-1}), secondary production rate (mg C m^{-3} d^{-1}) and turnover rate (d^{-1}) of *A. erythraea* in Manao Bay and Si Racha bay, January to August 2008. These data indicated secondary production of planktonic copepods in coastal areas of the upper Gulf of Thailand where *A. erythraea* was dominant and provided the low secondary production rate.

Table 25 Biomass (mg C m^{-3}), weight specific growth rate (d^{-1}), secondary production rate (mg C m^{-3} d^{-1}) and turnover rate (d^{-1}) of *A. erythraea* in Manao Bay and Si Racha bay, January to August 2008.

Parameter	**Manao Bay**	**Si Racha Bay**	**Average**
Biomass (mg C m^{-3})	0.006 ± 0.009	0.035 ± 0.036	0.02 ± 0.02
Growth rate (d^{-1})	0.0072 ± 0.0061	0.0121 ± 0.0103	0.0096 ± 0.0066
Secondary production rate (mg C m^{-3} d^{-1})	0.000014 ± 0.00003	0.0005 ± 0.00065	0.0003 ± 0.00034
Turnover rate (d^{-1})	0.005 ± 0.006	0.0121 ± 0.01	0.009 ± 0.007

Table 26 compares the secondary production rate of *Acartia* species in different areas. The production of small species represented only a few percentage of the total community production. Low production rate was due to those species having low growth rate or low biomass (Peterson *et al*., 2002).

Table 26 Comparision on secondary production rate (mg C m^{-3} d^{-1}) and the production biomass (P/B) ratio of *Acartia* spp.

Species	**Secondary production (mg C m^{-3} d^{-1})**	**P/B ratio (d^{-1})**	**Authors**
Acartia hudsonica	0.0001	0.025	Peterson *et al*. (2002)
Acartia longiremis	0.003	0.10	Peterson *et al*. (2002)
Acartia erythraea	0.0003	0.009	This study

In conclusion, this is the first study to estimate effects of pelagic environments on biological processes of a single species (A. erythraea) or planktonic copepod in two coastal areas. The results showed that similar average of the following values were obtained in both areas: abundance, biomass, EPR, weight specific growth rate, secondary production and turnover rate (P:B ratio). The secondary production of small copepods might be limited by varieties of interationg factors, such as food supplies, water temperature and salinity.

Moreover, hydrographic parameters and biotic factors could limit primary and secondary productions and consequently changes plankton community.

7. Application to trophic dynamics

To demonstrate the food chain structure among the two study areas, the annual average biomass of phytoplankton and zooplankton were compared in terms of production rate from September 2006 to August 2007. Average production rate was calculated in order to obtain trophic structures of plankton communities in the study areas. Food web structure was simplified into a food chain (Figure 37 a, b). Annual average phytoplankton biomass was calculated from chlorophyll *a* concentration based on a conversion factor of 40 (Parsons *et al*., 1984). The herbivorous and ½ of omnivorous zooplankton biomass was obtained from the 200-µm net zooplankton. And also carnivorous and ½ of omnivorous zooplankton biomass was estimated from the 330-µm net zooplankton (Peterson *et a*l., 2002; Hayashita and Uye, 2008).

To examine the potential carbon flow from producers to consumers, the gross growth efficiency of each trophic level was used. The gross growth potential of zooplankton was estimated from the amount of carbon required by consumers to support their production rates (Krebs, 2009). The gross growth efficiency was calculated using the value of 0.3 for metazoans (Ikeda and Motoda, 1978). The growth rate was generalized to estimate from *A. erythraea* in Manao Bay (0.0076 d^{-1}) and in Si Racha Bay (0.0126 d^{-1}). In the present study, the estimated trophic structures do not include bacteria, detritus feeders and protozoan micro-zooplankton.

The relationship of carbon biomass of primary producer, secondary and tertiary consumers and their trophic structures for Manao Bay and Si Racha Bay are shown in Figure 37 a and b. In Manao Bay the biomass of total phytoplankton was 52 mg C m^{-3} and the daily carbon requirement of secondary zooplankton was 0.025 mg C m^{-3} d^{-1} or equal to 0.048 % of the phytoplankton biomass. The daily carbon requirement by tertiary zooplankton was 0.029 mg C m^{-3} d^{-1} or corresponds to 0.6 % of the total secondary zooplankton. Also the transfer efficiency from the secondary to tertiary production was about 160 % in Manao Bay.

In Si Racha Bay, the total carbon phytoplankton biomass (104 mg C m^{-3}) was higher than those in Manao Bay. Daily carbon requirement of secondary consumers was 0.042 mg C m^{-3} d^{-1}, equal to 0.04 % of the total primary producer biomass. The tertiary consumers required 0.047 mg C m^{-3} d^{-1} or 0.83 % of the secondary consumer biomass. Finally, the transferring efficiency from secondary to tertiary production was 112 % in Si Racha Bay.

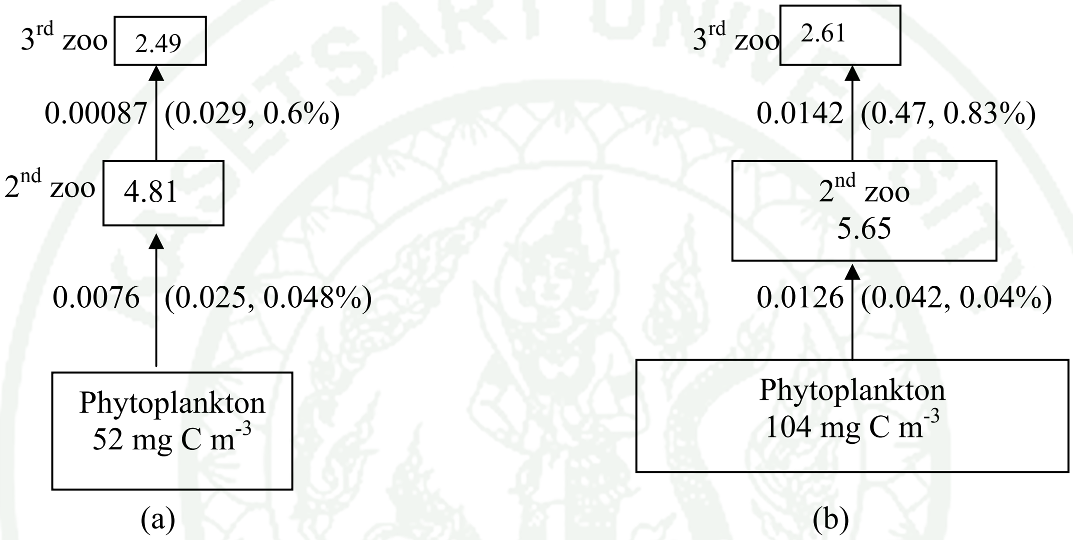


Figure 37 Daily carbon flow through plankton community in Manao Bay (a) and Si Racha Bay (b). Values in boxes denoted biomass (mg C m^{-3}); those with arrows are daily production rate (mg C m^{-3} d^{-1}); (those between parentheses are daily requirements (mg C m^{-3} d^{-1}); 2nd zoo: secondary producers; 3rd zoo: tertiary consumers.

If the measured growth rate of *A. erythraea* was typical for the tropical coastal zooplankton, the estimated values for food chain efficiency and ecological efficiency should be constant throughout the annual cycle. However, the estimations were probably underestimated because it did not include important groups, especially microzooplankton and detritus feeders that were major trophic linkage between primary producers and secondary consumers. Thus, the total food chain efficiency for the upper Gulf of Thailand need to be further assessed.

For *Acartia*, the potential carbon flow from producers to *Acartia* was estimated in both study areas in 2008. The gross growth efficiency was estimated from the average value of 0.33 in *A. clausi* in turbulence condition (Saiz *et al.*, 1992). The average growth rate in Manao Bay and Si Racha Bay was 0.0072 d^{-1} and 0.0121 d^{-1}, respectively. The biomass of total phytoplankton in Manao bay and Si Racha Bay were 195.2 mg C m^{-3} and 81.6 mg C m^{-3} in 2008, respectively.

The daily carbon requirement of *Acartia* in Manao Bay (0.022 mg C m^{-3} d^{-1}) was lower than that value in Si Racha Bay (0.037 mg C m^{-3} d^{-1}) or equal to 0.011 % and 0.045 % of the phytoplankton biomass, respectively. Consequently the carbon requirement of *Acartia* was related to the egg produced per day and weight of female (Saiz *et al.*, 1992). Regarding to this omnivorous copepods showed relatively low carbon requirement from the primary producer. Therefore the carbon source might be received from ciliates other than phytoplankton in the coastal areas of the upper Gulf of Thailand.

Although this model can not be completed, it will probably help to develop a clearer understanding of secondary production in the upper Gulf of Thailand, or tropical area as well. This is the first study of *A. erythraea* in ecological aspects to generate the information on the growth pattern and secondary production and also may provide a better understanding of the tropical pelagic ecosystems.

8. Hydrographical variables and nutrients

The annual cycle in the hydrographical data and nutrient values were measured twice a month in Manao Bay, Prachuap Khiri Khan Province (the upper western coast) and Si Racha Bay, Chon Buri Province (the inner eastern coast) (Figure 10). The studies were carried for 12 months from September 2006 to August 2007. The data were pooled in 6 stations of 2 transect lines within 3 sampling zones (inner, middle and outer stations) in both study areas. The raw data in the hydrographical data and nutrient values are available in the Appendix (Tables 11 and 12).

A. Water temperature

The average water temperature was 29.7 ± 1.6 °C in the upper Gulf of Thailand in annual cycle. The water temperature ranged between 26.0 °C in January 2007 to 31.4°C in

June 2007 in Manao Bay (Figure 38). The mean was 29.4 ± 1.5°C (mean± SD). Figure 38 shows the water temperature that fluctuated in narrow range. The significant higher temperature values than mean were recorded in April to June 2007 and the lower value than those were recorded in January to February 2007 in the upper western coast.

In the inner eastern coast, the water temperature ranged between 26.1°C in January 2007 and 31.7°C in April 2007 and showed no distinct seasonal variations that a slightly decreased in January to February 2007 (Figure 38). The mean of water temperature was 30.0 ± 1.7 °C. The significant difference of water temperature was found in January to February.

To compare with the two coast of the upper Gulf of Thailand, the annual water temperature showed the similar patterns. And also the average values between the western and eastern coast did not significantly differed. Water temperature showed distinct seasonal variations. The high water temperature was recorded during the Southwest monsoon and summer period. The decreasing temperature was recorded in January to February 2007 during the Northeast monsoon season.

B. Salinity

Average salinity was 27 ± 5 psu in the coastal areas of the upper Gulf of Thailand. In the upper western coast, salinity values varied from 21 psu in June 2007 to 31 psu in November 2006 in Manao Bay (Figure 39). The mean value was 29 ± 3 psu. The temporal variation in salinity showed significant differences in June to September or November during the Southwest monsoon.

In the eastern coast, salinity values were relatively highly fluctuated that varied from 14 psu in October 2006 to 33 psu in January –February 2007 (Figure 39). Mean of salinity was 25 ± 6 psu. Monthly values were less variable during the Northeast monsoon than during the Southwest monsoon.

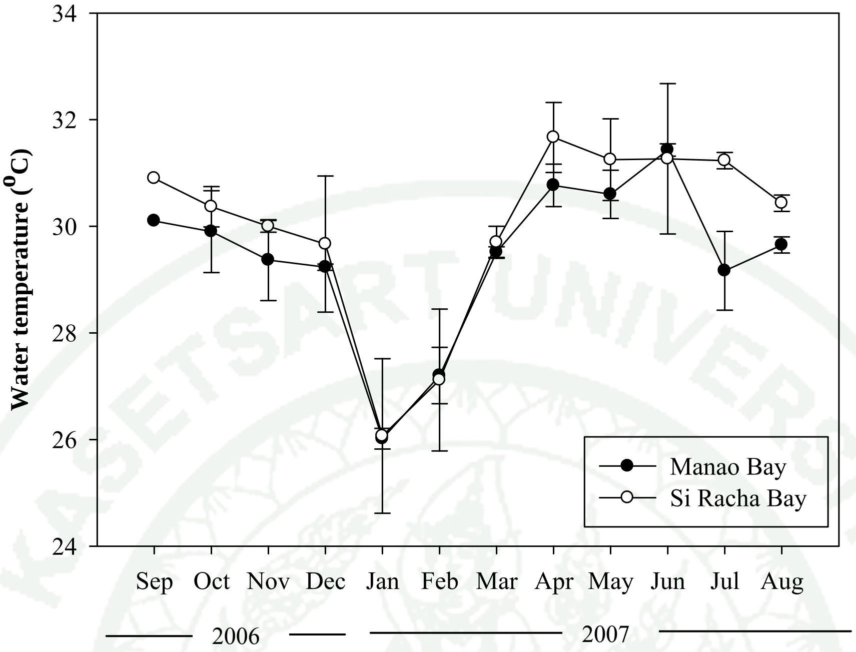


Figure 38 The average water temperature (°C) in Manao Bay and Si Racha Bay, September 2006 to August 2007.

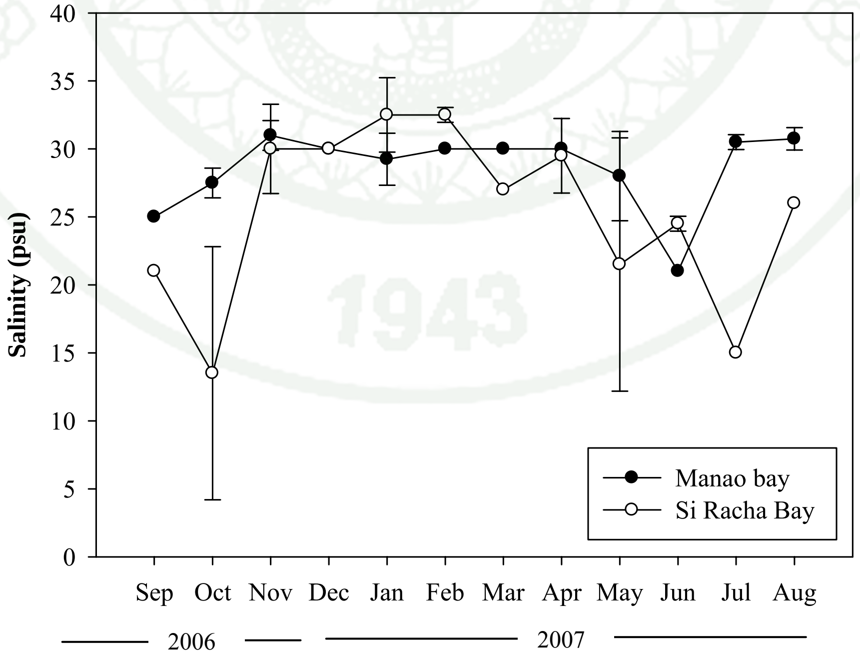


Figure 39 Temporal average salinity (psu) in Manao Bay and Si Racha Bay, September 2006 to August 2007.

To compare between the western and eastern coasts, average salinity in the western coast (Manao Bay) was higher than the average value in the eastern coast (Si Racha Bay). The seasonal variation in salinity showed similar patterns in two coasts of the upper Gulf of Thailand. The high value during the Northeast monsoon season and summer period also the low values were recorded during the Southwest monsoon season. In addition, salinity varied with the rainfall because of two study areas has no freshwater runoff from river.

C. Dissolved oxygen

Average dissolved oxygen was 7.4 ± 1.3 mg l^{-1} in the coastal areas of the upper Gulf of Thailand. In Manao Bay, dissolved oxygen varied between a minimum of 5.0 mg l^{-1} in September 2006 and a maximum of 10.7 mg l^{-1} in August 2007 (Figure 40). The average mean was 7.3 ± 1.6 mg l^{-1}. The variation in dissolved oxygen is presented in Figure 40 that significantly differed in August to November and January to February.

In Si Racha Bay, dissolved oxygen varied between a minimum of 6.0 mg l^{-1} in April 2007 and a maximum of 9.2 mg l^{-1} in January 2007 (Figure 40). The average value was 7.4 ± 1.1 mg l^{-1}.

The temporal variation in dissolved oxygen showed similar trends between two coasts of the upper Gulf. But the average dissolved oxygen in seasonal variation was similar value around 7.0 -7.5 mg l^{-1} in both monsoon seasons and summer period.

D. pH

Average pH value of seawater was 8.1 ± 0.2 in the upper Gulf of Thailand. In the western coast, pH fluctuated between 7.7 in October 2006 to 8.2 in May 2007 in Manao Bay (Figure 41). The average mean value was 8.0 ± 0.1. Figure 41 shows the temporal fluctuation of pH during the sampling period. In term of seasonal variation, pH values did not show any difference in both monsoon seasons.

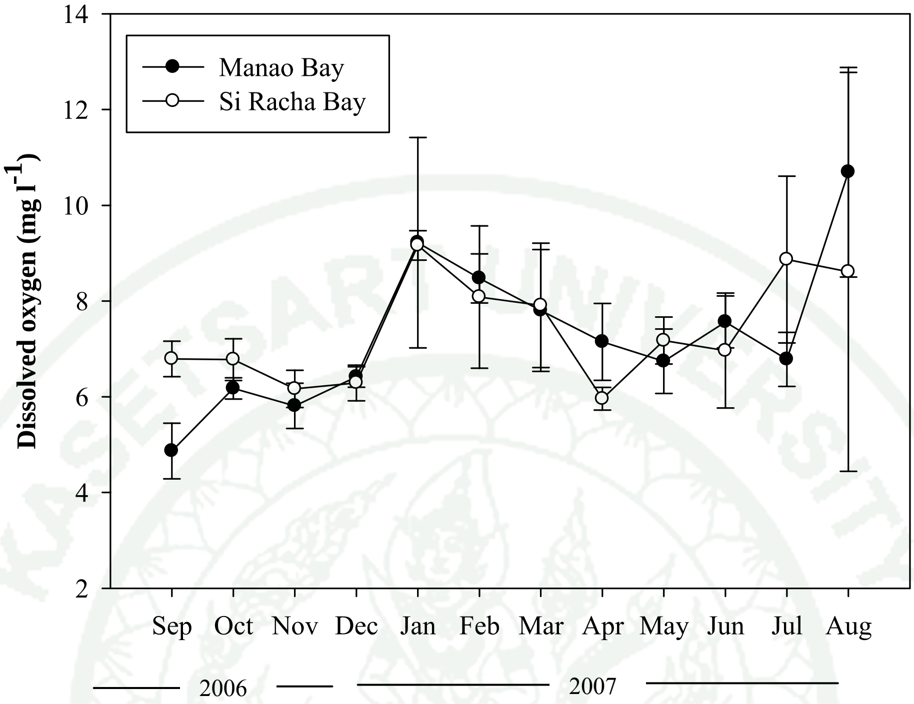


Figure 40 The average dissolved oxygen (mg l^{-1}) in Manao Bay and Si Racha Bay, September 2006 to August 2007.

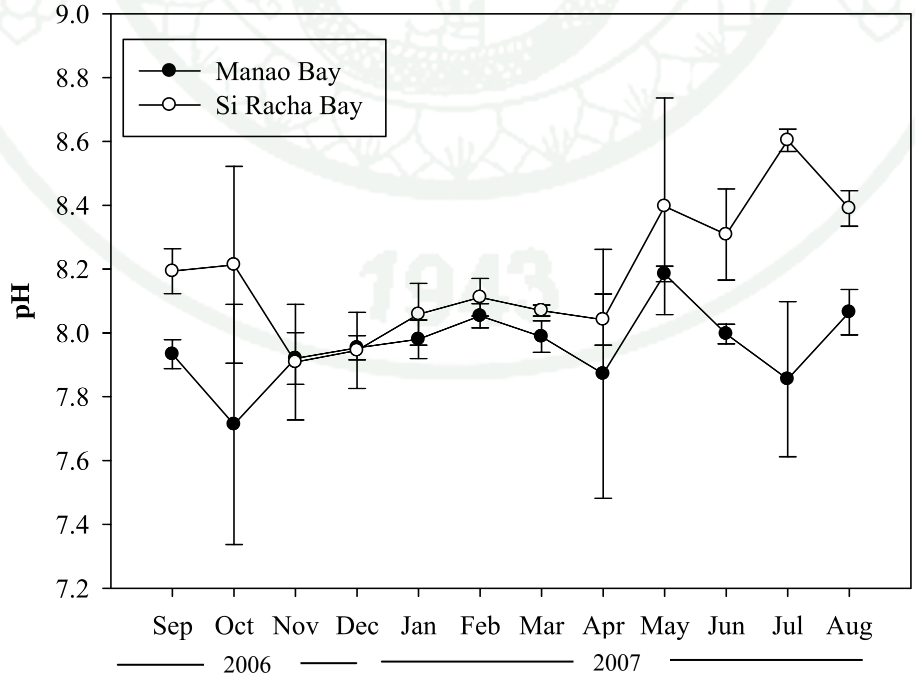


Figure 41 The average seawater pH of seawater in Manao Bay and Si Racha Bay, September 2006 to August 2007.

In the eastern coast, pH fluctuated between 7.9 in November 2006 to 8.6 in July 2007 in Si Racha Bay (Figure 41). The average mean value was 8.2 ± 0.12. The pH values were rather low and slightly fluctuated during the Northeast monsoon and summer than the value increased and reached the highest value of 8.6 in July 2007 (Southwest monsoon).

To compare with the two study areas, the average pH in the eastern coast (Si Racha Bay, 8.2 ± 0.12) was higher than those in the upper western coast (Manao Bay, 8.0 ± 0.12). Figure 41 shows the similar trends of pH values between Manao Bay and Si Racha Bay that pH slightly fluctuated during the Northeast monsoon season.

E. Precipitation

Average monthly precipitation was 102.8 ± 75.8 mm in the upper Gulf of Thailand. In the western coast, average monthly precipitation for 30 years in Prachaup Khiri Khan Province showed a clear trend of seasonal variation with a maximum of 226.7 mm in November and a minimum of 41 mm in April. The average mean value was 96.08 ± 63.36 mm. This trend relates to two monsoon seasons; hence, increasing during the Southwest monsoon is the wet season (May-October) and decreasing during the Northeast monsoon is the dry season (November-February). Summer period (March – April) also had rainfall at a minimum level (Figure 42). Additionally, the highest average value was 118.0 ± 44.2 mm during the Southwest monsoon season while the average value of 89.6 ± 91.7 mm was recorded during the Northeast monsoon season. The summer period contained the average lowest value (41.6 ±0.8 mm).

Average monthly precipitation for 30 years in Chon Buri Province showed a clear seasonal variation with a maximum of 286.9 mm in September and a minimum of 8.9 mm in December (Figure 42). The average mean was 109.55 ± 88.94 mm. This trend related to two monsoon seasons; hence, the increase during the Southwest monsoon was the wet season (May-October) and the decrease during the Northeast monsoon was the dry season (November-February). In addition, the average value of 83.5 ± 58.3 mm was recorded during the Southwest monsoon season while the average value of 25.9 ± 26.5 mm was recorded during the Northeast monsoon. During the summer period, the average precipitation was 55 ± 33.3 mm.

The seasonal variation in precipitation showed the similar trend in both western and eastern coasts of the upper Gulf. The dry period was affected by the Northeast monsoon. The average precipitation in Si Racha bay (109.55 ± 88.94 mm) was higher than the value in Manao Bay (96.08 ± 63.36 mm).

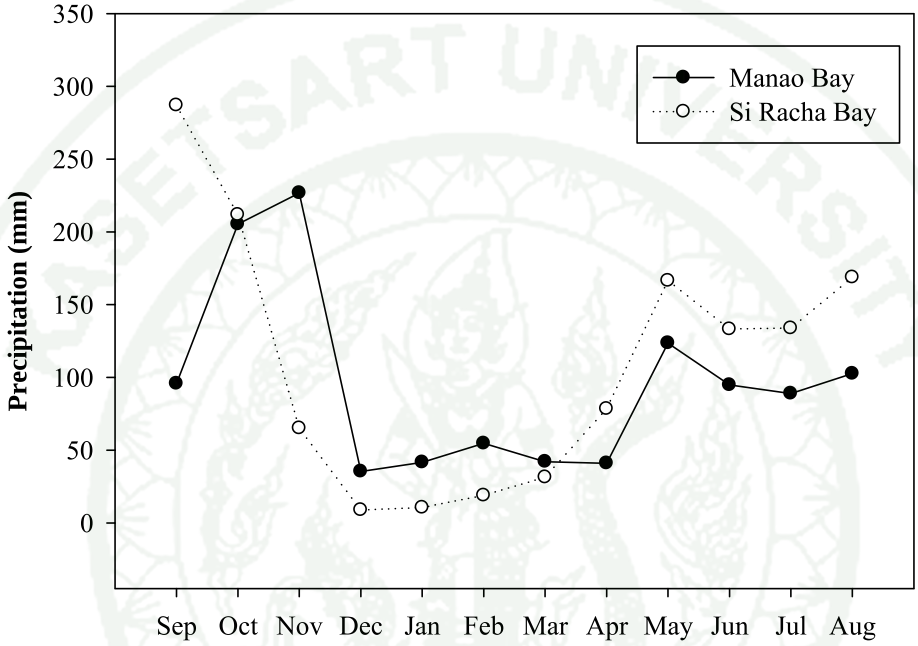


Figure 42 The average monthly precipitation (mm) for 30 years in Prachaup Khiri Khan Province and Chon Buri Province.

F. Chlorophyll a concentration

Chlorophyll a concentration ranged between 0.24 mg m^{-3} in December 2006 and 2.67 mg m^{-3} in June 2007 and the average value was 1.30 ± 0.67 mg m^{-3} over the sampling period in Manao Bay. Chlorophyll a values regularly changed with two peaks in concentration: a small one (2.14 mg m^{-3}) in October 2006 and a large one (2.67 mg m^{-3}) in June 2007 during the Southwest monsoon. The lowest chlorophyll a concentration was recorded during the Northeast monsoon season (Figure 43). The highest average value was 1.53 ± 0.76 mg m^{-3} during the Southwest monsoon season, followed by the value of 1.42 ± 0.28 mg m^{-3} in summer period. The lowest average value was recorded during the Northeast monsoon season (0.89 ± 0.28 mg m^{-3}).

Average chlorophyll a concentration ranged between 0.80 mg m^{-3} in January 2007 and 7.51 mg m^{-3} in October 2006 and the mean value was 2.59 ± 2.33 mg m^{-3} over the sampling period (Figure 43). Chlorophyll a values regularly changed with two peaks in concentration: a small one (4.27 mg m^{-3}) in May 2007 and a large one (6.80 – 7.54 mg m^{-3}) in September to October 2006 during the Southwest monsoon (May to October). The lowest total chlorophyll a concentration was recorded in December 2006 to January 2007 during the Northeast monsoon season. The graph also showed two fairly constant periods from November 2006 to March 2007 and June to August 2007. These periods showed a clear average value of 3.85 ± 2.79 mg m^{-3} during the Southwest monsoon that was higher than during the Northeast monsoon season (1.11 ± 0.36 mg m^{-3}) and summer (1.77 ± 0.80 mg m^{-3}).

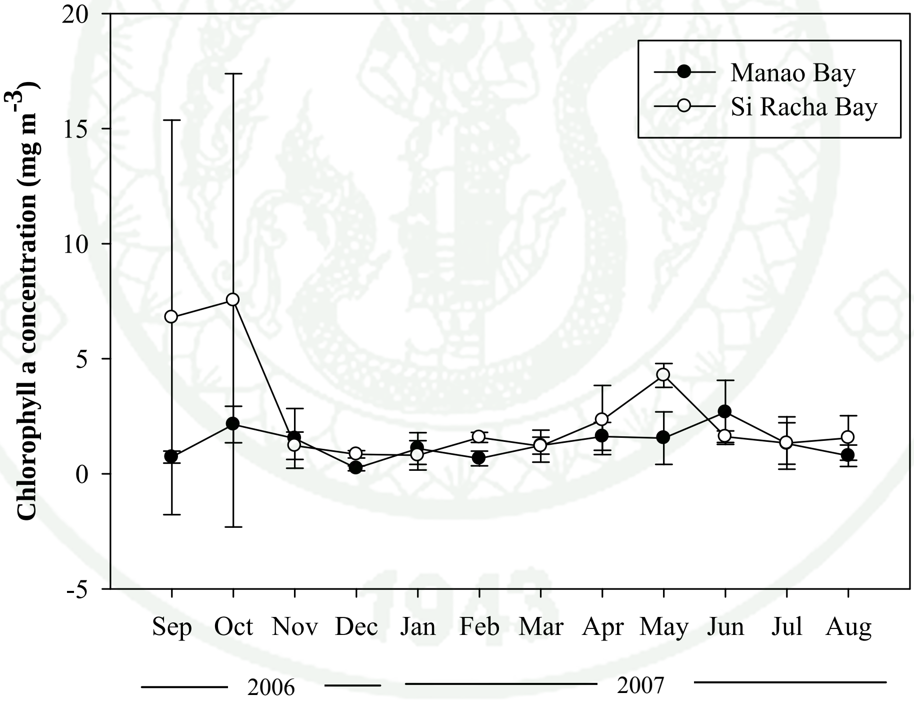


Figure 43 The average chlorophyll a concentration (mg m^{-3}) in Manao Bay and Si Racha Bay, September 2006 to August 2007.

G. Nitrite

Average nitrite was 0.004 ± 0.002 mg l^{-1} in the upper Gulf of Thailand. Nitrite values fluctuated with a minimum of 0.002 mg l^{-1} in February 2007 and a maximum of 0.009

mg l^{-1} in August 2007 in Manao Bay (Figure 44). The mean value was 0.004 ± 0.002 mg l^{-1}. Figure 44 shows the temporal fluctuation of nitrite value that highest value was recorded during the Southwest monsoon season and summer period. While the nitrite values reduced during the Northeast monsoon season.

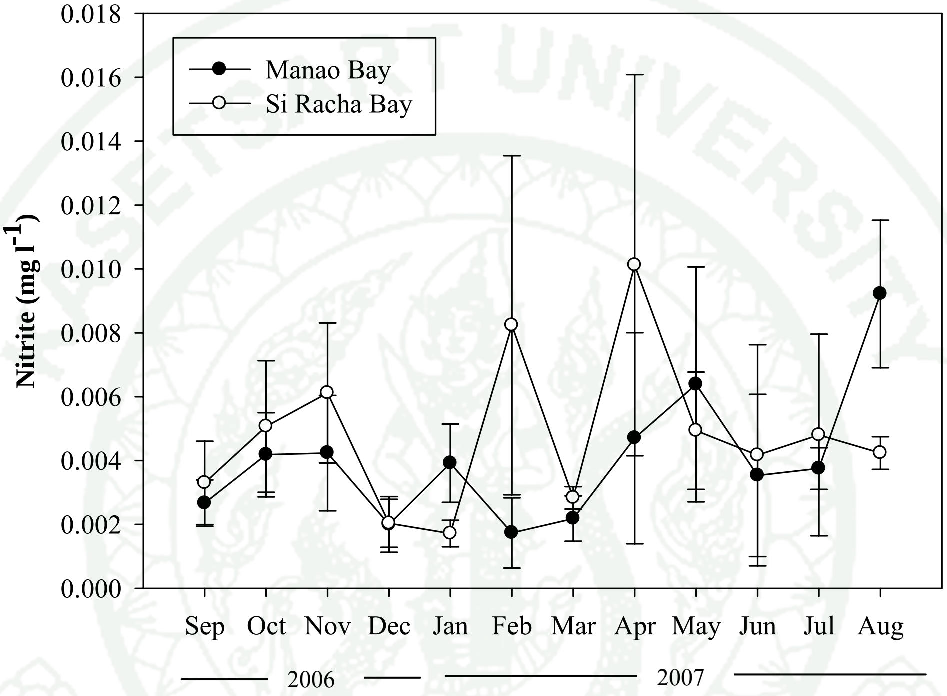


Figure 44 The average nitrite (mg l^{-1}) in Manao Bay and Si Racha Bay, September 2006 to August 2007

In Si Racha Bay, nitrite values fluctuated with a minimum of 0.0017 mg l^{-1} in January 2007 and a maximum of 0.0101 mg l^{-1} in April 2007 (Figure 44). The mean value was 0.005 ± 0.002 mg l^{-1}. Nitrite values regularly changed with three peaks: a small one (0.006 mg l^{-1}) in November 2006 and two large peaks (0.008 – 0.010 mg l^{-1}) in February and April 2007 during the Northeast monsoon and summer period. Nitrite in the eastern coast expressed the highly fluctuation and the average value (0.005 ± 0.002 mg l^{-1}) was higher than the nitrite value (0.004 ± 0.002 mg l^{-1}) in the western coast.

H. Nitrate

Average nitrate was 0.008 ± 0.005 mg l^{-1} in the upper Gulf of Thailand. Nitrate values ranged between 0.004 mg l^{-1} in November 2006 and 0.018 mg l^{-1} in March 2007 in Manao Bay (Figure 45). The mean value was 0.008 ± 0.004 mg l^{-1}. The temporal fluctuation showed the highest peak in March 2007 and other months showed the regularly variation in narrow range. The seasonal variation of nitrate values was highest recorded during the summer period and decreasing in the Southwest and Northeast monsoon season.

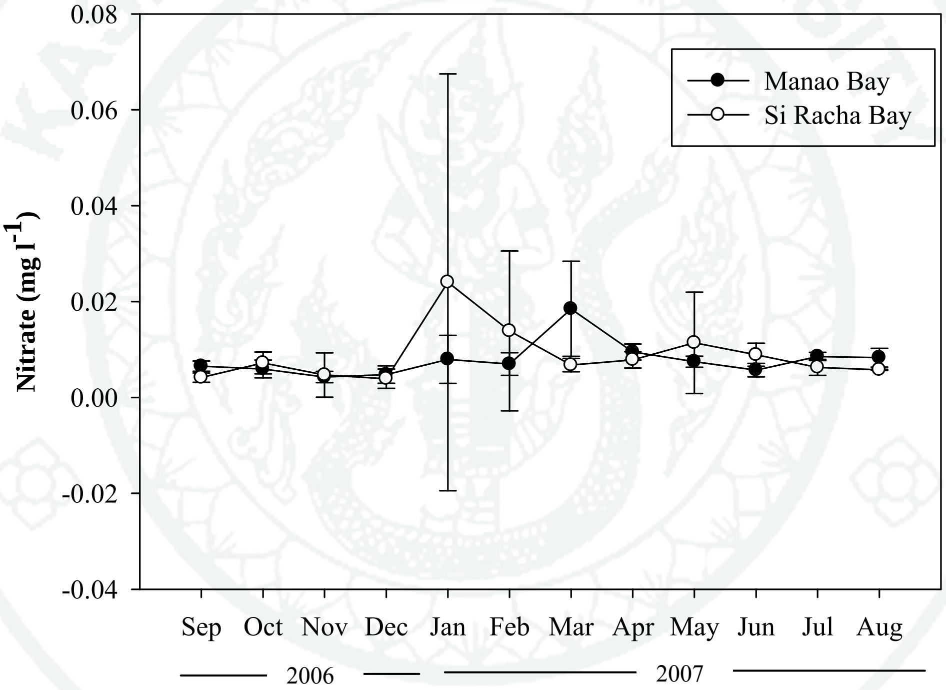


Figure 45 The average nitrate (mg l^{-1}) in Manao Bay and Si Racha Bay, September 2006 to August 2007.

In the eastern coast, nitrate values ranged between 0.0039 mg l^{-1} in December 2006 and 0.024 mg l^{-1} in January 2007 in Si Racha Bay (Figure 45). The mean was 0.009 ± 0.006mg l^{-1}. The highest peak was recorded in January during the Northeast monsoon. The nitrate value reduced during the Southwest monsoon and summer period. The average value of nitrate in Si Racha bay (0.009 ± 0.006mg l^{-1}) was higher than the value that recorded in Manao Bay (0.008 ± 0.004 mg l^{-1}).

I. Ammonia

Average ammonia value was 0.054 ± 0.024 mg l^{-1} in the upper Gulf of Thailand. In the western coast, ammonia varied from 0.027 mg l^{-1} in February and May 2007 to 0.088 mg l^{-1} in November 2006 in Manao Bay (Figure 46). The average value was 0.05 ± 0.02 mg l^{-1}. The three peaks were recorded in November, March, July. The ammonia values showed high fluctuation in Manao Bay. The seasonal variation of ammonia did not significantly differ between two monsoon seasons.

In the eastern coast, ammonia values varied from 0.0185 mg l^{-1} in May 2007 to 0.1170 mg l^{-1} in April 2006 in Si Racha Bay (Figure 46). The mean was 0.06 ± 0.03 mg l^{-1}. Figure 18 shows the temporal trend of ammonia that was recorded two high peaks in December and April. The average value showed higher value during the Northeast monsoon and summer period than the average value during the Southwest monsoon. In addition, the average value of ammonia in the eastern coast showed higher value than the western coast. The temporal trend showed similar patterns in both areas with exceptionally high in April 2007.

J. Silicate

Average silicate value was recorded of 0.8 ± 0.6 mg l^{-1} in the upper Gulf of Thailand. Silicate values varied from 0.393 mg l^{-1} in January 2007 to 1.278 mg l^{-1} in December 2006 in Manao Bay (Figure 47). The mean was 0.7 ± 0.3 mg l^{-1}. The temporal fluctuation showed three small peaks in December, April and June. The seasonal variation of silicate value did not differ between two monsoons.

In Si Racha Bay, silicate values varied from 0.0053 mg l^{-1} in March to2.478 mg l^{-1} in July 2006, with average of 0.9 ± 0.8 mg l^{-1} (Figure 47). Silicate values were relatively high during the southwest monsoon season.

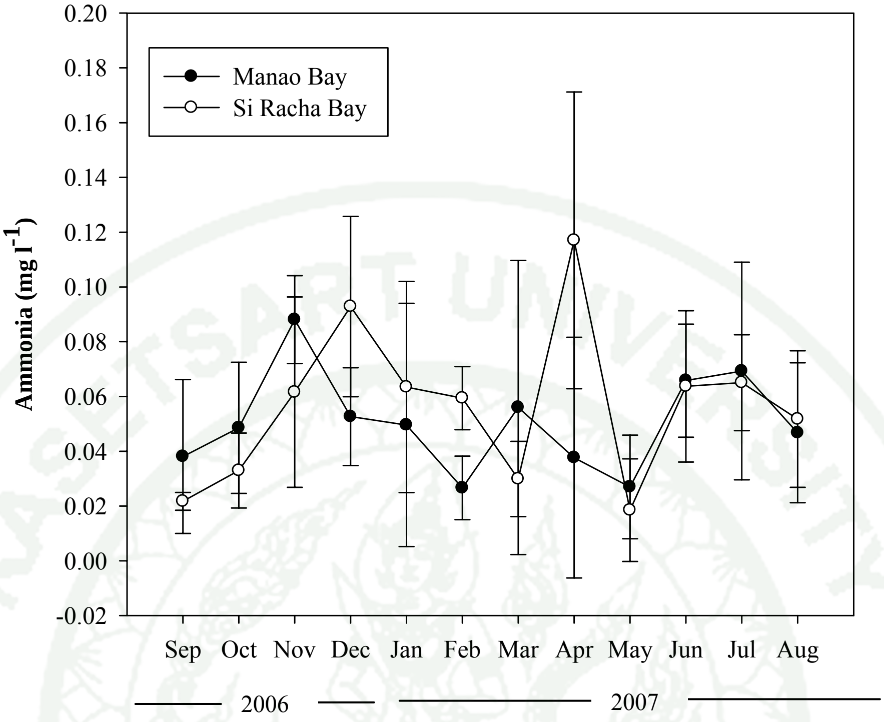


Figure 46 The average ammonia (mg l^{-1}) in Manao Bay and Si Racha Bay, September 2006 to August 2007.

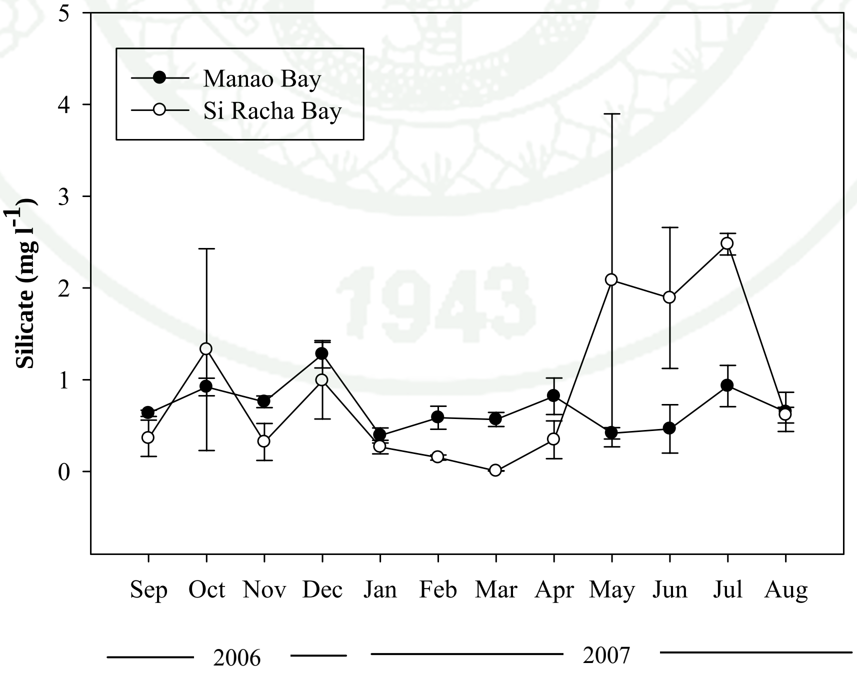


Figure 47 The average silicate (mg l^{-1}) in Manao Bay and Si Racha Bay, September 2006 to August 2007.

To compare between the western and eastern coast, silicate value in the eastern coast (0.9 ± 0.8 mg l^{-1}) was higher than the value in the western coast (0.7 ± 0.3 mg l^{-1}). Also the temporal trend of the eastern coast varied in dramatic fluctuation during the Southwest monsoon season.

K. Orthophosphate

Average orthophosphate value was 0.04 ± 0.1 mg l^{-1} in the upper Gulf of Thailand. The higher standard deviation than the mean showing high fluctuation in orthophosphate values during the sampling period. Orthophosphate fluctuated between 0.004 mg l^{-1} in February 2007 and 0.013 mg l^{-1} in November 2006 in Manao Bay, with mean of 0.009 ± 0.003 mg l^{-1} (Figure 48). The temporal trend showed smoothly fluctuated of orthophosphate during the sampling period.

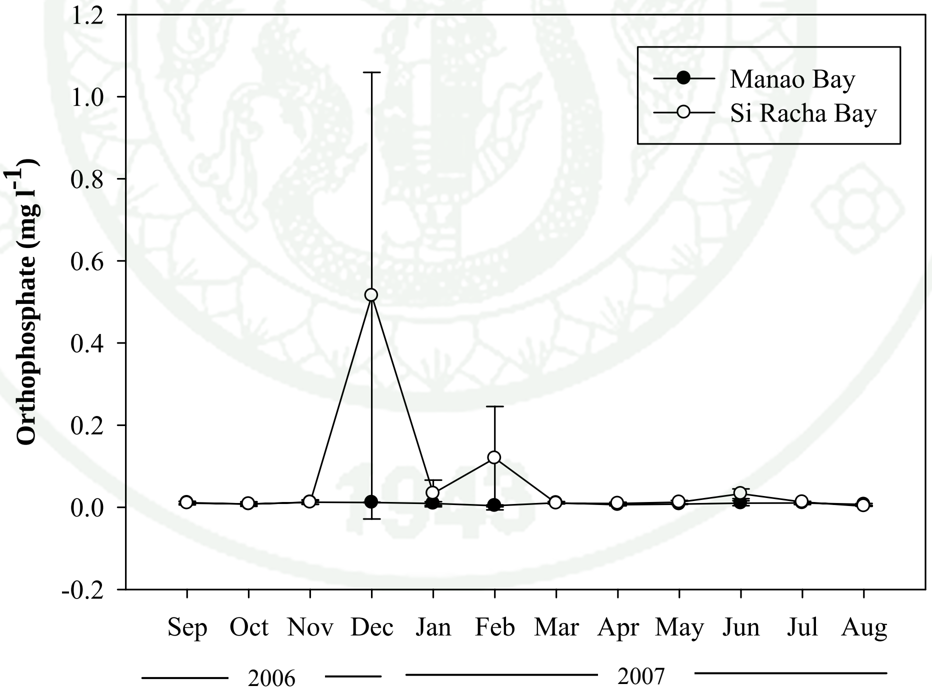


Figure 48 The average orthophosphate (mg l^{-1}) in Manao Bay and Si Racha Bay, September 2006 to August 2007.

In Si Racha Bay, orthophosphate fluctuated between 0.003 mg l^{-1} in August 2007 and 0.515 mg l^{-1} in December 2006 (Figure 48). The orthophosphate value in December 2006 and February 2007 showed two exceptionally highly peaks whereas other months slightly fluctuated.

Table 27 shows the comparison in average environmental parameters and nutrients in both study areas during the annual period. The results showed all parameters in Si Racha Bay being higher average values than those values in Manao Bay except salinity.

Table 27 Comparison on average hydrographic parameters and nutrient values in Manao Bay and Si Racha Bay, September 2006 to August 2007.

Parameters	**Manao Bay**	**Si Racha Bay**
Water temperature (°C)	29.4 ± 1.5	30 ± 1.7
Salinity (psu)	29 ± 3	25 ± 6
Dissolved oxygen (mg l^{-1})	7.31 ± 1.6	7.4 ± 1.1
pH	8.0 ± 0.12	8.2 ± 0.12
Rain fall (mm)	96.1 ± 63.4	110 ± 89
Nitrite (mg l^{-1})	0.004 ± 0.002	0.005 ± 0.002
Nitrate (mg l^{-1})	0.008 ± 0.004	0.009 ± 0.006
Ammonia (mg l^{-1})	0.051 ± 0.018	0.057 ± 0.029
Orthophosphate (mg l^{-1})	0.009 ± 0.003	0.065 ± 0.145
Silicate (mg l^{-1})	0.702 ± 0.256	0.903 ± 0.844
Chlorophyll a (mg m^{-3})	1.3 ± 0.67	2.59 ± 2.33

L. Pearson correlation

The result of Pearson correlation analysis showed no correlation between precipitation and environmental parameters including nutrients in Manao Bay (Table 28). In additionally, there is no freshwater run off from river in the adjacent areas of the sampling sites. The environmental parameters and nutrients did not show any significant variations to the annual precipitation.

In Si Racha Bay, the Pearson correlation was tested to determine the relationships between precipitation to environmental parameters and nutrient. The correlation showed positively significant between water temperature (r = 0.60, $P<0.05$), pH (r = 0.55, $P<0.05$) and chlorophyll a concentration (r = 0.81, $P<0.05$) to precipitation (Table 26). The following parameters showed negatively correlation: salinity (r = -0.76, $P<0.05$) and ammonia (r = -0.54, $P<0.05$) to precipitation. The remaining parameters (nitrite, nitrate, orthophosphate, silicate, and dissolved oxygen) showed no correlation to precipitation.

Table 28 Correlation coefficients (r) in relationships between precipitation to environmental parameters and nutrients; * $P<0.05$.

Parameter	**precipitation (mm)**	
	Manao Bay	**Si Racha Bay**
Water temperature (°C)	0.30	**0.60***
Salinity (psu)	-0.07	**-0.76***
Dissolved oxygen (mg l^{-1})	-0.38	-0.14
pH	-0.31	**0.55***
Nitrite (mg l^{-1})	0.30	-0.03
Nitrate (mg l^{-1})	-0.44	-0.40
Ammonia (mg l^{-1})	0.42	**-0.54***
Orthophosphate (mg l^{-1})	0.20	-0.44
Silicate (mg l^{-1})	0.05	0.36
Chlorophyll a (mg m^{-3})	0.45	**0.81***

The physical parameters (water temperature, D.O., salinity, pH) fluctuated slightly within narrow ranges in Manao Bay. The important factors are shallow depth (< 10m), strong coastal wind and mixed tidal current that affect both horizontal and vertical water column mixing in the Gulf of Thailand (Nasir *et al.*, 1999; Buranapratheprat *et al.*, 2009). Moreover, the rainfall data showed a clear trend that related to monsoon seasons and also affected salinity for more than 7 months in this area. Salinity value was relatively stable from November to April during the Northeast monsoon to summer months and showed its lowest value in July and September during the Southwest monsoon. Water temperature was fairly constant throughout the year but its lowest value was recorded in January to February during the Northeast monsoon. These revealed a clear trend in seasonal variation of hydrographical parameters and nutrients. These characteristics are generally apparent in tropical coastal water that was classified to conservative areas within normal Thai standard levels of seawater (Department of Pollutant Control, 2006). The comparative data in Manao bay is presented in Table 29.

Table 29 Comparison on average hydrographic parameters and nutrient values in Manao Bay, Prachuap Khiri Khan Province.

Parameters	2006*	This study
Water temperature (°C)	29.5-31.6	26.0-31.4
Salinity (psu)	31.9-32.8	21-31
Dissolved oxygen (mg l^{-1})	7.0-8.1	5.0-10.7
pH	8.08-8.17	7.7-8.2
Rain fall (mm)	-	41-226.7
Nitrite (mg l^{-1})	0.0005-0.001	0.002-0.009
Nitrate (mg l^{-1})	0.001-0.009	0.004-0.018
Ammonia (mg l^{-1})	0.004-0.02	0.027-0.088
Orthophosphate (mg l^{-1})	0.005-0.013	0.393-1.278
Silicate (mg l^{-1})	-	0.004-0.013
Chlorophyll a (mg m^{-3})	-	0.24-2.67

Remark: * Department of Pollutant Control (2006)

Nutrient loading to coastal waters is generally influenced by freshwater runoff from land and the availability of these nutrients in the water column (Dame and Allen, 1996; Philippart *et al*., 2000; McQuatters-Gollop *et al*., 2007). In a semi-enclosed bay, tidal current seems to be a major transporter exchanging between the coastal water and the open sea. However, there is no detailed knowledge to understand the effect of nutrient enrichment on Manao Bay. Dissolved nutrient contents fluctuated in temporal variation with no noticeable trend with monsoon seasons.

The chlorophyll a concentration showed two high peaks in both monsoon seasons and could be stated as an enrichment of Manao Bay. In shallow coastal water, the primary production of phytoplankton (chlorophyll a concentration) is generally related to nutrient content in the water column from bottom-up (Bot and Colijn, 1996; McQuatters-Gollop *et al*., 2007). This result showed a low average value of chlorophyll a concentration (1.30 ± 0.67 mg m^{-3}) during the sampling period and in this regard the area was assumed to be an oligotrophic coastal water (U.S. EPA, 2003; Calbet and Landry, 2004). Additionally, other nutrient values were at a normal level for Thai standard levels of seawater suitable for a conservative area (Department of Pollutant Control, 2006). Regarding to higher chlorophyll a concentration investigated in 2008, it was due to *Noctiluca* bloom in the northern area (the Prachuap Bay) where the alage distributed into this bay by wind.

In Si Racha Bay, the physical parameters and nutrients showed no significant differences between 6 sampling stations because the tidal current only slightly changed within narrow ranges and also the water column well mixed (Anongponyoskun and Bundismith, 1998). The sampling stations were set in shallow depth (3-9 m, average < 6 m) and mixed tidal current and wind are important factors that affect both horizontal and vertical water column mixing in this bay (Anongponyoskun, 2006). Moreover, the tidal current seems to be standing water being influenced by many aquaculture rafts that blocked the flow of current. The area had no major transporter exchanging between the coastal water and the open sea especially in May and July that showed the rather weak coastal currents from the northern to southern in May and opposite direction in July (Buranapratheprat, 2009) (Appendix Figure 4).

There were dramatic change in seasonal variations of salinity and water temperature which was a result of precipitation. Salinity values were relatively high from November to April (the Northeast monsoon). The lowest value was recorded in July and October (the Southwest monsoon). In contrast, water temperature was fairly constant throughout year with the low values recorded in December to February (the Northeast monsoon).

Our study showed that the dissolved nutrient contents fluctuated in temporal variation with no noticeable trend with monsoon seasons excluding the chlorophyll a concentration. The chlorophyll a concentration showed two high peaks during the Southwest monsoon season and could be stated as an enrichment of this bay. This result showed a moderate value of chlorophyll a concentration (3.85 ± 2.79 mg m^{-3}) but low value of 1.11± 0.36 mg m^{-3} in the Northeast monsoon and 1.77 ± 0.8 mg m^{-3} in summer. It can be explained by seasonal changes in coastal circulation patterns, phytoplankton density and nutrient loading in the raining season (Boonyapiwat, 1999). In this regard, this area was assumed to be a mesotrophic water during the Southwest monsoon but an oligotrophic coastal water in the Northeast monsoon and summer (Calbet and Landry, 2004; U.S. EPA, 2003).

Regarding to nitrogen sources: nitrite, nitrate and ammonia, there is a large raft – cultured mussel area that provided high dissolved nitrogen compound to water column by excretion. The ammonia showed the clear trend in temporal variation that the highest value was recorded in April. It might be a high metabolic rate of mussel excretion during a low rainfall to dilute nutrient in summer period (Dame and Prins, 1998; Hawkins *et al*., 1998; Prins *et al*., 1998). In addition, nitrite and nitrate were not stable and rapidly changed into other forms (Howarth and Marino 2006). They also showed no noticeable variation and weakly affected to phytoplankton than ammonia in this bay.

Our results agreed with previous findings by Yoosamran *et al*. (2004; 2006) that there were clear patterns of seasonal variations in salinity, water temperature and chlorophyll a concentration in Si Racha Bay. Additionally, the environmental parameters and nutrient values were at a normal level for Thai standard levels of seawater suitable for an aquaculture area (Department of Pollutant Control, 2006). Table 30 shows the comparative data in Si Racha Bay in time series.

Table 30 Comparison on average hydrographic parameters and nutrient values in Si Racha Bay, Chon Buri Province.

Parameters	2004*	2006**	2006***	This study
Water temperature (°C)	26.3-31.0	29.3-30.3	26.6-30.3	26.1-31.7
Salinity (psu)	25-34	23.5-30.0	23-32	14-33

Table 30 (Continued)

Parameters	2004*	2006**	2006***	This study
Dissolved oxygen ($mg\ l^{-1}$)	3.9-7.9	3.3-6.9	4.7-6.1	6.0-9.2
pH	7.8-9.2	7.38-8.56	8.11-8.41	7.9-8.6
Rain fall (mm)	-	-	-	8.9-286.9
Nitrite ($mg\ l^{-1}$)	0-0.013	0-0.008	0.00003-0.0031	0.002-0.01
Nitrate ($mg\ l^{-1}$)	0.005-1.017	0.014-0.068	0.001-0.007	0.004-0.024
Ammonia ($mg\ l^{-1}$)	0-0.081	0.001-0.065	0-0.013	0.019-0.117
Orthophosphate ($mg\ l^{-1}$)	0-0.003	0.003-0.039	0.0005-0.002	0.005-2.478
Silicate ($mg\ l^{-1}$)	0.06-0.82	-	0.042-0.75	0.003-0.515
Chlorophyll a ($mg\ m^{-3}$)	-	-	0.24-8.41	0.8-7.51

Remarks: - not measured; * Yoosamran (2004); **Department of Pollutant Control (2006); ***Yoosamran (2006)

9. Community structure of plankton

A. Phytoplankton community

1. Taxonomic composition

A total of 66 genera belonging to 35 families, 9 orders, 4 classes, 2 divisions of phytoplankton were recorded in this study. They consisted of four classes: Cyanophyceae (blue-green algae), Bacillariophyceae (centric and pennate diatoms), Dinophyceae (dinoflagellates), and Dictyochophyceae (silicoflagellates). Centric diatoms were the most diverse group, comprising 30 genera, followed by pennate diatoms (23 genera), dinoflagellates (8 genera), blue-green algae (4 genera) and silicoflagellate (1 genus) (Table

31). The abundance and mean percentages of all genera are also presented. Raw data, including species lists, are available in Appendix (Tables 13 and 14).

Table 31 Phytoplankton diversity with mean, maximum, and minimum abundance (cells l^{-1}), and mean percentage of contribution (%) to total abundance of each taxon.

Taxa	**Manao Bay**				**Si Racha Bay**			
	Abundance (cells l^{-1})			**Mean**	**Abundance (cells l^{-1})**			**Mean**
	Mean	**Max**	**Min**	**%**	**Mean**	**Max**	**Min**	**%**
DIVISION CYANOPHYTA								
CLASS CYANOPHYCEAE								
Lyngbya	-	-	-	-	8	45	0	0
Oscillatoria	7059	22754	0	32.4	40525	294867	1690	14
Cylindrospermiopsis	94	849	0	0.4	-	-	-	-
Richelia	59	388	0	0.3	-	-	-	-
DIVISION CHROMOPHYTA								
CLASS BACILLARIOPHYCEAE								
ORDER BIDDULPHIALES								
Cyclotella	0.14	1.73	0	0	-	-	-	-
Lauderia	41	165	2.5	0.2	491	2716	0	0.2
Skeletonema	3	27	0	0	562	1992	0	0.2
Stephanodiscus	1	5	0	0	-	-	-	-
Thalassiosira	5	32	0	0	2899	26966	0	1
Planktoniella	3	27	0	0	1	5	0	0
Paralia	7	15	0	0	13	34	0	0
Melosira	23	154	0	0.1	667	7539	0	0.2
Corethron	8	77	0	0	31	345	0	0.1
Palmeria	0	3	0	0	1	6	0	0
Coscinodiscus	307	2223	23	1.4	353	1722	14	0.1
Pseudoguinardia	32	116	0	0.1	12	50	0	0
Actinoptychus	1	11	0	0	1	9	0	0
Asteromphalus	4	13	0	0	1	9	0	0
Leptocylindrus	-	-	-	-	365	3804	0	0.1
Dactyliosolen	11	95	0	0	50	435	0	0
Guinardia	317	2258	16	1.5	997	6579	0	0.3
Proboscia	383	1948	6	1.8	724	3945	0	0.3

Table 31 (Continued)

Taxa	Manao Bay				Si Racha Bay			
	Abundance (cells l^{-1})			Mean	Abundance (cells l^{-1})			Mean
	Mean	Max	Min	%	Mean	Max	Min	%
Pseudosolenia	111	900	0	0.5	300	1123	0	0.1
Rhizosolenia	443	1543	0	2	664	2523	2	0.2
Climacodium	-	-	-	-	13	115	0	0
Eucampia	13	43	0.43	0.1	131	833	0	0
Hemiaulus	87	371	9	0.4	623	3300	0	0.2
Biddulphia	-	-	-	-	0	4	0	0
Cymatosira	-	-	-	-	0	2	0	0
Bacteriastrum	3272	1961	4	15	32849	221490	93	11.4
Chaetoceros	3465	10601	0	15.9	182241	560430	5543	63.1
Ditylum	79	660	0	0.4	353	2463	0	0.1
Odontella	41	144	6	0.2	48	166	1	0
Triceratium	16	185	0	0.1	-	-	-	-
ORDER BACILLARIALES								
Asterionella	7	61	0	0	18	79	0	0
Fragilaria	-	-	-	-	2	5	0	0
Synedra	52	626	0	0.2	1	10	0	0
Thalassionema	3657	11003	265	16.8	18114	114124	14	6.3
Thalassiothrix	1	4	0	0	-	-	-	-
Amphora	0	3	0	0	0	2	0	0
Gyrosigma	17	36	0.41	0.1	20	195	0	0
Navicula	8	26	0	0	20	105	0	0
Pleurosigma	647	1948	25	3	281	3847	1	0.1
Gammatophora	-	-	-	-	0	1	0	0
Climacosphenia	0	1.28	0	0	4	13	0	0
Meunier	46	223	0	0.2	-	-	-	-
Nitzschia	419	733	0	1.9	97	333	0	0
Bacillaria	441	1846	32	2	636	1540	0	0.2
Pseudo-nitzschia	421	2664	53	1.9	520	1823	1	0.2
Cylindrotheca	1	7	0	0	-	-	-	-
Cocconeis	0	1	0	0	3	31	0	0
Lyrella	-	-	-	-	1	4	0	0
Diploneis	-	-	-	-	0	3	0	0

Table 31 (Continued)

Taxa	Manao Bay				Si Racha Bay			
	Abundance (cells l^{-1})			Mean	Abundance (cells l^{-1})			Mean
	Mean	Max	Min	%	Mean	Max	Min	%
Denticula	-	-	-	-	0	1	0	0
Epithemia	0.03	0.33	0	0	1	5	0	0
Entomoneis	5	20	0	0	23	157	0	0
Surirella	7	32	0	0	21	74	0	0
CLASS DINOPHYCEAE								
Prorocentrum	2	7	0	0	19	135	2	0
Dinophysis	32	169	0	0.1	61	142	2	0
Ornithocercus	1	5	0	0	0	2	0	0
Noctiluca	2	8	0	0	32	171	0	0
Ceratium	81	190	20	0.4	2836	25610	34	1
Pyrophacus	11	33	0	0	10	65	0	0
Peridinium	6	17	0	0	-	-	-	-
Protoperidinium	28	58	1	0.1	180	601	0	0.1
CLASS DICTYOCHOPHYCEAE								
Dictyocha	8	31	0	0	10	38	0	0

Remarks: - = not found

Among 56 genera of phytoplankton recorded from Manao Bay, centric diatoms were the most diverse group, comprising 26 genera, followed by pennate diatoms (18 genera), dinoflagellates (8 genera), blue-green algae (3 genera) and silicoflagellate (1 genus), (Table 31). Number of phytoplankton genera ranged from 28 genera in February to 42 genera in April 2007, with an average of 37±4 genera (Figure 49).

In Si Racha Bay, a total of 57 genera of phytoplankton were recorded. Centric diatoms were the most diverse group, comprising 27 genera, followed by pennate diatoms (20 genera), dinoflagellates (7 genera), blue-green algae (2 genera) and silicoflagellate (1 genus) (Table 31). Number of genera ranged from 23 genera in September 2006 to 46 genera in February 2007, with an average of 36±7 genera (Figure 49).

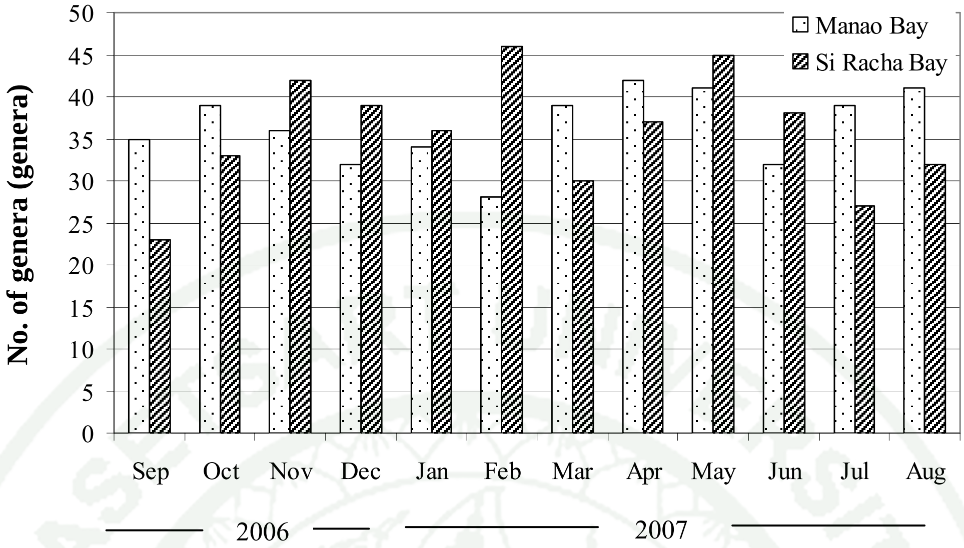


Figure 49 Number of phytoplankton genera in Manao bay and Si Racha Bay, September 2006 to August 2007.

Data on taxonomic composition of phytoplankton from 6 sampling stations were pooled and compared between two study sites which showed a similar pattern as in Table 32. Regarding seasonal pattern, comparison of generic occurrence is shown in Appendix (Tables 13 and 14).

Table 32 Taxonomic composition of phytoplankton in the upper Gulf of Thailand.

Taxa	Manao Bay		Si Racha Bay	
	Family	**Genera**	**Family**	**Genera**
Division Cyanophyta				
Class Cyanophyceae				
1. Order Nostocales	2	3	1	2
Division Chromophyta				
Class Bacillariophyceae				
1. Order Biddulphiales	12	26	15	27
2. Order Bacillariales	8	18	10	20
Class Dinophyceae				
1. Order Prorocentrales	1	1	1	1

Table 32 (Continued)

Taxa	Manao Bay		Si Racha Bay	
	Family	**Genera**	**Family**	**Genera**
2. Order Dinophysiales	1	2	1	2
3. Order Noctilucales	1	1	1	1
4. Order Gonyaulacales	2	2	2	2
5. Order Peridiniales	2	2	1	1
Class Dictyochophyceae				
1. Order Dictyochales	1	1	1	1
Total	**30**	**56**	**33**	**57**

2. Abundance

Phytoplankton abundance showed no statistical differences between the 6 stations, thus all data were pooled prior to the analysis. Total abundance of phytoplankton varied a lot during the study period, with a minimum of 8141 cells l^{-1} in October 2006, and a maximum of 53,883 cells l^{-1} in January 2007 in Manao Bay, with mean abundance was 21,780 ± 13,841 cells l^{-1} (Figure 50). The maximum peak of abundance coincided with the abundance of *Oscillatoria*, *Thalassionema, Bacteriastrum* and *Chaetoceros* while the graph shows fairly constant abundance during March to August.

In Si Racha Bay, the total abundance of phytoplankton ranged from a minimum of 22,500 units l^{-1} in April 2007 to a maximum of 825,837 cells l^{-1} in August 2007 during the period of study (Figure 50), a mean abundance of 288,837 ± 251,113 cells l^{-1}. The abundance of phytoplankton varied with three peaks: the highest peak (825,837 cells l^{-1}) in August 2007 and two smaller ones (555,422 and 517,242 cells l^{-1}) in November 2007 and September 2006, respectively. The maximum peak of abundance coincided with the abundance of diatom genera: *Chaetoceros, Oscillatoria* and *Bacteriastrum*. Figure 50 shows two relatively constant abundance periods between December 2006 to January 2007 and May to July 2007. Temporal abundance showed significant difference between months. The 95% confidence interval was 288,837 ± 251,113 cells l^{-1} during the sampling period. Higher values, compared to mean, were recorded in October and November 2006 and August 2007, lower values were found in December 2006 and January, March and April 2007.

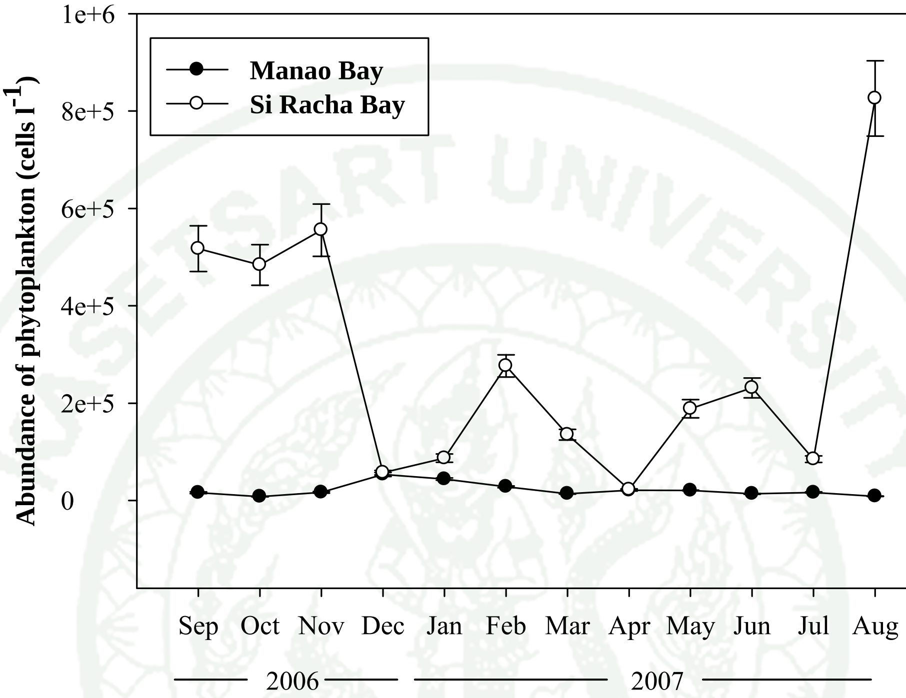


Figure 50 Total abundance of phytoplankton in Manao bay and Si Racha Bay, September 2006 to August 2007.

To analyse seasonal pattern, total abundance of phytoplankton were classified into three periods: Southwest monsoon, Northeast monsoon, and summer. In Manao Bay, the highest average abundance (35,591 ± 16,384 cells l^{-1}) was recorded during the Northeast monsoon, followed by summer period (17,455 ± 4,890 cells l^{-1}). The lowest average abundance was 14,015 ± 4,815 cells l^{-1} during the Southwest monsoon (November – February) (Figure 51). No statistical difference in seasonal abundance of phytoplankton during the two monsoons was demonstrated in the western coast.

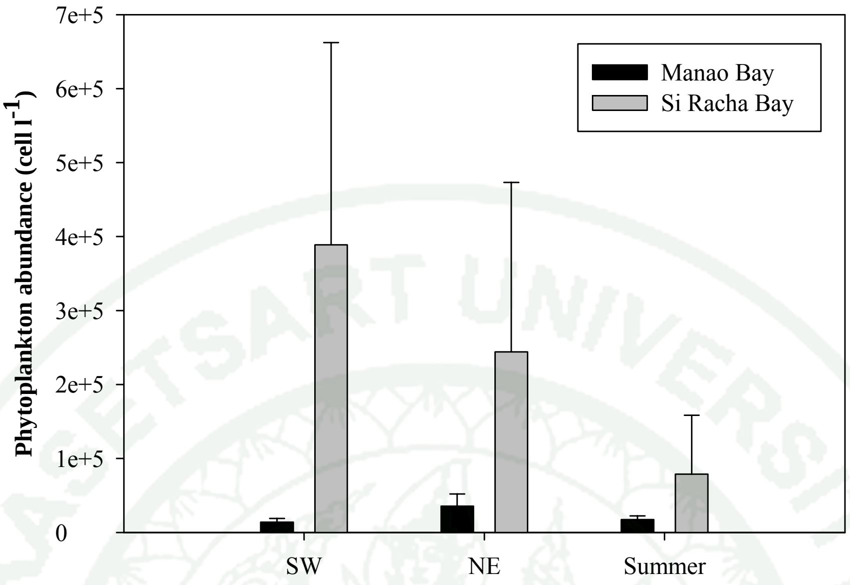


Figure 51 Seasonal average abundance of phytoplankton in Manao bay and Si Racha Bay, September 2006 to August 2007.

In Si Racha Bay, noticeable variation in seasonal abundance of phytoplankton during the two monsoons was demonstrated in the eastern coast. During the Southwest monsoon (May – October), the average abundance of phytoplankton had a highest value of 388,659 ± 273,429 cells l^{-1}, followed by an average value of 244,081 ± 229,129 cells l^{-1} during the Northeast monsoon (November – February). The lowest average abundance was 78,879 ± 79,731 cells l^{-1} in summer (March-April) (Figure 51). Two-way ANOVA was applied to test those differences of abundance between the areas and season, revealed phytoplankton abundance to be no significantly different between two seasons. Results on one-way ANOVA also revealed no statistical difference of phytoplankton abundance between the two seasons.

3. Contribution percentage

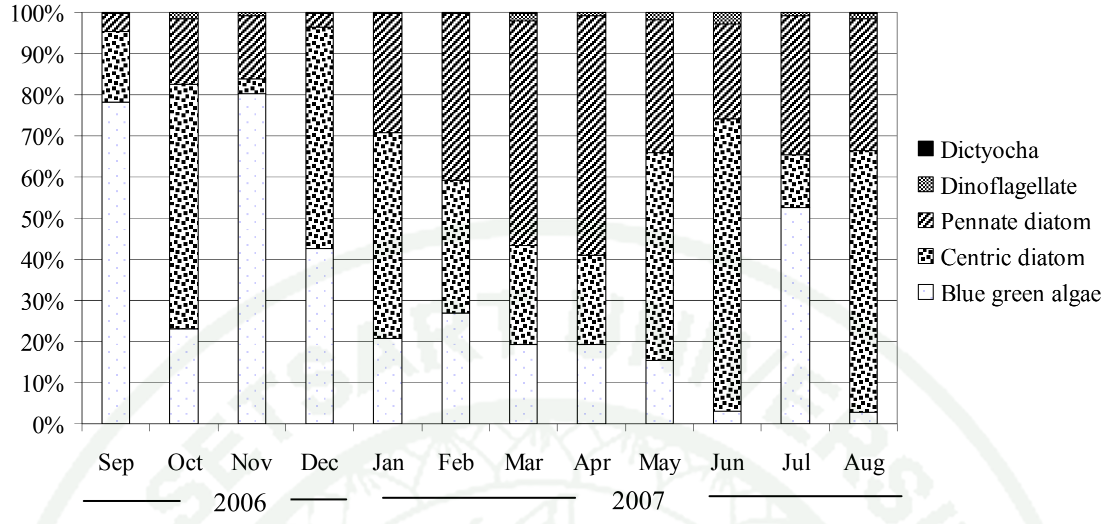
In the western coast, the contribution of phytoplankton was dominated by centric diatoms, comprising 39.8% of total abundance, with a mean value of 8,672 ± 8,529 cells l^{-1}. Blue-green algae contributed 33.1% (7,211 ± 6,633 cells l^{-1}), followed by pennate diatoms (26.3%, 5,728 ± 4,393 cells l^{-1}), dinoflagellates (0.7%, 161 ± 117 cells l^{-1}), and silicoflagellates (0%, 8 ± 9 cells l^{-1}). Four dominant genera which frequently occurred and relatively abundant were *Oscillatoria* (32.4%), *Thalassionema* (16.8 %), *Coscinodiscus* (15.9 %) and *Bacteriastrum* (15 %) (Table 31).

Diatoms dominated with a high percentage composition during the Southwest and Northeast monsoons (Figure 52). A shift of dominant group developed from diatoms to blue-green algae in September and November 2006 and July 2007. Contrarily, dinoflagellates and silicoflagellates occurred in low percentage throughout the study period.

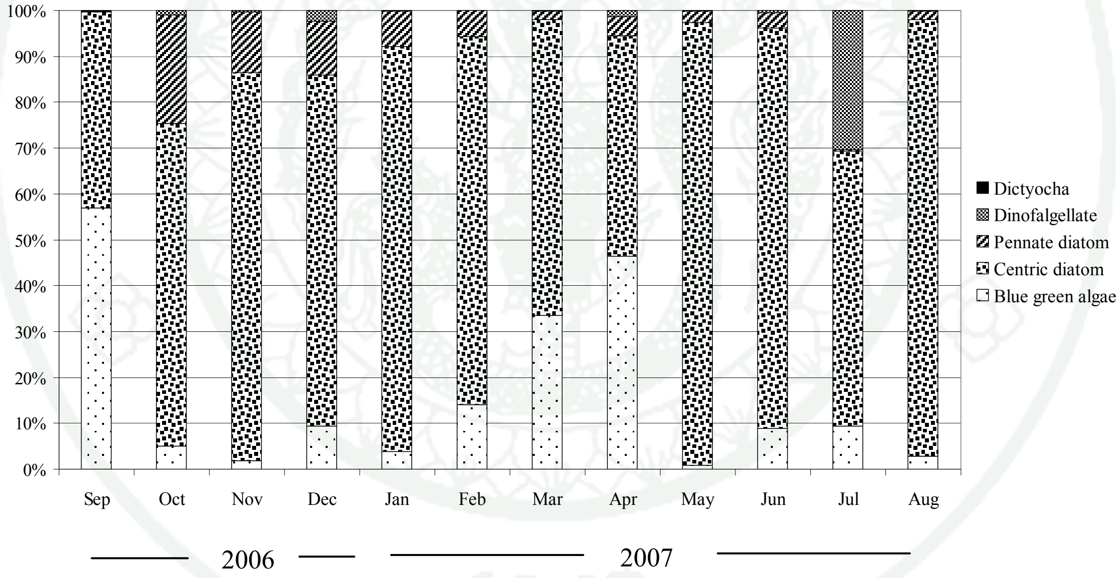
In the eastern coast, phytoplankton community was dominated by centric diatoms, comprising 77.7% of total abundance, with a mean value of 224,390 ± 221,809 cells l^{-1}, followed by blue-green algae (14%, 40,533 ± 81,287 cells l^{-1}), pennate diatom (7.2%, 20,766 ± 35,615 cells l^{-1}), dinoflagellates (1.1 %, 3,138 ± 7,204 cells l^{-1}) and silicoflagellates (0 %, 10 ± 14 cells l^{-1}) (Table 31). Four dominant genera which frequently occurred and relatively abundant were *Chaetoceros* (63.1%), *Bacteriastrum* (11.4 %), *Oscillatoria* (14 %) and *Thalassionema* (6.3 %) (Figure 52).

In Si Racha Bay, diatoms dominated with a high percentage composition in most of the sampling period during both monsoons (Figure 52). A shift of dominant group developed from diatoms to blue-green algae (*Oscillatoria*) which had high abundance in September 2006 with a maximum value of 294887 cells l^{-1}. Dinoflagellates (*Ceratium furca* (Ehrenberg) Claparède & Lachmann) had high proportion in July 2007 with a maximum value of 25,610 cells l^{-1}, while silicoflagellates presented in low percentage throughout the study period.

Seasonal patterns of phytoplankton composition and abundance slightly fluctuated in the semi-enclosed shallow bay (Manao Bay). The variation was mainly resulted from interaction of hydrographic conditions, rather than depending on nutrients concentration during the two monsoons. This is probably due to the well mixed water column and no freshwater run-off into this bay (Nasir *et al*., 1999).



(a)



(b)

Figure 52 Temporal variation of phytoplankton communities in Manao Bay (A) and Si Racha Bay (B), September 2006 to August 2007.

However, the average abundance during summer was clearly lower than those in both monsoon seasons. This can be explained by limitation of nutrient supply, such as nitrogen or silicate, and also the slight coastal tidal currents (Smyda, 1983; Turner *et al.*, 1998; Wu and Chou, 2003; Howarth and Marino, 2006). This period (March-April) had no heavy turbulence in the water column so nutrients were not stirred up from the bottom to surface water, which might limit phytoplankton growth (Robinson, 1963; Karl *et al*., 1998; Boonyapiwat, 1999; Snidvongs and Sojisuporn, 1999).

Various data obtained from several regions in the Gulf of Thailand indicate that species composition of phytoplankton does not differ among the Southwest and Northeast monsoon seasons (Boonyapiwat, 1999; Panchote, 2005; Boondao, 2006; Patarajinda *et al*., 2007). The marked trend shows a quite characteristic phytoplankton composition with diatoms the major contributor of the phytoplankton community in the Gulf of Thailand. But, the proportions of other groups varied by sampling areas (Pienpichit, 1999; Teanpisut, 2006). The important factors were salinity and nutrients loading. However, in terms of abundance, it showed temporal variation in some areas, such as estuaries or coastal zones affected by nutrients loading or freshwater run-off during monsoon seasons (Thongbor, 2004; Boondao, 2006; Patarajinda *et al*., 2007).

Species composition of phytoplankton in Si Racha Bay in this study was similar to the study of Yoosamran *et al*. in 2006. Diatoms were predominant in terms of abundance. Total abundance of plankton community was related to monsoon seasons and showed a high peak during the Northeast monsoon. It can be explained by the variation of lower salinity influenced by heavy rainfall from May to October.

The plankton community was generally composed of brackish species in Si Racha Bay. In addition, a shift in the dominant group developed from diatoms to dinoflagellates in July 2007, as there was a bloom of *Ceratium furca* occurred and another shifting to blue-green algae in September 2006. These results agreed with previous findings by Chuchit (2004) and Chuchit and Yoosamran (2005, 2006), who found abundance of *C. furca* increased during the Northeast monsoon season in the annual period. However, Mardnui and Lirdwitayaprasit (2007) found that this phenomenon was negatively correlated to salinity.

Si Racha Bay has highly major nutrient supply to water column from the excretion of green mussels especially nitrogen compound that supports phytoplankton growth and reproduction. Moreover, light and water temperature have not limited during annual period so the considered factor of phytoplankton growth might be light penetration and depth. But this shallow bay has well mixed tidal current and also can assume that depth was not effective to light penetration. Another important factor that affected on plankton growth was the grazing activity by mussels. It might conclude that the plankton community in Si Racha Bay was controlled by the biological and chemical factors than the physical factors.

On the other hand, it was clear that Manao Bay had low productivity, and was an undisturbed area from human activities. Moreover, nutrient concentration was in the suitable range for a conservation area, based on Thai standard levels of seawater (Department of Pollutant Control, 2006). But the expected species composition changes and abundance increases were found in September and November 2006. Also, they shifted from main species composition of diatoms to blue-green algae was recorded. In addition, dinoflagellate, *Noctiluca* bloom was recorded in May 2008. It can explain by the coastal current and wind were the main transporters on the plankton community in this bay. These results revealed that a small shallow bay was affected from adjacent area such as Prachuap Bay in the northern coast where a pier is located for the local fisheries and loading the drainage water from the communities to the bay. The plankton bloom or changing in composition had occurred in the northern bay, thus current and wind transferred them into Manao Bay. It might conclude that the physical factors were the main effective influences on plankton community in this semi-protected bay.

B. Zooplankton community

1. Taxonomic composition

Zooplankton diversity was studied from samples obtained by the 200-µm mesh size net. Data on higher taxa were pooled at each sampling area throughout the sampling period. Overall, 45 groups from 14 phyla were recorded, including 19 groups of holoplankton and 26 groups of meroplankton in both sampling areas. The zooplankton list is presented in Table 33 including its average abundance, minimum, maximum and relative abundance in percentage. The frequency of occurrence of each group is presented in Appendix (Tables 15 and 16).

In Manao Bay, zooplankton belonging to 8 phyla were recorded: Sarcomastigophora, Cnidaria, Annelida, Mollusca, Arthropoda, Chaetognatha, Echinodermata and Chordata. They were identified into 35 groups: 14 groups of holoplankton, and 21 groups of meroplanktin (Table 33). Crustaceans occurred in majority, mainly copepods and decapod larvae. Other common groups were bivalve veligers, chaetognaths, protozoea of *Lucifer*, cirripede nauplii, and larvaceans.

In Si Racha Bay, zooplankton belonging to 14 phyla was recorded: Sarcomastigophora, Ciliophora, Cnidaria, Ctenophora, Nemertea, Annelida, Mollusca, Arthropoda, Bryozoa, Phoronida, Chaetognatha, Echinodermata, Hemichordata and Chordata. They were identified into 17 groups of holoplankton and 23 groups of meroplantkon (Table 33). Crustaceans, mainly copepods, were predominant. Other common groups were cirripede nauplii, larvaceans, protozoea of *Lucifer*, chaetognaths, and polychaete larvae.

Table 33 Zooplankton diversity with mean, maximum and minimum abundance (ind.m^{-3}), and mean percentage of contribution (%) to total abundance of each taxon.

Taxa	**Manao Bay**				**Si Racha Bay**			
	Abundance (ind.m^{-3})			**Mean %**	**Abundance (ind.m^{-3})**			**Mean %**
	Mean	**Max**	**Min**		**Mean**	**Max**	**Min**	
Phylum Sarcomastigophora^{5}								
Foraminiferan	0.7	6	0	0.02	1	4	0	0
Radiolarian	18	54	0	0.52	2	9	0	0
Phylum Ciliophora^{5}								
Tintinnid	-	-	-	-	84	907	0	3
Phylum Cnidaria^{2}								
Hydromedusae	45	96	10	1.32	41	154	5	1
Phylum Ctenophora^{2}								
Cydippid larvae	-	-	-	-	0	1	0	0
Ctenophore	-	-	-	-	1	7	0	0

Table 33 (Continued)

Taxa	Manao Bay				Si Racha Bay			
	Abundance (ind.m^{-3})			**Mean %**	**Abundance (ind.m^{-3})**			**Mean %**
	Mean	**Max**	**Min**		**Mean**	**Max**	**Min**	
Phylum Nemertea[1]								
Pilidium larvae	-	-	-	-	2	10	0	0
Phylum Annelida								
Polychaete larvae[1]	77	223	8	2.28	85	344	10	3
Tomopterid[5]	-	-	-	-	2	11	0	0
Phylum Mollusca[1]								
Gastropod veliger	39	120	0	1.16	24	64	3	1
Bivalve veliger	266	1268	7	7.86	41	101	15	1
Pteropod	33	81	0	0.98	4	26	0	0
Phylum Arthropoda								
Penilia avirostris Dana[5]	7	20	0	0.22	-	-	-	-
Pseudevadne tergestina Claus[5]	37	182	0	1.08	41	330	0	1
Ostracod[5]	6	15	0	0.18	0	1	0	0
Copepod nauplii[1]	17	73	0	0.52	54	123	7	2
Pontellid nauplii[1]	-	-	-	-	3	14	0	0
Copepod[3]	1749	2544	1001	52	1570	4320	509	48
Cirrepede nauplii[1]	153	478	16	4.53	509	1206	217	19
Cypris larvae[1]	28	211	0	0.82	31	194	0	1
Mysid[5]	3	23	0	0.09	0	3	0	0
Amphipod[5]	0.6	4	0	0.02	2	16	0	0

Table 33 (Continued)

Taxa	**Manao Bay**				**Si Racha Bay**			
	Abundance (ind.m^{-3})			**Mean %**	**Abundance (ind.m^{-3})**			**Mean %**
	Mean	**Max**	**Min**		**Mean**	**Max**	**Min**	
Protozoea of *Lucifer*[1]	218	740	25	6.45	114	298	36	4
Lucifer sp.[5]	90	447	4	2.67	56	245	10	2
Protozoea of *Acetes*[1]	12	59	0	0.37	-	-	-	-
Acetes sp.[5]	75	499	0	2.23	-	-	-	-
Euphausiid[5]	-	-	-	-	0	1	0	0
Shrimp larvae[1]	24	113	0	0.72	33	128	2	1
Brachyuran zoea[1]	31	136	5	0.92	13	65	0	0
Brachyuran megalopa[1]	0.9	6	0	0.03	1	6	0	0
Porcellanid larvae[1]	0.3	3	0	0.01	-	-	-	-
Alima larvae[1]	0.7	4	0	0.02	-	-	-	-
Phylum Bryozoa								
Cyphonautes larvae[1]	-	-	-	-	0	2	0	0
Phylum Phoronida								
Actinotrocha larvae[1]	-	-	-	-	1	9	0	0
Phylum Chaetognatha								
Sagitta spp.[4]	233	371	58	6.88	127	285	41	4
Phylum Echinodermata[1]								
Bipinnaria larvae	0.9	4	0	0.03	0	4	0	0
Auricularia larvae	-	-	-	-	1	4	0	0
Echinopluteus larvae	7	18	0	0.20	11	38	0	0

Table 33 (Continued)

Taxa	Manao Bay				Si Racha Bay			
	Abundance (ind.m^{-3})			**Mean %**	**Abundance (ind.m^{-3})**			**Mean %**
	Mean	**Max**	**Min**		**Mean**	**Max**	**Min**	
Ophiopluteus larvae	79	313	0	2.34	27	87	0	1
Phylum Hemichordata[1]								
Tornaria larvae	-	-	-	-	0	1	0	0
Phylum Chordata								
Larvacean[2]	122	322	24	3.61	166	746	17	5
Thaliacean[2]	2	19	0	0.05	64	414	0	2
Tadpole larvae[1]	-	-	-	-	0	4	0	0
Fish eggs[1]	1	7	0	0.04	36	179	0	1
Fish larvae[5]	3	10	0	0.08	12	8	0	0

Remark: - = not found; [1] meroplankton; [2] gelatinous zooplankton; [3] copepods; [4] chaetognath; [5] others

2. Abundance

In Manao Bay, total abundance of zooplankton varied from a minimum of 1,582 ind. m^{-3} in July 2007 to a maximum of 5,676 ind. m^{-3} in June 2007, with an average of 3,380 ± 1,264 ind. m^{-3} (Figure 53). Two peaks in abundance were observed in April and June 2007, coincided with the abundance of bivalve veliger, copepodid stages of copepods, protozoea of *Lucifer*, protozoea of *Acetes*, adult copepods, and chaetognaths. Three minimum values were found in September 2006, and January and July 2007. The 95% confidence interval was 3,380 ± 803 ind. m^{-3}. The temporal variation showed significantly higher values, compared to mean, in April and June 2007, and lower values were found in September 2006 and January and July 2007.

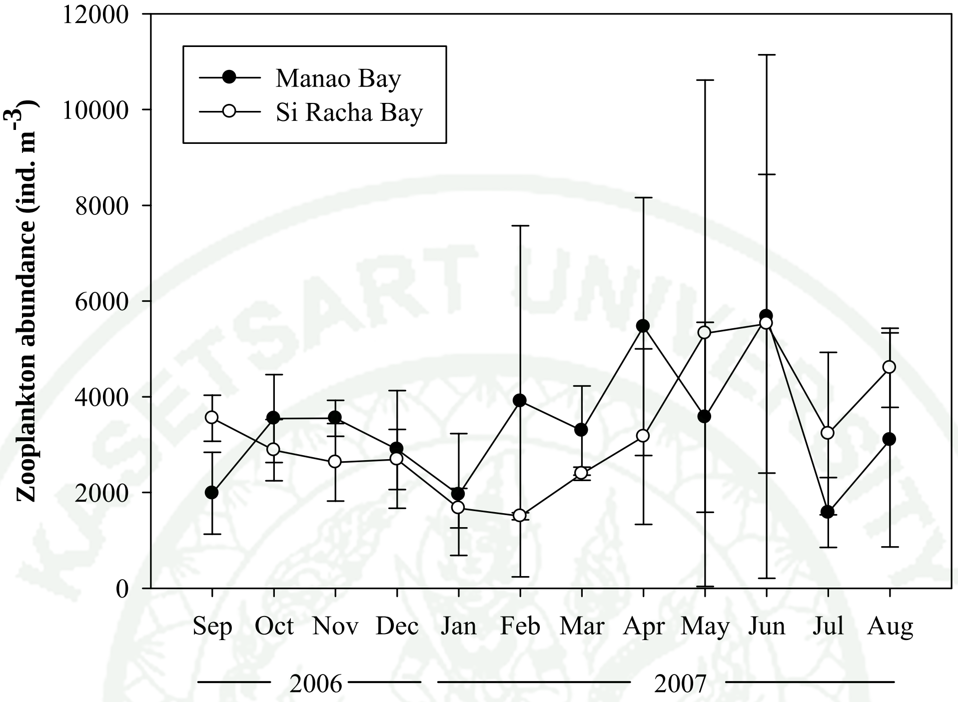


Figure 53 Total abundance of zooplankton in Manao Bay and Si Racha Bay, during September 2006 and August 2007.

In Si Racha Bay, total abundance of zooplankton varied from a minimum of 1,504 ind. m^{-3} in February 2007 to a maximum of 5,526 ind. m^{-3} in June 2007 with the mean abundance of 3,265 ± 1,298 ind. m^{-3} (Figure 53). Two peaks in abundance were observed in May and June 2007, coincided with the abundance of copepods and cirripede nauplii. Minimum values were found in January to February 2007. The 95% confidence interval was 3,265 ± 825 ind. m^{-3} during the sampling period. The results showed significantly higher abundance, compared to mean, in May, June and August 2007, and lower values found in January, February and March 2007.

Regarding seasonal variation, the average abundance of zooplankton was highest (4,380 ± 1536 ind. m^{-3}) in summer (March – April), followed by the Southwest monsoon season (3,269 ± 1,456 ind. m^{-3}) and the Northeast monsoon season (3,045 ± 834 ind. m^{-3}), in Manao Bay (Figure 54), though, no statistical difference was found during the whole study period.

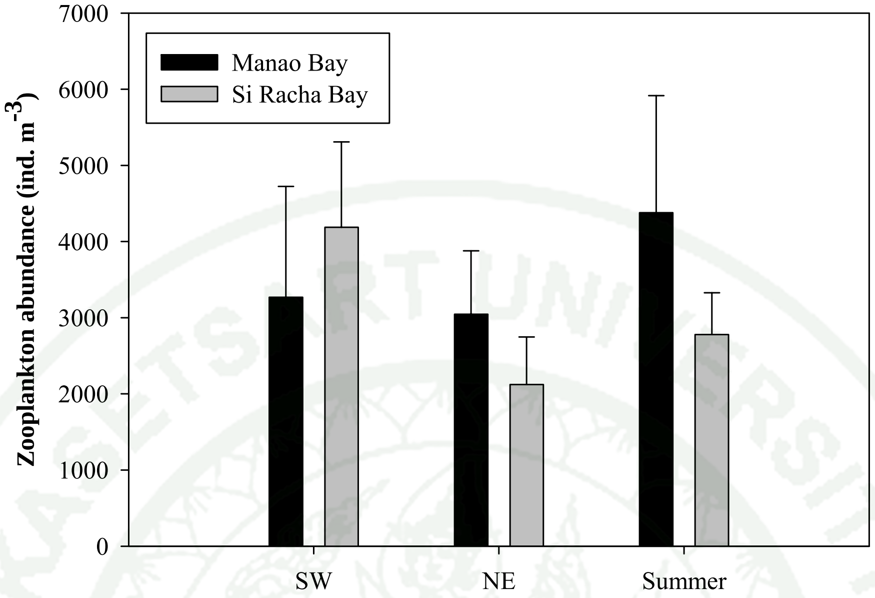


Figure 54 Averaged seasonal abundance of total zooplankton in Manao Bay and Si Racha Bay, during September 2006 and August 2007.

In Southwest monsoon season, the average abundance of zooplankton in Si Racha Bay estimated the highest value (4,188 ± 1,121 ind. m^{-3}), followed by summer period (2,779 ± 548 ind. m^{-3}) and the Northeast monsoon season (2,124 ± 623 ind. m^{-3}). Figure 54 shows the noticeable trend between the two monsoon seasons, but the average abundance during the whole sampling period was not statistically different.

3. Contribution percentage

In Manao Bay, copepods were predominant, contributing 52% to total zooplankton abundance, with their mean abundance of 1,767 ± 553 ind. m^{-3}. The other four subdominant groups were meroplankton or larval forms (20%), others (15%), Chaetognaths (7%) and gelatinous zooplankton (6%). The remaining were those having generally low abundance or absent in some months (Table 33). Figure 55a shows the percentages in composition of the main zooplankton groups during the sampling period. The most dominant group was copepods, which generally dominated with the highest percentage. While meroplankton increased their percentage in summer (March-April) and the Southwest monsoon (May to September), copepods, as the holoplankton, decreased their composition of total zooplankton abundance. In addition, gelatinous zooplankton increased their proportion of occurrence in August and December.

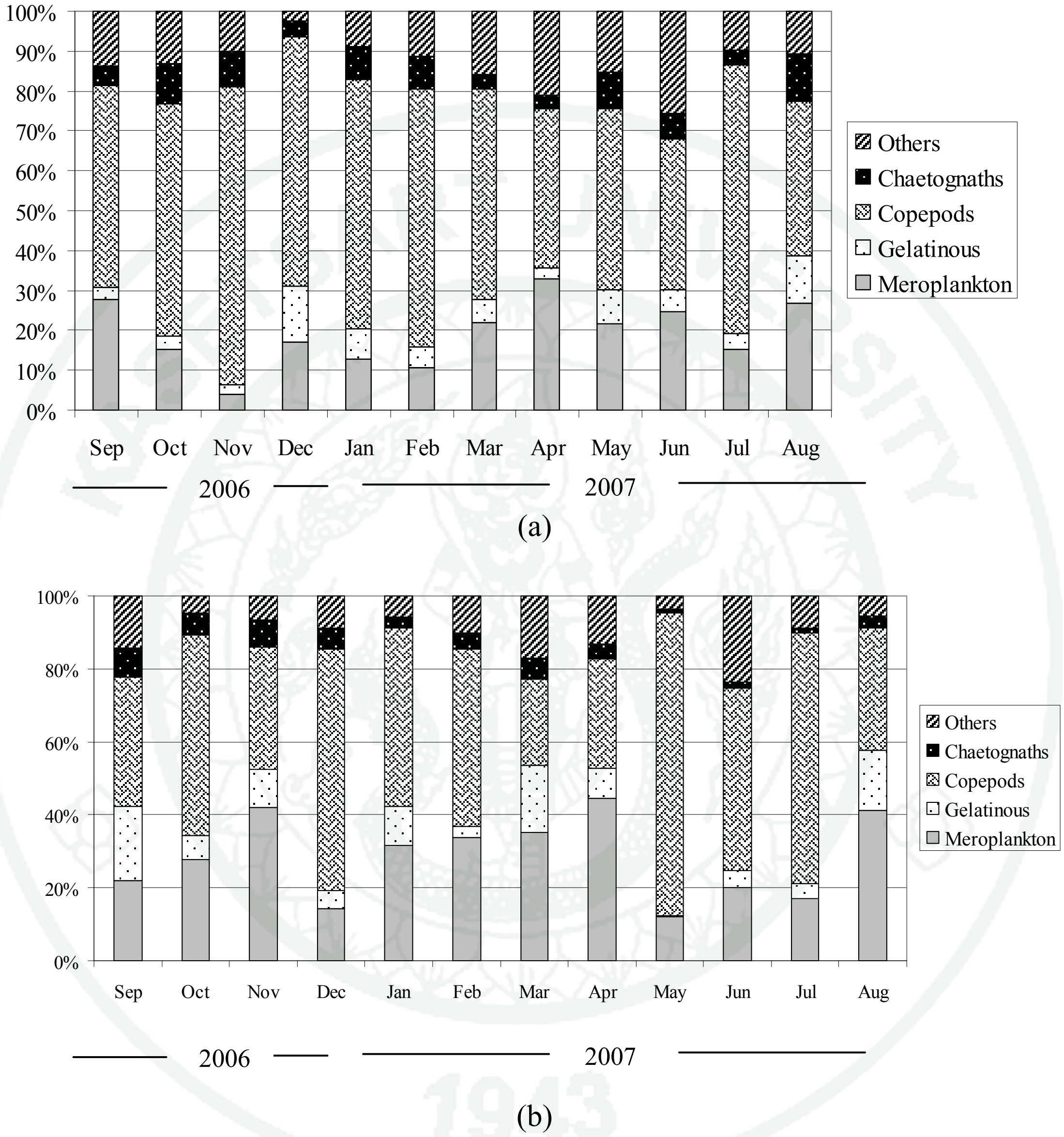


Figure 55 Temporal contribution percentage of zooplankton in Manao bay (a) and Si Racha bay (b).

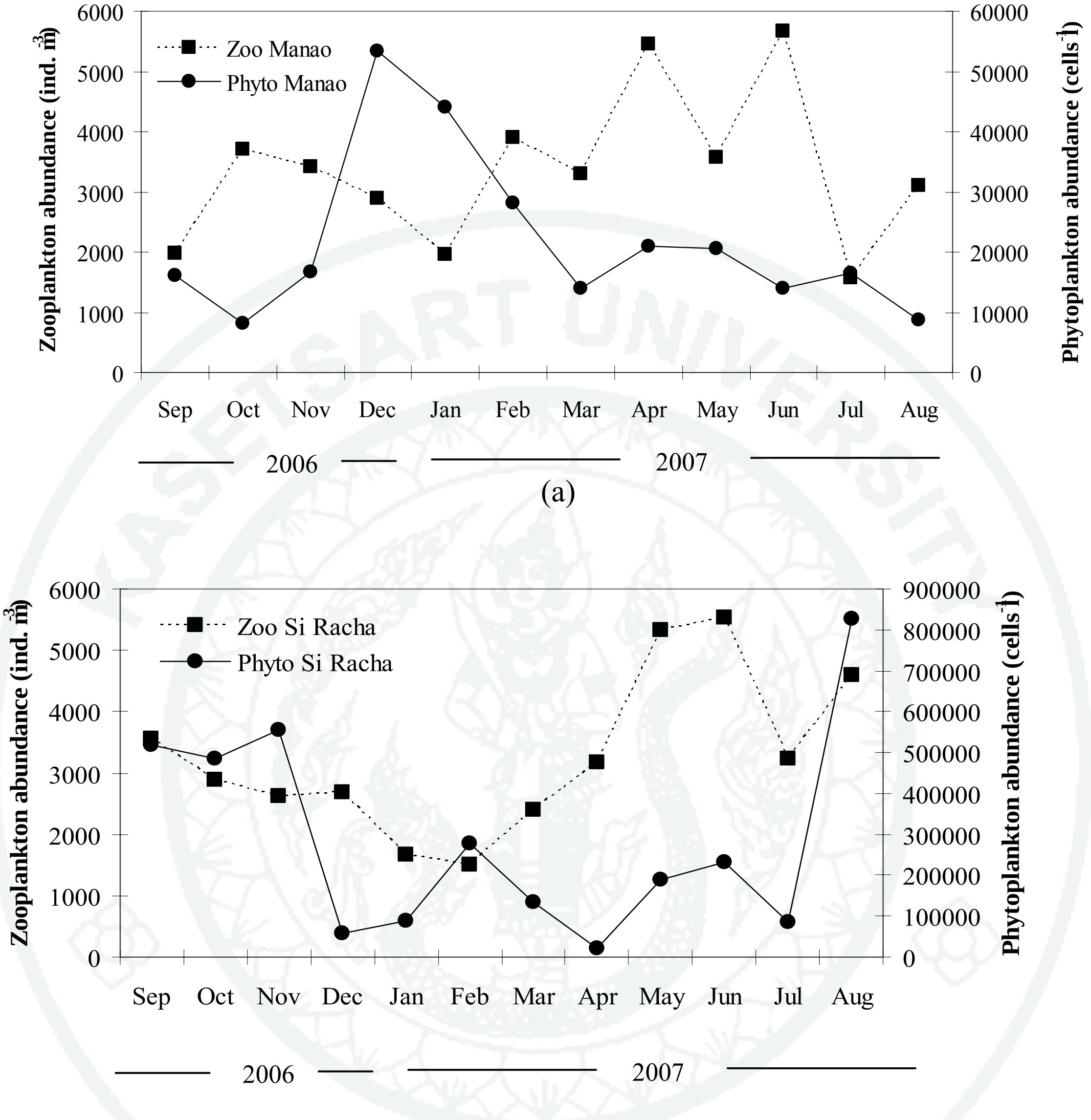
In Si Racha Bay, copepods, mostly copepodid stages and adults, dominated over other groups, contributing 48 % to the total zooplankton abundance in the eastern coast, with a mean value of 1,627 ± 1098 ind. m^{-3} (Table 33). Four subdominant groups were meroplankton (27 %), others (11 %), gelatinous zooplankton (9%) and chaetognaths (4 %) (Figure 55 b). The noticeable variation presented in August, November, and January to

April, that the percentage of copepods decreased while the proportion of meroplankton increased.

The dominant group of zooplankton was copepods, which contributed the highest abundance over the sampling period. This result agreed with previous findings by Sribyatte (1996), Jivaluk (1999), Panchote (2005), Boondao (2006) and Srinui (2007) in the Gulf of Thailand. Long-term monitoring in composition and abundance of zooplankton by Sribyatte (1996) who found that the seasonal patterns were not different between the Southwest and Northeast monsoons in the upper western coast of the Gulf of Thailand. In this regard, a maximum abundance was recorded in July and a minimum value was marked in March with data obtained from a 330 μm mesh size plankton net.

4. Phytoplankton versus zooplankton

Figure 56 a and b show the graphs plotted phytoplankton abundance against zooplankton abundance from September 2006 to August 2007 in both study areas. The results showed basically trend, hence the zooplankton abundance increased, phytoplankton decreased by grazing. These could be explained that grazing by zooplankton in the coastal areas might control the phytoplankton crop. It is possible for the phytoplankton standing crop to decline due to grazing while the rate of primary productivity increases or remains steady (Nybakken, 2001). In Si Racha Bay, under the unlimited nutrient supply, important grazers might not be zooplankton but they should be green mussels that have highly potential suspension feeders (Hawkins *et al*., 1998).

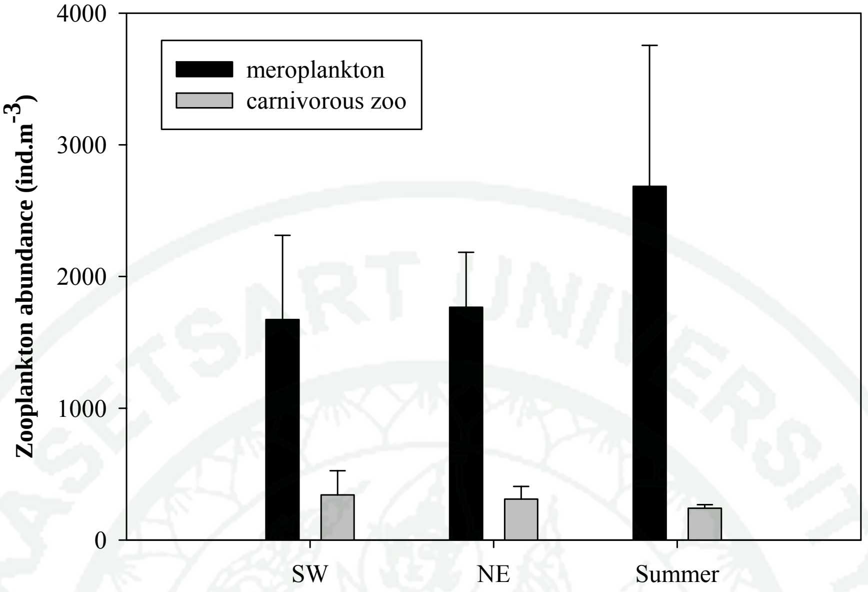


(a)

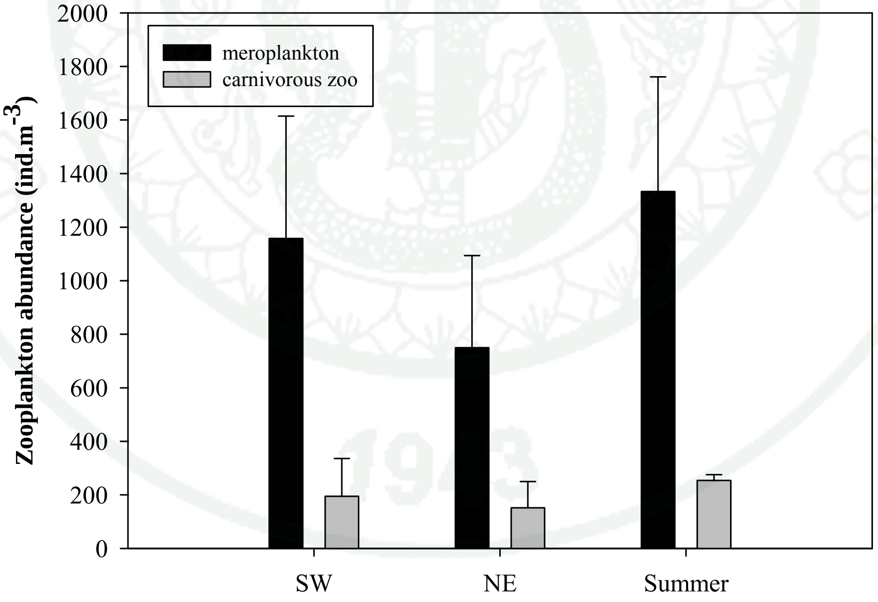
(b)

Figure 56 Abundance of phytoplankton plot against zooplankton abundance in Manao Bay (a) and Si Racha Bay (b), September 2006 to August 2007.

Different mesh sizes of sampling equipment influence the composition and abundance of zooplankton (Munk *et al*., 2003; Punnarak, 2004). Our study using a 200-µm plankton net showed a high proportion of copepodid larvae and other meroplankton. Figure 57 shows the abundance between merozooplankton and carnivorous zooplankton in both study areas. The contribution of meroplankton was significantly higher abundance than



(a)



(b)

Figure 57 Seasonal abundance of meroplankton and carnivorous zooplankton in Manao Bay (a) and Si Racha Bay (b), from September 2006 to August 2007.

those of carnivorous zooplankton in both monsoon seasons. It indicates that this was a high reproductive period for marine organisms, especially copepods and bivalves, in this study area (Poulet *et al*., 1995; Froneman, 2004; Hooff & Peterson, 2006; Castro and Huber, 2008). These results supported that the coastal areas are suitable for nursing marine larvae because of providing high primary production.

4. Pearson correlation

a) Phytoplankton and hydrographic parameters

Pearson correlation analyses between hydrographic parameters, nutrients and phytoplankton abundance are shown in Table 34. In Manao Bay, phytoplankton abundance was positively correlated to nitrite (r = 0.537, P<0.5), dissolved oxygen (r = 0.708, P<0.5) and pH (r = 0.529, P<0.5) while was no negative correlation. However, phytoplankton abundance showed no correlation with nitrate, ammonia, orthophosphate, silicate, chlorophyll a concentration, salinity and water temperature.

Accordingly, the correlation analysis indicated that chlorophyll a concentration (phytoplankton biomass) was positively correlated to temperature (r = 0.511, P<0.05), while negatively correlation to salinity (r = -0.557, P<0.05). Other hydrographical parameters (dissolved oxygen, pH, rainfall) and nutrients (nitrite, ammonia, orthophosphate, silicate) were not correlated to chlorophyll a concentration in Manao Bay.

In Si Racha Bay, phytoplankton abundance was not correlated to hydrographical parameters (water temperature, salinity, dissolved oxygen, pH, rainfall) and also nutrients (nitrite, nitrate, ammonia, orthophosphate, silicate) (Table 34). Similarity with abundance, the results of correlation between hydrographic parameters, nutrients and phytoplankton biomass indicated that chlorophyll a concentration was negatively correlated to salinity (r = -0.661, P<0.05) and ammonia (r = -0.546, P<0.05). Other hydrographical parameters (temperature, dissolved oxygen, rainfall, pH) and nutrients (nitrite, nitrate, orthophosphate, silicate) were not correlated to chlorophyll a concentration.

Table 34 Correlation coefficients (r) in relationships between hydrographic parameters, nutrients and phytoplankton abundance; * *P*<0.05.

Parameter	**Manao Bay**		**Si Racha Bay**	
	Chlorophyll a	**Phytoplankton**	**Chlorophyll a**	**Phytoplankton**
Water temperature (°C)	**0.51***	-0.29	0.34	0.11
Salinity (psu)	**-0.56***	-0.01	**-0.66***	-0.28
Dissolved oxygen (mg l^{-1})	-0.15	**0.71***	-0.33	0.12
pH	-0.27	**0.53***	0.18	0.25
Rainfall (mm)	0.45	-0.25	0.24	0.44
Nitrite (mg l^{-1})	0.14	**0.54***	0.05	0.07
Nitrate (mg l^{-1})	-0.05	-0.01	-0.22	-0.30
Ammonia (mg l^{-1})	0.31	-0.28	**-0.55***	-0.39
Orthophosphate (mg l^{-1})	0.00	-0.27	-0.29	-0.35
Silicate (mg l^{-1})	-0.29	-0.43	0.14	-0.01
Chlorophyll a (mg m^{-3})	-	-0.02	-	0.24

b) Zooplankton and hydrographic parameters

In Manao Bay, zooplankton abundance was positively related to chlorophyll a concentration (r = 0.62, *P*<0.05); hence, when the chlorophyll a concentration was high the zooplankton abundance increased (Table 35). The abundance of zooplankton had no correlation to other environmental values (water temperature, salinity, rainfall, DO, and pH).

Results on Pearson correlation analyses between hydrographic parameters, nutrients and zooplankton abundance in Si Racha Bay are shown in Table 35. The data indicated that zooplankton abundance was positively correlated to water temperature (r = 0.71, *P*<0.05), pH (r = 0.60, *P*<0.05) and rainfall (r = 0.58, *P*<0.05). Other hydrographical parameters (dissolved oxygen, salinity) and chlorophyll a concentration had no correlation to zooplankton abundance.

Table 35 Correlation coefficients (r) in relationships between hydrographic parameters, chlorophyll a concentration and zooplankton abundance; * P<0.05.

Parameter	Manao Bay	Si Racha Bay
Water temperature (°C)	0.17	**0.71***
Salinity (psu)	-0.38	-0.40
Dissolved oxygen (mg l^{-1})	0.30	-0.09
pH	0.18	**0.60***
Rainfall (mm)	-0.01	**0.58***
Chlorophyll a (mg m^{-3})	**0.62***	0.12

Relationships between hydrographical parameters and nutrients, and variation of phytoplankton and zooplankton abundances varied among monsoon seasons were not clearly demonstrated. This can be explained by the well-mixed tidal currents and no freshwater discharges in both bays. All parameters slightly fluctuated in narrow ranges over the sampling period in Manao bay. It showed that fairly constant conditions in this semi-enclosed bay are probably due to the nutrient limitation (Munk *et al*., 2003; Rodrigo *et al*., 2003). Moreover, it was difficult to compare with the previous reports by Thongbor (2004), Boondao (2006), and Permsirivanich (2007) because of different sampling equipments and techniques used, and also these studies covered only 2 restricted areas in the coastal areas of the upper Gulf of Thailand.

Generally, diatoms formed the majority in phytoplankton community and utilized silicate for their frustules; hence, when phytoplankton abundance increased, silicate decreased (Turner, *et al*., 1998; Wu and Chou, 2003). In addition, the ration of silicate to the dissolved inorganic nitrogen ratio was above 1:1 that is suitable for marine diatom growth, and also potentially controls the coastal phytoplankton community (Karl *et al*., 1998; Turner *et al*., 1998).

The decreasing trend of phytoplankton biomass during the Northeast monsoon and summer months could be explained by mussel grazing, as the study area was located in the area of aquaculture rafts in Si Racha Bay. Our results clearly showed two peaks of bivalve veliger larvae abundance in April and May 2007. This might indicate a high reproductive phase for mussels in this area. The bivalve filtration highly affected the fluctuation in both composition and abundance of suspended seston (Hawkins *et al*., 1998; Norén *et al*., 1999).

Other grazing on phytoplankton also comes from zooplankton across the trophic structure or food web (Landry *et al*., 1995; Turner, 2004). In addition to the temporal variation, there may be seasonal availability in food supply to the filtration activity of the mussels. However, the local food competition requires knowledge of the interactions between the environments and food supply on the mussel population (Dame and Prins, 1998; Prins *et al*., 1998). On the other hand, the amounts of inorganic nutrients released from mussel populations and sediment re-suspension may be a major source of nutrients for phytoplankton in Si Racha Bay. Finally, an evaluation of relationship between mussel growth and production and their environment is required to establish a model of the mussel role in the pelagic ecosystem.

One implication from this study was that chlorophyll a concentration represented a primary production in the water column that was negatively correlated to salinity in both sampling areas. These results demonstrated clear relationship between environmental parameters and primary production and also that salinity were influenced by monsoon seasons (Robinson, 1963; Snidvongs and Sojisuporn, 1999). Moreover, phytoplankton in Si Racha Bay showed significantly higher abundance than that in Manao Bay. It supported that dissolved inorganic nitrogen is an important factor for phytoplankton growth in coastal waters (Bot and Colijn, 1996; Karl *et al*., 1998; Philippart *et al*., 2000; Howarth and Marino, 2006).

This finding suggests that chlorophyll a concentration could be a better indicator for enrichment determination and correlation with environmental variability than phytoplankton abundance. In addition, chlorophyll a concentration representing most phytoplankton composition in the water column but phytoplankton abundance is based on larger cells (> 20 μm) such as diatoms and underestimating nano- and picoplankton (Bot and Colijn, 1996; McQuatters-Gollop *et al*., 2007).

CONCLUSION AND RECOMMENDATION

Conclusion

This study involved the comparison of copepods community structure and the production of *A. erythraea* in terms of biological processes between two study areas: Manao Bay and Si Racha Bay. One hypothesis was set up based on the concept that the variation of quantity and quality of food available was the major factor affecting to growth rate and production of planktonic copepods (both adult and juvenile stages), and also associated with hydrographic parameters at both areas. Additionally, the plankton community and production of *A. erythraea* in Manao Bay was not equal to those of *A. erythraea* in Si Racha Bay.

1. Planktonic copepods community structure

Fourty-six species in 27 genera were recorded in the upper Gulf of Thailand from September 2006 to August 2007. The combined data from two types of mesh sizes (200 and 330 µm). The calanoid copepods comprised 27 species, followed by cyclopoid copepods (13 species) and harpacticoid copepods (6 species). This result established new records of copepods in Thai waters, such as a cyclopoid copepod, *Kelleria australica* Bayly, 1971. Calanoid copepods: *Labidocera bataviae* A. Scott and *L. pectinata* Thompson & Scott were new recorded in the upper Gulf of Thailand.

Six dominant species observed were the estuarine and neritic species. They were *Acartia erythraea*, *Acrocalanus gibber*, *Centropages furcatus*, *C. orsinii*, *Euterpina acutifrons* and *Pseudodiaptomus aurivilli*. Five oceanic species occurred in high frequency were *Clytemnestra scutellata*, *Corycaeus asiaticus*, *Oithona* spp., *Oncaea conifera* and *Subeucalanus subcrassus*. In terms of percentage or frequency of occurrence, the majority group was sporadic species (21 species), followed by the very frequent species (14 species) and the frequent species (5 species) and the infrequent species (5 species).

Regarding copepod abundance, the average abundance of 200-µm net samples was remarkably higher than 330-µm abundance up to 4-5 times. The average abundance of planktonic copepods were 4,348 ± 398 ind. m^{-3}, based on 200-µm net and 912 ± 129 ind. m^{-3}, based on 330-µm net in the upper Gulf of Thailand. The main contribution was copepodid stages over other stages, bringing about 64-83% of the total copepods abundance based on the 200-µm net. While, the 330-µm net samples showed mixture of copepodid stages and adult *A. erythraea* contributing about 30% to the total copepods abundance. The temporal and seasonal variation in abundance of planktonic copepods varied according to the different areas.

The trophic structure of planktonic copepods in the upper Gulf of Thailand showed the highest composition of carnivorous copepods (24 species), followed by omnivores (14 species) and herbivores (5 species). In terms of contribution percentage to the total abundance, the carnivores varied from 39 – 50 %, based on the 200-µm net and 20-30 %, based on 330-µm net. The omnivorous copepods dominated from 38-52 %, based on the 200-µm net and 57-74 %, based on 330-µm net. The lowest contribution was the herbivorous copepods estimating of only 10 %, based on the 200-µm net and 7-13 %, based on 330-µm net

Shannon diversity index (H´) could revealed differences between the 200- and 330-µm net used. The 200- µm net showed the significant higher diversity index than that of the 330- µm net. Temporal variations in diversity indices of planktonic copepods in the upper Gulf of Thailand were found and they showed significant differences. Diversity indices of the 200- µm net samples varied from 0.47-2.49 while the 330- µm net samples diversity index ranged from 0.36-2.14.

2. The length-weight relationship

The prosome length and weight of *A. erythraea* were examined in Manao Bay from September 2006 to August 2007. The average prosome length of adult male and female were 951 ± 20 µm and 1,055 ± 31 µm, respectively. The average width of adult male and female were 316 ± 12 µm and 330 ± 21 µm, respectively. The dry weight and carbon weight of male were 7.15 ± 0.58 µg and 4.96 ± 1.0 µg and female dry weight and carbon weight of male were 8.04 ± 0.66 µg and 5.48 ± 1.06 µg. The prosome length, dry weight and carbon weight of fouth copepodid stage (CIV) were 724 ± 41 µm, 2.4 µg DW and 1.67 µg CW. Prosome length, dry weight and carbon weight of fifth copepodid stage (CV) were 878 ± 26 µm, 3.7 µg DW and 2.56 µg CW.

The length to -weight equation of *A. erythraea* was established in prosome length (µm) and dry and carbon weight (µg). The regressions are presented in the following equations:

$$\ln CW = 2.48 \ln L - 16.1 \qquad R^2 = 0.75$$

$$\ln DW = 2.66 \ln L - 16.5 \qquad R^2 = 0.76$$

The carbon weight of copepod was lost about 53 % during one year preservation in formaldehyde – seawater buffered solution at 10 % of the final concentration. In addition, average dry and carbon weight equation was CW = 0.471 DW, R^2=0.97.

3. The egg production rate and weight specific growth rate

The egg production rate (EPR) of *A. erythraea* was conducted from January – August 2008. The average EPR of *A. erythraea* was 1.02 egg female^{-1} d^{-1} in the coastal areas of the upper Gulf of Thailand. The weight specific growth rate was calculated from the weight of egg produced in the incubation time (24 hr.) and female weight. The average weight specific growth rate of female from January – August 2008 was 0.0096 ± 0.0066 d^{-1}.

On comparison of EPR between both study areas, the EPR of *Acartia* in Si Racha Bay (1.28 ± 0.94 egg female^{-1} d^{-1}) showed higher value than that of *Acartia* in Manao Bay (0.75 ± 0.77 egg female^{-1} d^{-1}). According to mean EPR, the growth rate of *Acartia* in Si Racha (0.0121 ± 0.01 d^{-1}) also showed higher value than that of *Acartia* in Manao Bay (0.0072 ± 0.006 d^{-1}).

4. Annual biomass

The average annual biomass of *A. erythraea* was determined from September 2006 to August 2007 in the coastal areas of the upper Gulf of Thailand. The average biomass were 1.08 ± 0.73 mg C m^{-3}. Additionally, the total biomass of phytoplankton and zooplankton based on the 200- and 330-µm net samples were estimated as 52, 4.81 and 2.49 mg C m^{-3} in Manao Bay. In Si Racha Bay the biomass of phytoplankton and zooplankton based on the 200- and 330-µm net samples were 104, 5.65 and 2.61 mg C m^{-3}, respectively. Finally, the total biomass of plankton community was 66.04 mg C m^{-3} (Manao Bay) and 112.26 mg C m^{-3} (Si Racha Bay).

5. Secondary production and turnover rate

Secondary production and turnover rate (P:B ratio) of *A. erythraea* were determined in the coastal areas of the upper Gulf of Thailand from January to August 2008. In general secondary production average value was very low (0.0003 ± 0.0003 mg C m^{-3} d^{-1}) over the study period. The value recorded for Manao Bay was much lower than that of Si Racha Bay, 0.000014 ± 0.00003 versus 0.0005 ± 0.0006 mg C m^{-3} d^{-1}). Regarding turnover rate values, they appeared to be rather low (average 0.009 ± 0.01 d^{-1}). Similar trend was observed for both areas; the value recorded at Manao Bay was lower than that of Si Racha Bay (0.0051 ± 0.006 versus 0.012 ± 0.01 d^{-1}).

These results showed significantly difference of *Acartia* secondary production rate between two study areas. The important factors were quantity and quality of food available which varied and associated with hydrographic parameters at both areas. In addition, microzooplankton might be an important trophic linkage between primary and secondary production in the areas.

Recommendation

This is the first study involved a single species of the dominant zooplankton in the tropical area. Further study should be determined on other important zooplankton group in terms of length and weight relationship. The carbon content of phytoplankton related to chlorophyll a concentration should be considered. Then the trophodynamic of plankton community can be assessed and evaluated to the top predator. Knowledge on integrated pelagic ecosystem will help to manage fishery resources and environmental conservation in the coastal zones.

Regarding to the length-weight relationship of *Acartia erythraea*, the prosome length - dry weight regression could be applied for general aspects, because the dry weight technique is simpler than the carbon technique. The egg production rate of *A. erythraea* should determine every month to confirm the enrichment of the sea throughout an annual cycle. Interpretation of secondary production rate should be considered for turnover rate are the real time determination in the field to obtain data in the same sampling period.

As *A. erythraea* expressed the highly abundance and frequency of occurrence throughout the annual cycle in both study areas, *Acartia* is an appropriate test organism for toxicity tests or live food for marine fish. Moreover, *Acartia* is characterized by its short life span, high adaptive in surviving from unfavorable condition and also ability to continuously produce egg which only one copulation with male required.

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APPENDIX

Appendix Table 1 Taxonomic lists of copepods abundance (ind.m^{-3}), mean value and contribution to total abundance of each taxon in Manao Bay, based on the 200- μm in mesh size from September 2006 to August 2007.

Taxa	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Average**	**SD**	**%**
Order CALANOIDA															
Acartia erythraea	165	314	200	288	199	306	502	513	257	559	52	138	**291**	**160**	**7**
Candacia catula	0	0	0	0	0	0	0	0	0	0	0	2	**0**	**1**	**0**
Centropages furcatus	14	21	34	22	16	48	73	103	52	16	8	46	**38**	**28**	**1**
C. orsinii	0	3	6	16	15	8	10	5	13	37	0	1	**10**	**10**	**0**
C. tenuiremis	6	2	0	0	24	7	3	0	0	3	0	0	**4**	**7**	**0**
Calanopia aurivilli	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**
C. thompsoni	0	0	0	0	5	0	0	0	0	0	0	0	**0**	**1**	**0**
Labidocera bipinnata	0	2	0	0	0	0	0	0	0	0	0	0	**0**	**1**	**0**
L. minuta	0	2	4	0	0	3	5	5	1	0	1	0	**2**	**2**	**0**
L. pectinata	0	0	0	0	2	9	0	0	0	0	0	0	**1**	**3**	**0**
Pseudodiaptomus aurivilli	36	291	122	0	137	351	265	216	138	178	58	66	**155**	**109**	**4**
P. clevei	0	2	0	0	12	0	0	37	0	0	44	2	**8**	**16**	**0**
Tortanus forcipatus	0	9	0	0	0	0	0	2	1	29	7	7	**5**	**8**	**0**
T. gracilis	0	0	0	0	0	0	0	3	6	15	0	3	**2**	**4**	**0**
Canthocalanus puaper	0	3	8	0	0	0	0	0	0	0	0	11	**2**	**4**	**0**
Acrocalanus gibber	95	73	157	233	77	67	62	59	151	137	38	129	**107**	**56**	**3**

Appendix Table 1 (Continued)

Taxa	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Average**	**SD**	**%**
Paracalanus aculeatus	0	2	183	21	0	0	0	0	0	0	0	0	**17**	**52**	**0**
Subeucalanus subcrassus	0	0	7	3	48	6	6	0	0	27	1	27	**10**	**15**	**0**
Order HARPACTICOIDA															**0**
Macrosetella gracilis	0	0	0	0	0	6	0	14	9	75	1	0	**9**	**21**	**0**
Microsetella norvegica	0	2	0	0	0	0	5	0	2	0	5	0	**1**	**2**	**0**
Cleytemnestra scutellata	0	22	13	0	4	13	30	32	23	75	5	13	**19**	**21**	**0**
Euterpina acutifrons	73	105	88	32	552	220	43	71	172	277	134	118	**157**	**144**	**4**
Order CYCLOPOIDA															
Oithona plumnifera	10	3	18	47	21	70	38	18	24	5	5	44	**25**	**21**	**1**
Oithona spp.	40	19	63	184	72	212	204	163	303	64	43	140	**126**	**88**	**3**
Oncaea conifera	4	92	18	4	37	57	67	64	192	16	148	102	**67**	**59**	**2**
Corycaeus asiaticus	557	123	48	112	63	398	167	132	201	230	108	144	**190**	**148**	**5**
C. catus	387	98	57	33	49	54	150	13	116	70	43	74	**95**	**99**	**2**
C. speciosus	10	67	9	35	17	56	62	53	33	42	24	39	**37**	**20**	**1**
Sapphirina stellata	0	0	0	0	0	0	0	0	2	0	0	0	**0**	**1**	**0**
Copepod nauplii	0	0	0	0	281	221	57	28	45	150	51	102	**78**	**94**	**2**
Copepodid	1396	2447	3448	1313	2303	4333	3057	3776	3210	3082	1757	1212	**2611**	**1035**	**64**

Appendix Table 1 (Continued)

Taxa	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Average	SD	%
Total	**2793**	**3701**	**4483**	**2342**	**3934**	**6446**	**4806**	**5308**	**4952**	**5088**	**2535**	**2420**	**4067**	**1333**	**100**

Appendix Table 2 Taxonomic lists of copepods abundance (ind.m^{-3}), mean value and contribution to total abundance of each taxon in Manao Bay, based on the 330- μm in mesh size from September 2006 to August 2007.

Taxa	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Average**	**SD**	**%**
Order CALANOIDA															
Acartia erythraea	92	319	220	335	247	407	422	415	316	709	99	234	**318**	**166**	**32**
Candacia catula	0	0	0	0	0	0	0	0	0	0	0	1	**0**	**0**	**0**
Centropages furcatus	24	17	17	26	12	22	87	53	50	37	1	21	**31**	**23**	**3**
C. orsinii	2	1	0	0	25	29	16	34	8	53	2	7	**15**	**17**	**1**
C. tenuiremis	0	0	0	0	42	18	0	1	0	2	0	1	**5**	**13**	**1**
Calanopia aurivilli	0	0	0	5	5	13	0	0	0	0	0	0	**2**	**4**	**0**
C. thompsoni	0	0	0	0	6	0	0	0	0	6	0	0	**1**	**2**	**0**
Labidocera bataviae	0	0	0	0	0	0	0	0	2	0	0	0	**0**	**0**	**0**
L. bipinnata	0	0	0	0	1	0	0	0	3	0	0	0	**0**	**1**	**0**
L. minuta	0	6	14	0	0	11	0	0	4	4	4	0	**4**	**5**	**0**
L. pectinata	0	0	0	0	1	10	0	0	2	0	0	0	**1**	**3**	**0**
L. rotunda	0	0	0	0	0	0	0	0	1	0	0	0	**0**	**0**	**0**
Pseudodiaptomus aurivilli	28	224	104	18	83	383	224	109	296	165	52	78	**147**	**114**	**15**
P. clevei	0	0	8	0	7	3	0	7	0	0	25	4	**5**	**7**	**0**
Temora discaudata	0	0	1	0	6	0	0	0	0	0	0	0	**1**	**2**	**0**
Totanus forcipatus	0	8	0	0	0	0	6	0	10	13	10	8	**5**	**5**	**0**
T. gracilis	0	0	0	0	0	0	0	0	6	33	0	2	**3**	**9**	**0**

Appendix Table 2 (Continued)

Taxa	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Average**	**SD**	**%**
Canthocalanus puaper	0	0	31	5	10	0	0	0	0	0	0	3	**4**	**9**	**0**
Clausocalanus furcatus	8	43	31	0	0	0	0	0	0	0	0	0	**7**	**15**	**1**
Acrocalanus gibber	38	32	93	31	21	107	27	4	39	52	18	60	**43**	**30**	**4**
Paracalanus aculeatus	0	0	13	5	11	0	0	0	0	0	0	0	**2**	**5**	**0**
Subeucalanus subcrassus	10	62	47	21	93	15	4	2	5	5	11	11	**24**	**29**	**2**
Order HARPACTICOIDA															
Macrosetella gracilis	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**
Microsetella norvegica	0	0	0	0	0	0	0	0	0	0	0	7	**1**	**2**	**0**
Cleytemnestra scutellata	0	0	0	0	0	0	0	0	0	4	0	0	**0**	**1**	**0**
Euterpina acutifrons	0	0	2	0	4	0	0	0	2	0	0	0	**1**	**1**	**0**
Order CYCLOPOIDA															
Oithona plumnifera	0	0	0	0	0	0	4	2	3	0	8	28	**4**	**8**	**0**
Oithona spp.	0	9	2	3	0	2	0	0	0	0	7	8	**3**	**4**	**0**
Oncaea conifera	0	0	0	0	0	0	0	1	0	0	0	0	**0**	**0**	**0**
Corycaeus agilis	7	6	1	5	14	23	11	5	17	7	12	10	**10**	**6**	**1**
Corycaeus asiaticus	2	2	25	27	22	26	6	5	6	23	6	12	**14**	**10**	**1**
Corycaeus catus	0	0	0	0	0	0	0	0	0	18	0	0	**1**	**5**	**0**
Corycaeus speciosus	0	0	0	0	0	10	0	0	0	0	0	1	**1**	**3**	**0**
Sapphirina stellata	0	0	3	0	0	0	0	0	0	0	0	2	**0**	**1**	**0**

Appendix Table 2 (Continued)

Taxa	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Average**	**SD**	**%**
Copepod nauplii	0	0	0	0	16	3	2	0	2	4	5	6	**3**	**4**	**0**
Copepodid	161	316	216	213	645	684	181	216	446	378	346	367	**347**	**173**	**35**
Total	**371**	**1046**	**828**	**695**	**1271**	**1767**	**988**	**856**	**1218**	**1513**	**608**	**872**	**1003**	**391**	**100**

Appendix Table 3 Taxonomic lists of copepods abundance (ind.m^{-3}), mean value and contribution to total abundance of each taxon in Si Racha Bay, based on the 200- μm in mesh size from September 2006 to August 2007.

Taxa	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Average**	**SD**	**%**
Order CALANOIDA															
Acartia erythraea	310	188	225	250	86	87	108	94	1498	367	46	72	**278**	**398**	**6**
A. pacifica	24	17	0	0	0	0	0	0	0	0	0	0	**3**	**8**	**0**
A. spinicuada	35	0	0	0	0	0	0	0	0	0	0	0	**3**	**10**	**0**
Candacia bradyi	0	0	0	2	0	0	0	0	0	0	0	0	**0**	**1**	**0**
Centropages furcatus	45	9	39	53	40	32	29	19	0	22	0	0	**24**	**19**	**1**
C. orsinii	8	0	10	6	14	6	0	0	0	0	0	16	**5**	**6**	**0**
C. tenuiremis	2	0	8	19	2	24	9	8	0	0	0	0	**6**	**8**	**0**
Labidocera bengalensis	0	0	0	0	0	2	0	0	3	0	0	0	**0**	**1**	**0**
L. kroyeri	0	0	0	0	0	0	7	0	0	0	0	0	**1**	**2**	**0**
L. minuta	0	0	2	0	3	0	0	0	0	0	0	0	**0**	**1**	**0**
L. pectinata	7	0	0	0	0	0	0	0	19	0	0	18	**4**	**7**	**0**
Pseudodiaptomus aurivilli	43	0	59	101	29	15	88	188	32	0	4	0	**47**	**56**	**1**
P. clevei	8	0	0	0	5	2	0	0	3	0	0	0	**2**	**3**	**0**
Totanus forcipatus	3	2	13	31	10	36	5	23	0	0	0	4	**11**	**13**	**0**
Canthocalanus puaper	0	0	0	0	9	2	32	2	0	0	0	0	**4**	**9**	**0**
Acrocalanus gibber	161	24	28	5	11	12	0	6	0	6	0	0	**21**	**45**	**0**

Appendix Table 3 (Continued)

Taxa	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Average**	**SD**	**%**
Paracalanus aculeatus	0	165	28	127	11	7	0	4	0	19	0	0	**30**	**55**	**1**
Subeucalanus subcrassus	49	4	6	11	11	8	35	67	0	16	0	0	**17**	**22**	**0**
Temora discaudata	0	0	0	0	0	2	0	0	0	0	0	0	**0**	**1**	**0**
Order HARPACTICOIDA															
Macrosetella gracilis	5	0	0	0	0	2	10	16	0	0	0	0	**3**	**5**	**0**
Microsetella norvegica	0	0	0	2	0	0	0	0	0	0	0	0	**0**	**1**	**0**
M. rosea	0	0	0	0	0	0	10	6	0	0	0	0	**1**	**3**	**0**
Cleytemnestra scutellata	8	0	12	3	4	2	18	25	13	0	0	0	**7**	**8**	**0**
Euterpina acutifrons	55	96	382	54	93	74	86	29	27	40	19	49	**84**	**98**	**2**
Longipedia sp.	0	23	10	0	0	7	0	0	0	0	0	8	**4**	**7**	**0**
Order CYCLOPOIDA															
Oithona spp.	62	181	269	103	131	77	144	66	63	11	25	20	**96**	**75**	**2**
Acantholochus sp.	0	0	0	5	0	0	0	0	0	0	0	0	**0**	**1**	**0**
Oncaea conifera	13	3	52	10	29	28	18	22	0	0	0	4	**15**	**16**	**0**
Corycaeus asiaticus	96	0	143	87	92	69	25	103	0	35	0	20	**56**	**48**	**1**
Corycaeus longistylis	3	0	0	0	0	0	0	0	0	0	0	0	**0**	**1**	**0**
Corycaeus speciosus	0	0	77	20	21	19	4	3	0	9	4	34	**16**	**22**	**0**
Corycaeus sp.	5	0	17	0	3	0	0	0	0	0	0	0	**2**	**5**	**0**

Appendix Table 3 (Continued)

Taxa	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Average**	**SD**	**%**
Kelleria australica	0	0	2	0	3	0	13	0	0	0	0	0	**1**	**4**	**0**
Copepod nauplii	56	99	74	52	45	44	15	16	87	20	18	36	**47**	**28**	**1**
Copepodid larvae	2073	5295	2965	6758	2179	1372	916	1808	9631	5011	5403	2686	**3842**	**2606**	**83**
Total	**3072**	**6105**	**4421**	**7699**	**2830**	**1928**	**1572**	**2507**	**11377**	**5556**	**5519**	**2968**	**4629**	**2835**	**100**

Appendix Table 4 Taxonomic lists of copepods abundance (ind.m^{-3}), mean value and contribution to total abundance of each taxon in Si Racha Bay, based on the 330- μm in mesh size from September 2006 to August 2007.

Taxa	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Average	SD	%
Order CALANOIDA															
Acartia erythraea	488	191	253	409	128	239	154	144	1158	506	23	69	**313**	**308**	**38**
A. pacifica	0	45	0	0	0	0	0	0	0	0	0	0	**4**	**13**	**0**
A. spinicuada	0	8	0	0	0	0	0	0	0	0	0	0	**1**	**2**	**0**
Centropages furcatus	25	9	57	52	38	81	3	27	6	24	5	3	**27**	**25**	**3**
C. orsinii	0	0	1	12	13	29	0	2	0	5	0	22	**7**	**10**	**1**
C. tenuiremis	0	0	11	20	5	16	7	8	3	4	0	0	**6**	**7**	**1**
Labidocera bengalensis	0	0	0	0	0	4	3	0	0	0	0	0	**1**	**1**	**0**
L. kroyeri	0	0	0	0	0	0	0	2	0	0	0	0	**0**	**1**	**0**
L. pectinata	0	0	0	0	4	0	0	0	13	0	9	14	**3**	**6**	**0**
Pseudodiaptomus aurivilli	81	0	38	60	38	28	214	204	39	0	0	47	**62**	**73**	**8**
P. clevei	0	0	0	10	1	3	0	0	3	0	0	0	**1**	**3**	**0**
Totanus forcipatus	0	6	22	12	10	27	0	5	5	0	0	6	**8**	**9**	**1**
Canthocalanus puaper	0	0	0	0	1	3	11	10	0	5	0	0	**3**	**4**	**0**
Clausocalanus frucatus	14	0	0	0	0	0	0	0	0	0	0	0	**1**	**4**	**0**
Acrocalanus gibber	0	11	48	10	39	12	0	3	0	9	0	0	**11**	**16**	**1**
Paracalanus aculeatus	0	1	10	11	28	2	0	0	0	11	0	0	**5**	**9**	**1**

Appendix Table 4 (Continued)

Taxa	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Average**	**SD**	**%**
Subeucalanus subcrassus	23	0	0	18	13	25	21	80	10	0	0	0	**16**	**23**	**2**
Order HARPACTICOIDA															
Cleytemnestra scutellata	0	2	0	0	0	0	0	0	0	0	0	0	**0**	**1**	**0**
Euterpina acutifrons	0	13	0	0	0	0	0	0	0	0	0	0	**1**	**4**	**0**
Longipedia sp.	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**
Order CYCLOPOIDA															
Oithona spp.	0	16	10	9	19	5	0	4	5	0	0	7	**6**	**6**	**1**
Acantholochus sp.	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**
Oncaea conifera	0	0	0	0	0	2	0	0	0	0	0	0	**0**	**1**	**0**
Corycaeus asiaticus	3	0	12	19	41	16	11	8	0	0	0	0	**9**	**12**	**1**
C. speciosus	0	0	3	0	0	0	0	0	0	0	0	0	**0**	**1**	**0**
Corycaeus sp.	0	0	0	0	2	2	4	0	0	0	0	0	**1**	**1**	**0**
Copepod nauplii	0	28	2	3	1	0	0	0	5	0	374	0	**34**	**107**	**4**
Copepodid larvae	34	397	282	300	453	193	179	404	440	364	165	377	**299**	**131**	**36**
Total	**668**	**726**	**749**	**942**	**834**	**686**	**607**	**900**	**1686**	**927**	**576**	**545**	**821**	**304**	**100**

Appendix Table 5 Species lists of planktonic copepods and its trophic categories, with comparison in the frequency of occurrence (%) in annul cycle in Manao Bay (M) and Si Racha Bay (S); distribution regions (region: N: neritic; O: oceanic; E: estuarine) from September 2006 to August 2007.

Species	Trophic category	region	%	Sep.		Oct.		Nov.		Dec.		Jan.		Feb.		Mar.		Apr.		May		Jun.		Jul.		Aug.	
				M	**S**	**M**	**S**	**M**	**S**	**M**	**S**	**M**	**S**	**M**	**S**	**M**	**S**	**M**	**S**	**M**	**S**	**M**	**S**	**M**	**S**	**M**	**S**
ORDER CALANOIDA																											
Acartia erythraea	O	E-N	100	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
A. pacifica	O	E-N	8.3		*		*																				
A. spinicuada	O	E-N	8.3		*		*																				
Candacia bradyi	C	N	4.2								*																
C. catula	C	O	4.2																							*	
Centropages furcatus	O	N	100	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
C. orsinii	O	N	79.2	*	*	*		*	*	*	*	*	*	*	*	*		*	*	*		*	*			*	*
C. tenuiremis	O	N	62.5	*	*	*			*		*	*	*	*	*	*	*		*		*	*	*				
Calanopia aurivilli	O	N-O	12.5							*		*		*													
C. thompsoni	O	O	8.3									*										*					
Labidocera batavaie	C	N	4.2																	*							
L. bengalensis	C	N	12.5												*		*				*						
L. bipinnata	C	N	12.5			*						*								*							
L. kroyeri	C	N	8.3														*		*								
L. minuta	C	O	41.7			*		*	*				*	*		*		*		*				*		*	
L. pectinata	C	N	33.3		*							*	*	*						*	*				*		*

Appendix Table 5 (Continued)

Species	Trophic category	region	%	Sep.		Oct.		Nov.		Dec.		Jan.		Feb.		Mar.		Apr.		May		Jun.		Jul.		Aug.	
				M	S	M	S	M	S	M	S	M	S	M	S	M	S	M	S	M	S	M	S	M	S	M	S
L. rotunda	C	N	4.2																	*							
Pseudodiaptomus aurivilli	C	E-N	91.7	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*	*
P. clevei	C	E-N	50		*	*		*			*	*	*	*	*			*			*			*		*	
Temora discaudata	C	O	12.5					*				*			*												
Tortanus forcipatus	C	N	70.8		*	*	*		*		*		*		*	*	*	*	*	*	*	*		*		*	*
T. gracilis	C	N	16.7															*		*		*				*	
Canthocalanus puaper	H	N-O	41.7			*		*		*		*	*		*		*		*				*			*	
Clausocalanus furcatus	H	O	12.5	*		*		*																			
Acrocalanus gibber	H	N	83.3	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*		*	*	*		*	
Paracalanus aculeatus	H	N-O	45.8			*	*	*	*	*	*	*	*		*				*				*				
Subeucalanus subcrassus	H	O	87.5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*		*	
ORDER HARPACTICOIDA																											
Clytemnestra scutellata	O	N	79.2		*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*		*		*	
Euterpina acutifrons	O	N	100	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Longipedia sp.	O	N	16.7				*		*						*												*
Macrosetella gracilis	O	O	37.5		*									*	*		*	*	*	*		*		*			
Microsetella norvegica	O	O	25			*					*					*				*				*		*	
M. rosea	O	O	8.3														*		*								

Appendix Table 5 (Continued)

Species	Trophic category	region	%	Sep.		Oct.		Nov.		Dec.		Jan.		Feb.		Mar.		Apr.		May		Jun.		Jul.		Aug.	
				M	S	M	S	M	S	M	S	M	S	M	S	M	S	M	S	M	S	M	S	M	S	M	S
ORDER CYCLOPOIDA																											
Acantholocus sp.	-	-	4.2								*																
Corycaeus agilis	C	N	50	*		*		*		*		*		*		*		*		*		*		*		*	
C. asiaticus	C	N	87.5	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*		*	*
C. catus	C	N	50	*		*		*		*		*		*		*		*		*		*		*		*	
C. longistylis	C	N	4.2		*																						
C. speciosus	C	N	87.5	*		*		*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*
Corycaeus sp.	C	N	12.5		*				*				*														
Kelleria australica	C	N	16.7						*				*		*		*										
Oithona spp.	C	N-O	100	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Oncaea conifera	C	N	87.5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*		*		*	*
Sapphirina stellata	C	O	4.2																	*							
Nauplii		N	83.3		*		*		*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Copepodid larvae		N	100	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Remark: * : found; - : parasitic copepod; C: Carnivore; H: Herbivore; O: Omnivore

Appendix Table 6 Species number (species), abundance (ind. m^{-3}), evenness and diversity index of planktonic copepods in Manao Bay, based on 200 and 330 - μm in mesh sizes, measuring from September 2006 to August 2007.

Month/ Season	**200-μm in mesh size**				**330-μm in mesh size**			
	Species No.	**Abundance**	**Evenness (J')**	**Diversity index H'(loge)**	**Species No.**	**Abundance**	**Evenness (J')**	**Diversity index H'(loge)**
September	12	1397	0.669603	1.66	9	210.7553	0.754805	1.66
October	21	1254	0.715388	2.18	12	729.9687	0.617313	1.53
November	17	1035	0.817815	2.32	16	611.6965	0.717772	1.99
December	13	1029	0.771691	1.98	11	481.9994	0.513473	1.23
January	18	1350	0.7142	2.06	18	610.5393	0.697767	2.02
February	18	1892	0.770152	2.23	15	1079.303	0.6114	1.66
March	17	1692	0.776921	2.20	10	804.5344	0.566398	1.30
April	18	1504	0.75406	2.18	12	639.6285	0.469629	1.17
May	19	1697	0.795231	2.34	17	770.2578	0.523667	1.48
June	19	1862	0.772484	2.27	15	1131.047	0.518369	1.40
July	18	706	0.800096	2.31	13	256.7273	0.758191	1.94
August	19	1107	0.846042	2.49	19	498.059	0.628023	1.85
SW	25	1338	0.740798	2.38	29	599.4692	0.513176	1.73
NE	21	1327	0.76228	2.32	23	695.8847	0.610478	1.91
Summer	20	1598	0.727609	2.20	13	722.0814	0.495401	1.27

Remarks: SW: Southwest monsoon; NE: Northeast monsoon

Appendix Table 7 Species number (species), abundance (ind. m^{-3}), evenness and diversity index of planktonic copepods in Si Racha Bay, based on 200 and 330 - µm in mesh sizes, measuring from September 2006 to August 2007.

Month/ Season	200-µm in mesh size				330-µm in mesh size			
	Species No.	Abundance	Evenness (J')	Diversity index (H'(loge))	Species No.	Abundance	Evenness (J')	Diversity index (H'(loge))
September	6	634	0.457	0.819	20	943	0.743	2.23
October	10	301	0.571	1.314	11	710	0.727	1.74
November	11	466	0.658	1.577	19	1381	0.735	2.16
December	12	640	0.572	1.422	18	889	0.770	2.23
January	15	380	0.791	2.142	20	605	0.790	2.37
February	16	493	0.651	1.806	21	512	0.810	2.47
March	9	428	0.560	1.230	17	641	0.825	2.34
April	12	497	0.622	1.546	17	683	0.793	2.25
May	9	1242	0.163	0.359	8	1659	0.228	0.48
June	7	563	0.249	0.485	9	524	0.540	1.19
July	3	37	0.819	0.900	5	98	0.809	1.30
August	7	168	0.780	1.518	10	246	0.861	1.98
SW	24	697	0.529	1.682	19	491	0.291	0.86
NE	27	847	0.723	2.382	18	495	0.618	1.79
Summer	19	662	0.810	2.385	14	462	0.548	1.45

Remarks: SW: Southwest monsoon; NE: Northeast monsoon

Appendix Table 8 Prosome length (μm), dry weight(μg) and carbon weight (μg) of male and female *A. erythraea* in Manao Bay, measuring from September 2006 to August 2007.

Month	Male			Female		
	Prosome length (μm)	Dry weight (μg)	Carbon weight (μg)	Prosome length (μm)	Dry weight (μg)	Carbon weight (μg)
September	981	6.71	3.14	1111	7.79	3.68
October	959	7.06	3.38	1073	7.74	3.60
November	944	6.95	3.32	1057	7.33	3.54
December	971	7.93	3.74	1065	8.99	4.3
January	984	6.49	3.13	1089	7.30	3.48
February	953	7.52	3.53	1042	8.03	3.67
March	939	7.63	3.57	1079	8.74	4.08
April	953	7.73	3.55	1058	8.86	4.06
May	921	7.44	3.48	1023	8.47	3.96
June	926	6.04	2.90	1009	6.94	3.28
July	943	7.59	3.64	1020	8.10	3.84
August	942	6.70	3.18	1036	8.22	3.85
Average	**951**	**7.14**	**3.38**	**1055**	**8.08**	**3.78**
SD	**19.74**	**0.64**	**0.25**	**30.55**	**0.67**	**0.29**

Appendix Table 9 Prosome length (μm), dry weight and carbon weight (μg) of copepodid IV (C IV) and V (CV), male and female *A. erythraea* in Manao Bay, based on size classes.

Stage	Male			Female		
	Prosome length (μm)	**Dry weight (μg)**	**Carbon weight (μg)**	**Prosome length (μm)**	**Dry weight (μg)**	**Carbon weight (μg)**
C IV	724	2.02	0.95	724	2.02	0.95
C V	878	4.19	1.88	878	4.19	1.88
	880	6.7	2.96	960	6.87	3.23
	912	6.7	2.96	992	6.87	3.23
	928	6.94	3.1	1008	6.87	3.23
	944	6.94	3.1	1024	7.26	3.4
	960	7.28	3.04	1040	7.26	3.4
	976	7.28	3.04	1056	8.54	3.6
	992	7.28	3.04	1072	8.54	3.6
	1008	7.28	3.04	1088	8.54	3.6
				1120	8.54	3.6
				1152	8.54	3.6

Appendix Table 10 Stage composition and abundance (ind.m^{-3}) of *A. erythraea* based on 200-µm in mesh size in Manao Bay and Si Racha Bay from January to August 2008.

Month	CV1	CV 2	CV3	CV4	CV5	Female	Male
Manao Bay							
January	1	2	12	15	6	0	6
March	1	2	1	2	1	0	0
May	1	0	0	1	1	0	0
August	3	2	2	2	2	0	1
Average	**1**	**2**	**4**	**5**	**2**	**0**	**2**
SD	**1**	**1**	**6**	**7**	**2**	**0**	**3**
%	**8.0**	**10.5**	**24.8**	**30.8**	**14.8**	**0.3**	**10.8**
Si Racha Bay							
January	0	0	1	0	0	0	0
March	0	1	0	1	1	1	1
May	2	3	3	10	3	4	9
August	15	16	11	22	8	7	15
Average	**4**	**5**	**4**	**8**	**3**	**3**	**7**
SD	**7**	**7**	**5**	**10**	**4**	**3**	**7**
%	**12.4**	**14.9**	**11.4**	**24.1**	**8.5**	**9.5**	**19.2**

Appendix Table 11 Mean EPR of *A. erythraea* (egg female^{-1} d^{-1}) in 2 transect lines in Manao Bay and Si Racha Bay from January to August 2008

Month	**Manao Bay**			**Si Racha Bay**		
	Line 1	**Line 2**	**Average ± SD**	**Line 1**	**Line 2**	**Average ± SD**
January	0	0	0	0.04	0	0.02 ± 0.03
March	0.29	0.64	0.465 ± 0.25	2.86	2.12	2.49 ± 0.52
May	1.85	0.97	1.41 ± 0.62	0.88	0.6	0.74 ± 0.20
August	0.35	1.92	1.135 ± 1.11	1.56	2.18	1.87 ± 0.44

Appendix Table 12 Biomass (mg C m^{-3}), secondary production (mg C m^{-3}d^{-1}) and turnover rate (d^{-1}) of *A. erythraea* in Manoa Bay and Si Racha Bay, from January to August 2008.

Month	**Biomass (mg C m^{-3})**		**Secondary production (mg C m^{-3}d^{-1})**		**Turnover rate (d^{-1})**	
	Manao Bay	**Si Racha Bay**	**Manao Bay**	**Si Racha Bay**	**Manao Bay**	**Si Racha Bay**
January	0.02	0.0023	0	0	0	0.00022
March	0.0007	0.0096	0.000003	0.00022	0.0043	0.0229
May	0.00	0.0489	0	0.000343	0	0.007
August	0.0047	0.0794	0.000052	0.001448	0.0111	0.0182
Average	**0.0059**	**0.035**	**0.000014**	**0.000503**	**0.0051**	**0.0121**
SD	**0.0085**	**0.036**	**0.000025**	**0.000646**	**0.0056**	**0.01034**
Average	**0.02 ± 0.02**		**0.0003 ± 0.0003**		**0.009 ± 0.01**	

Appendix Table 13 Hydrographic conditions and nutrients in Manao Bay, measuring from September 2006 to August 2007.

Month	**Temp. (°C)**	**S (psu)**	**D.O. (mg l^{-1})**	**pH**	**Rainfall (mm)**	**NO_2-N (mg l^{-1})**	**NO_3-N (mg l^{-1})**	**NH_3-N (mg l^{-1})**	**PO_4-P (mg l^{-1})**	**Si (mg l^{-1})**	**Chl a (mg m^{-3})**
September	30.1	25	4.87	7.93	95.8	0.0027	0.0065	0.0381	0.011	0.634	0.73
October	29.9	27.5	6.18	7.71	205.4	0.0042	0.0060	0.0486	0.008	0.921	2.14
November	29.4	31	5.81	7.92	226.7	0.0042	0.0043	0.0881	0.013	0.759	1.54
December	29.2	30	6.41	7.95	35.4	0.0020	0.0048	0.0527	0.012	1.278	0.24
January	26.0	29.25	9.22	7.98	41.7	0.0039	0.0079	0.0496	0.009	0.393	1.10
February	27.2	30	8.47	8.05	54.7	0.0017	0.0070	0.0266	0.004	0.587	0.66
March	29.5	30	7.80	7.99	42.1	0.0022	0.0185	0.0560	0.011	0.566	1.22
April	30.8	30	7.15	7.87	41	0.0047	0.0095	0.0377	0.006	0.820	1.62
May	30.6	28	6.74	8.19	123.6	0.0064	0.0075	0.0270	0.008	0.416	1.55
June	31.4	21	7.56	8.00	94.9	0.0035	0.0057	0.0658	0.010	0.464	2.67
July	29.2	30.5	6.78	7.86	89	0.0038	0.0086	0.0693	0.010	0.931	1.31
August	29.7	30.75	10.69	8.07	102.7	0.0092	0.0083	0.0468	0.007	0.649	0.79
Average	29.41	28.58	7.31	7.96	96.08	0.0040	0.0079	0.0505	0.0090	0.7015	1.30
SD	1.50	2.93	1.59	0.12	63.36	0.0021	0.0037	0.0178	0.0027	0.2562	0.67

Remarks: Temp.: water temperature; S: salinity; D.O.: dissolved oxygen; Si: silicate; Chl a: chlorophyll a concentration

Appendix Table 14 Hydrographic conditions and nutrients in Si Racha Bay, measuring from September 2006 to August 2007.

Month	**Temp. (°C)**	**S (psu)**	**D.O. (mg l^{-1})**	**pH**	**Rainfall (mm)**	**NO_2-N (mg l^{-1})**	**NO_3-N (mg l^{-1})**	**NH_3-N (mg l^{-1})**	**PO_4-P (mg l^{-1})**	**Si (mg l^{-1})**	**Chl a (mg m^{-3})**
September	30.9	21	6.79	8.19	286.9	0.0033	0.0041	0.0217	0.010	0.3617	6.80
October	30.4	13.5	6.78	8.21	211.8	0.0051	0.0072	0.0330	0.008	1.3285	7.54
November	30.0	30	6.17	7.91	65.1	0.0061	0.0047	0.0616	0.012	0.3209	1.22
December	29.7	30	6.29	7.95	8.9	0.0020	0.0039	0.0929	0.515	0.9898	0.85
January	26.1	32.5	9.16	8.06	10.6	0.0017	0.0240	0.0635	0.034	0.2664	0.80
February	27.1	32.5	8.08	8.11	18.9	0.0082	0.0139	0.0594	0.120	0.1515	1.58
March	29.7	27	7.91	8.07	31.4	0.0028	0.0068	0.0299	0.010	0.0053	1.20
April	31.7	29.5	5.96	8.04	78.5	0.0101	0.0079	0.1170	0.009	0.3454	2.34
May	31.3	21.5	7.18	8.40	166.6	0.0049	0.0114	0.0185	0.012	2.0824	4.27
June	31.3	24.5	6.97	8.31	133.2	0.0042	0.0089	0.0637	0.033	1.8905	1.61
July	31.2	15	8.87	8.60	133.9	0.0048	0.0063	0.0651	0.013	2.4777	1.34
August	30.4	26	8.61	8.39	168.8	0.0042	0.0058	0.0518	0.003	0.6137	1.56
Average	29.97	25.25	7.40	8.19	109.55	0.0048	0.0087	0.0565	0.0649	0.9028	2.59
SD	1.72	6.38	1.10	0.21	88.94	0.0024	0.0056	0.0288	0.1453	0.8440	2.33

Remarks: Temp.: water temperature; S: salinity; D.O.: dissolved oxygen; Si: silicate; Chl a: chlorophyll a concentration

Appendix Table 15 Taxonomic lists of phytoplankton abundance (cells l^{-1}), mean value and contribution to total abundance of each taxon in Manao Bay from September 2006 to August 2007.

Taxa	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Average**	**SD**	**%**
Division Cyanophyta															
Class Cycanophyceae															
Oscillatoria	12600	1871	13362	22754	8253	7399	2510	4001	3110	0	8669	177	**7059**	**6679**	**32**
Cylindrospermopsis	0	0	0	0	849	197	20	0	5	51	0	0	**94**	**245**	**0**
Richelia	0	0	0	0	0	0	174	0	60	388	0	82	**59**	**117**	**0**
Division Chromophyta															
Class Bacillariophyceae															
Order Biddulphiales															
Cyclotella	0	2	0	0	0	0	0	0	0	0	0	0	**0**	**1**	**0**
Lauderia	3	165	1	4	56	59	5	4	128	7	3	53	**41**	**55**	**0**
Skeletonema	27	0	0	0	0	0	0	0	0	0	0	12	**3**	**8**	**0**
Thalassiosira	21	5	0	0	0	0	0	32	0	0	0	0	**5**	**10**	**0**
Planktoniella	0	1	0	0	0	0	0	1	0	1	2	27	**3**	**8**	**0**
Stephanodiscus	0	1	0	0	0	0	0	5	0	0	1	0	**1**	**1**	**0**
Paralia	4	15	8	10	6	0	5	14	5	3	10	6	**7**	**4**	**0**
Melosira	1	6	0	0	0	0	0	154	82	7	0	25	**23**	**48**	**0**
Corethron	3	0	1	0	7	77	1	4	0	1	1	0	**8**	**22**	**0**
Palmeria	0	0	0	0	0	0	0	0	0	2	0	3	**0**	**1**	**0**
Coscinodiscus	78	2223	155	226	99	23	170	126	181	170	80	157	**307**	**606**	**1**
Pseudoguinardia	3	39	1	3	88	29	42	52	116	0	5	11	**32**	**38**	**0**
Actinoptychus	0	0	0	0	1	0	1	2	0	0	1	11	**1**	**3**	**0**

Appendix Table 15 (Continued)

Taxa	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Average**	**SD**	**%**
Asteromphalus	4	0	0	6	2	4	4	6	13	0	3	5	**4**	**4**	**0**
Dactyliosolen	7	4	0	0	2	0	6	95	4	0	12	1	**11**	**27**	**0**
Guinardia	26	131	16	77	245	48	154	224	2258	276	200	149	**317**	**617**	**1**
Proboscia	41	19	6	10	234	27	76	56	548	1697	32	1848	**383**	**668**	**2**
Pseudosolenia	0	4	0	0	0	0	14	44	348	0	17	900	**111**	**267**	**1**
Rhizosolenia	37	179	14	80	1252	189	295	101	1377	0	253	1543	**443**	**582**	**2**
Eucampia	6	1	0	14	7	23	7	3	33	2	18	43	**13**	**14**	**0**
Hemiaulus	9	72	37	48	17	20	48	104	241	19	59	371	**87**	**109**	**0**
Bacteriastrum	1165	840	32	17647	11014	3125	726	1154	1521	1688	123	227	**3272**	**5420**	**15**
Chaetoceros	1326	909	297	10601	8977	5504	1774	2322	2669	5947	1255	0	**3465**	**3496**	**16**
Ditylum	0	178	0	6	2	0	4	35	660	7	2	57	**79**	**190**	**0**
Odontella	6	47	25	19	79	7	32	35	51	17	25	144	**41**	**38**	**0**
Triceratium	0	1	0	0	2	0	0	0	185	0	0	2	**16**	**53**	**0**
Order Bacillariales															
Asterionella	3	0	2	3	0	8	0	61	0	0	0	1	**7**	**17**	**0**
Synedra	0	0	0	0	0	0	0	0	0	0	626	0	**52**	**181**	**0**
Thalassionema	372	705	1737	1444	4344	10477	5417	11003	3495	757	3863	265	**3657**	**3719**	**17**
Thalassiothrix	1	1	0	0	0	0	0	4	2	0	0	0	**1**	**1**	**0**
Amphora	0	0	3	1	0	0	0	0	0	0	0	0	**0**	**1**	**0**
Gyrosigma	0	3	13	23	14	11	32	9	36	33	24	9	**17**	**12**	**0**
Navicula	0	0	0	0	0	0	26	5	14	26	20	3	**8**	**11**	**0**
Pleurosigma	30	38	52	25	668	278	709	431	1948	1908	116	1556	**647**	**743**	**3**

Appendix Table 15 (Continued)

Taxa	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Average	SD	%
Climacosphenia	1	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**
Meunier	0	212	0	0	1	0	223	0	113	0	0	0	**46**	**87**	**0**
Nitzschia	135	72	392	23	3216	0	144	85	42	99	85	733	**419**	**905**	**2**
Bacillaria	107	98	284	246	1846	137	912	343	347	167	779	31	**441**	**518**	**2**
Pseudonitzschia	58	164	53	84	2664	448	157	236	687	222	45	236	**421**	**730**	**2**
Cylindrotheca	0	0	7	1	1	0	0	0	0	0	0	0	**1**	**2**	**0**
Cocconeis	0	0	1	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**
Epithemia	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**
Surirella	0	0	5	12	32	2	6	5	8	0	11	2	**7**	**9**	**0**
Entomoneis	1	1	20	2	8	1	1	4	4	0	6	10	**5**	**6**	**0**
Class Dinophyceae															
Order Prorcentrales															
Prorocentrum	6	0	0	0	0	1	2	0	7	1	0	0	**2**	**3**	**0**
Order Dinophysiales															
Dinophysis	0	14	25	14	1	0	32	41	75	169	8	9	**32**	**48**	**0**
Ornithocercus	0	0	0	0	0	0	0	0	2	0	5	0	**1**	**2**	**0**
Order Noctilucales															
Noctiluca	0	8	0	0	0	0	0	8	0	1	1	2	**2**	**3**	**0**
Order Gonyaulacales															
Ceratium	20	72	28	66	22	44	190	72	179	135	65	77	**81**	**58**	**0**
Pyrophacus	2	12	9	1	0	0	6	17	33	21	21	7	**11**	**10**	**0**
Order Peridiniales															

Appendix Table 15 (Continued)

Taxa	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Average	SD	%
Peridinium	0	1	5	6	1	9	16	4	13	6	2	4	**6**	**5**	**0**
Protoperidinium	1	28	33	19	38	35	25	8	57	58	18	15	**28**	**18**	**0**
Class Dictyochophyceae															
Order Dictyochales															
Dictyocha	0	0	16	9	0	8	31	4	5	2	3	14	**8**	**9**	**0**
Total	**16106**	**8141**	**16645**	**53483**	**44046**	**28192**	**13997**	**20912**	**20659**	**13888**	**16468**	**8829**	**21780**	**13841**	**100**

Appendix Table 16 Taxonomic lists of phytoplankton abundance (cells l^{-1}), mean value and contribution to total abundance of each taxon in Si Racha Bay from September 2006 to August 2007.

Taxa	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Average**	**SD**	**%**
Division Cyanophyta															
Class Cyanophyceae															
Lyngbya	0	45	0	0	0	2	0	0	26	4	15	0	**8**	**14**	**0.0**
Oscillatoria	294867	24303	10200	5360	3370	38990	45387	10423	1690	20653	8007	23053	**40525**	**81289**	**14.0**
Division Chromophyta															
Class Bacillariophyceae															
Order Biddulphiales															
Lauderia	0	4	1550	40	493	233	558	7	103	2716	18	165	**491**	**828**	**0.2**
Planktoniella	3	1	1	0	0	2	0	0	5	0	5	0	**1**	**2**	**0.0**
Skeletonema	0	9	1356	1431	1811	1992	0	0	147	0	0	0	**562**	**818**	**0.2**
Thalassiosira	0	1602	2074	75	0	0	105	11	585	26966	2539	830	**2899**	**7632**	**1.0**
Melosira	2	7539	23	1	3	5	0	1	4	18	410	3	**667**	**2167**	**0.2**
Paralia	0	34	14	16	11	18	5	17	14	6	15	6	**13**	**9**	**0.0**
Corethron	0	0	345	2	6	3	0	0	3	11	0	2	**31**	**99**	**0.0**
Coscinodiscus	23	111	1722	202	99	152	100	14	548	321	295	655	**353**	**475**	**0.1**
Palmeria	1	0	0	0	6	0	0	0	0	0	0	0	**1**	**2**	**0.0**
Pseudoguinardia	1	0	31	26	50	8	0	7	22	0	0	0	**12**	**17**	**0.0**
Asteromphalus	0	3	9	6	0	0	0	0	0	0	0	0	**1**	**3**	**0.0**
Actinoptychus	0	4	9	0	0	0	0	0	0	0	0	0	**1**	**3**	**0.0**
Leptocylindrus	0	3804	0	56	59	15	162	0	2	77	198	10	**365**	**1085**	**0.1**
Dactyliosolen	0	0	130	0	31	0	0	0	435	5	0	3	**50**	**127**	**0.0**

Appendix Table 16 (Continued)

Taxa	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Average**	**SD**	**%**
Guinardia	0	0	251	261	1579	1105	6579	1601	250	211	111	12	**997**	**1856**	**0.3**
Proboscia	2	26	143	16	406	1905	412	1719	3945	26	0	88	**724**	**1214**	**0.3**
Pseudosolenia	10	22	134	116	472	1111	1123	460	106	47	0	0	**300**	**415**	**0.1**
Rhizosolenia	73	240	593	145	828	2523	1580	214	110	2	5	1653	**664**	**825**	**0.2**
Climacodium	0	0	2	0	0	30	0	115	11	0	0	0	**13**	**33**	**0.0**
Eucampia	0	0	207	0	0	6	833	92	432	0	0	2	**131**	**257**	**0.0**
Hemiaulus	7	64	2285	77	301	889	226	243	3300	70	0	15	**623**	**1064**	**0.2**
Biddulphia	0	0	0	4	0	0	0	0	0	0	0	0	**0**	**1**	**0.0**
Cymatosira	0	0	0	0	0	2	0	0	0	0	0	0	**0**	**0**	**0.0**
Bacteriastrum	132	23682	48789	6950	5132	39738	1899	758	30021	15500	93	221490	**32849**	**61681**	**11.4**
Chaetoceros	220065	303512	410210	34440	65525	171729	73539	5543	141891	155297	44709	560430	**182241**	**168150**	**63.1**
Ditylum	0	50	29	31	4	6	3	2	11	470	2463	1173	**353**	**749**	**0.1**
Odontella	1	15	166	21	32	44	35	19	31	143	10	55	**48**	**52**	**0.0**
Order Bacillariales															
Asterionellopsis	0	0	0	79	29	81	18	6	0	0	0	0	**18**	**30**	**0.0**
Fragilaria	0	2	1	0	4	5	3	0	4	2	0	0	**2**	**2**	**0.0**
Synedra	0	10	0	0	0	0	0	0	0	0	0	0	**1**	**3**	**0.0**
Thalassionema	14	114124	68026	3498	3210	6476	213	239	296	6790	173	14306	**18114**	**35713**	**6.3**
Amphora	0	0	0	0	0	0	0	0	2	0	0	0	**0**	**1**	**0.0**
Gyrosigma	0	0	0	0	0	195	0	0	0	0	0	0	**16**	**56**	**0.0**
Pleurosigma	0	0	0	0	0	3201	172	0	0	0	0	0	**281**	**921**	**0.1**
Gammatophora	0	0	0	0	0	0	0	0	1	0	0	0	**0**	**0**	**0.0**

Appendix Table 16 (Continued)

Taxa	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Average**	**SD**	**%**
Climacosphenia	1	2	13	0	4	2	0	0	6	2	18	3	**4**	**6**	**0.0**
Cocconeis	0	0	0	31	0	0	0	2	0	0	0	0	**3**	**9**	**0.0**
Lyrella	0	0	4	3	0	2	0	1	1	0	0	0	**1**	**1**	**0.0**
Gyrosigma	0	0	0	0	0	195	0	0	0	45	0	0	**20**	**57**	**0.0**
Diploneis	0	0	0	0	0	0	0	1	2	0	0	3	**0**	**1**	**0.0**
Navicula	0	1	9	4	19	82	0	4	105	9	3	0	**20**	**35**	**0.0**
Pleurosigma	1	42	3487	1206	1962	3201	172	268	1375	52	5	65	**986**	**1280**	**0.3**
Bacillaria	1540	0	1532	1390	610	864	0	28	1322	308	0	32	**636**	**658**	**0.2**
Denticula	0	0	0	0	0	0	0	1	0	0	0	0	**0**	**0**	**0.0**
Entomoneis	0	0	36	59	21	53	0	8	74	2	0	3	**21**	**27**	**0.0**
Nitzschia	0	26	47	92	152	333	31	74	227	58	38	85	**97**	**97**	**0.0**
Pseudonitzschia	1	178	174	344	755	1028	1823	324	1105	328	18	162	**520**	**552**	**0.2**
Cocconeis	0	0	0	31	0	0	0	2	0	0	0	0	**3**	**9**	**0.0**
Epithemia	0	0	0	0	1	5	5	2	0	1	0	0	**1**	**2**	**0.0**
Surirella	0	0	157	0	0	71	0	0	10	28	0	5	**23**	**47**	**0.0**
Class Dinophyceae															
Order Prorocentrales															
Prorocentrum	15	6	17	4	2	6	2	2	8	135	30	3	**19**	**37**	**0.0**
Order Dinophysiales															
Dinophysis	142	95	136	48	5	2	61	114	20	55	10	40	**61**	**50**	**0.0**
Ornithocercus	0	0	0	0	0	0	0	0	0	2	0	0	**0**	**1**	**0.0**
Order Noctilucales															

Appendix Table 16 (Continued)

Taxa	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Average**	**SD**	**%**
Ceratium	80	4227	1291	1195	34	72	76	61	225	453	25160	1155	**2836**	**7129**	**1.0**
Noctiluca	171	0	0	10	0	6	66	114	20	0	0	0	**32**	**56**	**0.0**
Order Gonyaulacales															
Pyrophacus	0	0	4	7	0	6	2	6	1	11	65	23	**10**	**18**	**0.0**
Order Peridiniales															
Protoperidinium	91	189	194	65	16	58	69	0	120	601	418	335	**180**	**183**	**0.1**
Class Dictyochophyceae															
Order Dictyochales															
Dictyocha	0	1	24	13	38	30	0	0	3	2	5	0	**10**	**14**	**0.0**
Total	**517242**	**483972**	**555422**	**57353**	**87075**	**276476**	**135257**	**22500**	**186619**	**231424**	**84835**	**825865**	**288837**	**251113**	**100.0**

Appendix Table 17 Taxonomic lists of zooplankton abundance (ind.m^{-3}), mean value and contribution to total abundance of each taxon in Manao Bay, based on the 200- μm in mesh size from September 2006 to August 2007.

Taxa	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Average**	**SD**	**%**
Phylum Sarcomastigophora															
Foraminiferan	0	0	0	0	0	0	0	0	0	6	2	0	**1**	**2**	**0**
Radiolarian	0	1	2	0	0	3	30	31	54	46	15	28	**18**	**20**	**1**
Phylum Cnidaria															
Hydromedusae	22	37	13	10	96	71	54	48	80	52	30	22	**45**	**27**	**1**
Phylum Annelida															
Polychaete larvae	37	63	20	35	66	155	97	89	223	54	8	76	**77**	**60**	**2**
Phylum Mollusca															
Gastropod larvae	0	18	6	12	12	10	120	106	64	49	4	70	**39**	**42**	**1**
Bivalve larva	14	81	21	40	21	29	145	1268	379	710	7	471	**266**	**389**	**8**
Pteropod	0	31	3	81	10	49	44	21	54	74	5	25	**33**	**28**	**1**
Phylum Arthropoda															
Cladoceran	41	38	7	32	0	0	190	147	51	4	0	15	**44**	**62**	**1**
Ostracod	7	9	7	0	3	5	3	10	9	0	15	4	**6**	**4**	**0**
Nauplii	0	10	12	0	2	0	0	0	18	73	28	67	**17**	**26**	**1**
Copepod	1001	2147	2544	1810	1222	2519	1734	2172	1604	2064	1037	1131	**1749**	**669**	**52**
Cirripede larvae	478	269	38	90	133	65	164	196	16	228	99	62	**153**	**129**	**5**

Appendix Table 17 (Continued)

Taxa	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Average	SD	%
Cypris larvae	4	38	6	0	1	0	22	40	5	211	0	4	**28**	**60**	**1**
Alima larvae	4	2	2	0	0	0	0	0	0	0	0	0	**1**	**1**	**0**
Mysid	23	0	0	0	0	0	0	0	0	15	0	0	**3**	**8**	**0**
Amphipod	0	0	0	0	0	0	0	0	3	0	0	4	**1**	**2**	**0**
Protozoea *Lucifer*	59	248	132	25	111	363	199	740	125	420	46	149	**218**	**205**	**6**
protzoea *Acetes*	0	13	21	2	6	8	6	35	59	0	0	0	**12**	**18**	**0**
Decapods	29	129	152	4	40	52	88	180	190	946	69	108	**166**	**253**	**5**
Shrimp larvae	25	39	20	0	13	13	9	3	40	15	6	19	**17**	**13**	**0**
Brachyuran megalopa	3	6	0	0	0	0	0	0	0	0	0	3	**1**	**2**	**0**
Brachyuran zoea	9	6	11	5	11	43	33	29	44	135	12	35	**31**	**36**	**1**
Porcellanid larvae	0	1	0	0	0	0	0	0	0	3	0	0	**0**	**1**	**0**
Pagurid larvae	0	2	0	0	0	0	0	0	0	0	0	0	**0**	**1**	**0**
Peneid larvae	79	2	0	0	0	0	0	0	0	0	0	0	**7**	**23**	**0**
Caridean larvae	9	0	0	0	0	0	0	0	0	0	0	0	**1**	**3**	**0**
Phylum Chaetognatha															
Chaetognath	95	371	303	123	157	319	122	188	321	365	58	370	**233**	**119**	**7**
Phylum Echinodermata															
Bipinnaria larvae	0	3	0	0	0	0	0	0	3	0	1	4	**1**	**1**	**0**

Appendix Table 17 (Continued)

Taxa	Sep	Oct	Nov	Dec	Jan	Febr	Mar	Apr	May	Jun	Jul	Aug	**Average**	**SD**	**%**
Echinopluteus	0	7	2	2	0	15	8	0	18	4	9	15	**7**	**6**	**0**
Ophiopluteus	0	74	26	313	3	95	135	74	25	15	101	89	**79**	**86**	**2**
Phylum Chordata															
Larvacean	24	47	71	312	47	92	89	84	171	179	26	322	**122**	**104**	**4**
Thaliacean	19	2	0	0	0	0	0	0	0	0	0	0	**2**	**6**	**0.05**
Fish egg	0	1	0	0	0	0	1	0	7	6	1	0	**1**	**2**	**0**
Fish larvae	3	4	0	3	2	0	0	3	10	1	0	6	**3**	**3**	**0**
Total	**1984**	**3700**	**3418**	**2901**	**1957**	**3906**	**3294**	**5466**	**3573**	**5676**	**1582**	**3099**	**3380**	**1264**	**100**

Appendix Table 18 Taxonomic lists of zooplankton abundance (ind.m^{-3}), mean value and contribution to total abundance of each taxon in Si Racha Bay, based on the 200- μm in mesh size from September 2006 to August 2007.

Taxa	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Average	SD	%
Phylum Sarcomastigophora															
Foraminiferans	0	0	0	0	0	0	0	3	4	0	0	0	**1**	**1**	**0**
Radiolarians	0	0	0	0	5	4	0	6	3	0	0	0	**2**	**2**	**0**
Phylum Ciliophora															
Tintinnid	5	52	13	1	0	0	0	0	0	907	14	16	**84**	**260**	**3**
Phylum Cnidaria															
Siphonophores	0	0	13	4	2	1	43	5	0	6	0	0	**6**	**12**	**0**
Hydromedusae	154	21	18	54	3	7	46	19	1	135	13	15	**41**	**75**	**1**
Phylum Ctenophora															
Ctenophore	0	0	0	0	0	0	0	0	0	0	7	0	**1**	**2**	**0**
Cydippid larvae	0	1	0	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**
Phylum Nemertea															
Pilidium larvae	0	0	10	0	5	3	0	0	0	0	0	0	**2**	**3**	**0**
Phylum Annelida															
Polychaete larva	25	58	116	31	47	70	56	85	10	143	39	344	**85**	**90**	**3**
Tomopteris	9	4	11	0	0	0	0	0	0	0	0	0	**2**	**4**	**0**

Appendix Table 18 (Continued)

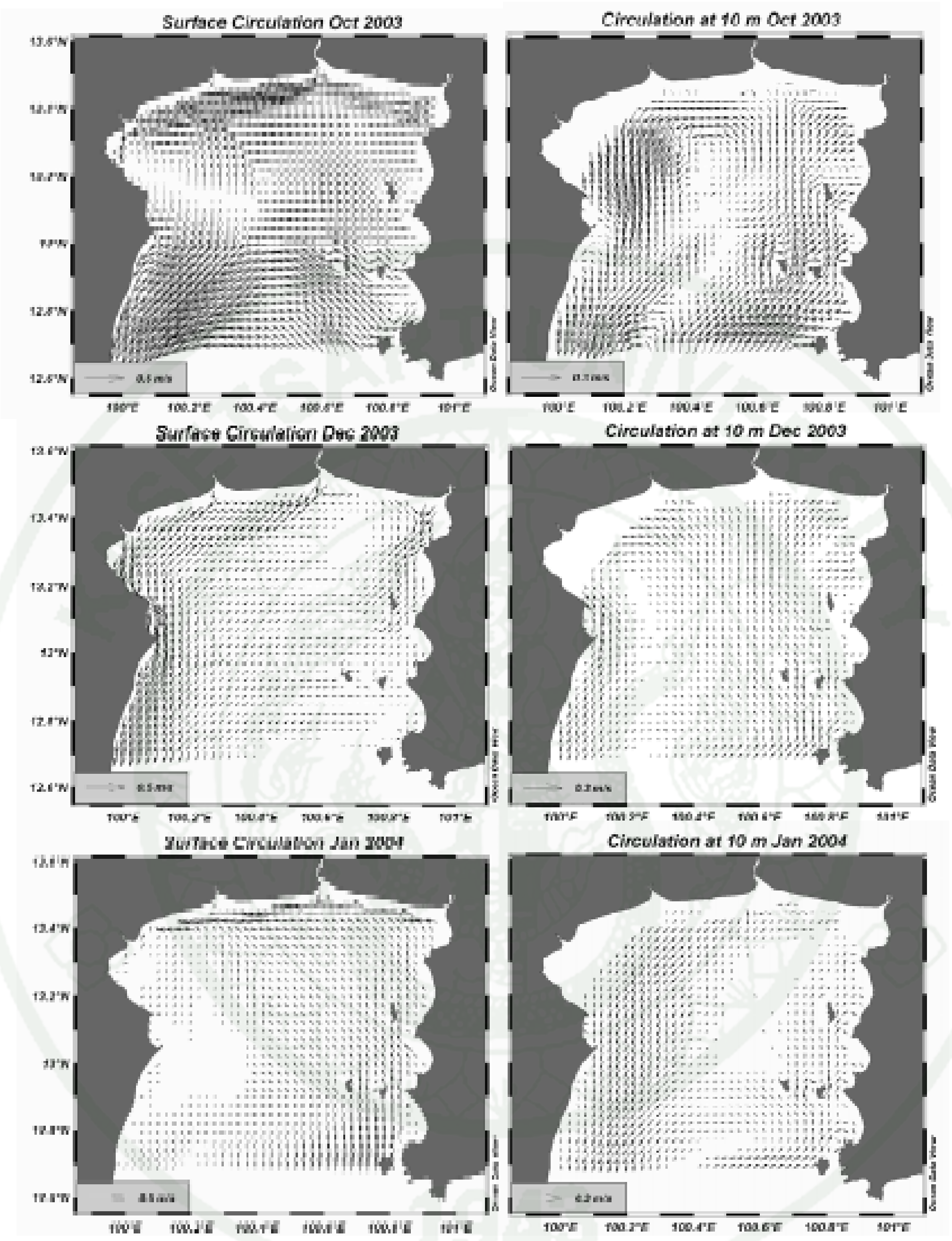
Taxa	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Average	SD	%
Phylum Mollusca															
Gastropod larvae	62	17	27	64	23	19	10	5	10	22	3	29	**24**	**20**	**1**
Bivalve larvae	101	92	56	35	18	15	30	20	46	33	15	24	**41**	**29**	**1**
Creseis sp.	3	6	13	0	0	0	0	26	0	2	0	3	**4**	**8**	**0**
Phylum Arthropoda															
Pseudovadne	23	4	3	81	19	0	0	1	3	330	11	15	**41**	**94**	**1**
Cirripede nauplius	576	598	751	216	357	275	418	1094	516	837	460	1206	**609**	**311**	**19**
Cypris larvae	0	6	22	13	7	9	57	41	14	3	5	194	**31**	**54**	**1**
Copepod nauplius	114	103	30	7	24	23	46	42	101	8	123	26	**54**	**43**	**2**
Pontellid nauplius	0	0	0	0	2	14	7	13	3	0	0	0	**3**	**5**	**0**
Copepod	1147	1483	851	1768	793	696	509	893	4320	2768	2100	1513	**1570**	**1165**	**48**
Ostracod	0	0	0	0	0	0	0	1	0	0	0	0	**0**	**0**	**0**
Amphipod	0	0	0	0	0	5	16	5	0	0	0	0	**2**	**5**	**0**
Lucifer	17	11	22	50	13	19	245	140	27	10	10	103	**56**	**72**	**2**
Lucifer protozoa	298	53	118	84	53	112	137	168	142	36	64	106	**114**	**71**	**4**
Mysid	0	0	0	0	0	3	0	0	2	0	0	0	**0**	**1**	**0**
Euphausiid	0	0	1	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**
Brachyuran zoea	2	3	7	10	7	13	65	24	14	1	0	15	**13**	**18**	**0**

Appendix Table 18 (Continued)

Taxa	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Average	SD	%
Brachyuran megalopa	0	0	0	1	2	0	2	6	2	0	0	0	**1**	**2**	**0**
Shrimp larvae	5	8	8	7	11	35	128	74	28	2	12	80	**33**	**40**	**1**
Phylum Bryozoa															
Cyphonautes larvae	0	0	2	0	0	0	0	0	0	0	0	0	**0**	**1**	**0**
Phylum Phoronida															
Actinotrocha larvae	0	0	9	0	0	0	0	0	0	0	0	0	**1**	**3**	**0**
Phylum Hemichordata															
Tornaria larvae	0	0	0	0	0	0	0	1	0	0	0	0	**0**	**0**	**0**
Phylum Echinodermata															
Bipinnaria larvae	0	0	4	0	1	0	0	0	0	0	0	0	**0**	**1**	**0**
Brachiolaria larvae	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**
Auricularia larvae	0	0	1	0	2	0	0	4	3	2	0	0	**1**	**1**	**0**
Echinopluteus	4	1	3	0	0	33	35	21	0	38	0	0	**11**	**16**	**0**
Ophiopluteus	4	19	87	9	49	38	40	39	0	23	13	0	**27**	**25**	**1**
Phylum Chaetognatha															
Sagitta spp.	285	173	192	161	49	66	142	131	47	84	41	152	**127**	**73**	**4**
Phylum Chordata															
larvacean	140	155	220	75	168	32	162	58	17	109	114	746	**166**	**192**	**5**

Appendix Table 18 (Continued)

Taxa	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Average	SD	%
Thaliacean	414	4	0	1	0	4	191	149	0	3	0	0	**64**	**128**	**2**
Tadpole larvae	0	0	0	0	4	0	0	0	0	0	0	0	**0**	**1**	**0**
Fish egg	163	15	14	5	8	3	0	6	13	20	179	9	**36**	**63**	**1**
Fish larvae	0	1	6	12	0	5	7	88	3	4	6	8	**12**	**24**	**0**
Total	**3551**	**2888**	**2629**	**2689**	**1673**	**1504**	**2391**	**3167**	**5327**	**5526**	**3229**	**4605**	**3265**	**1298**	**100**



Surface Circulation Oct 2003

Circulation at 10 m Oct 2003

Surface Circulation Dec 2003

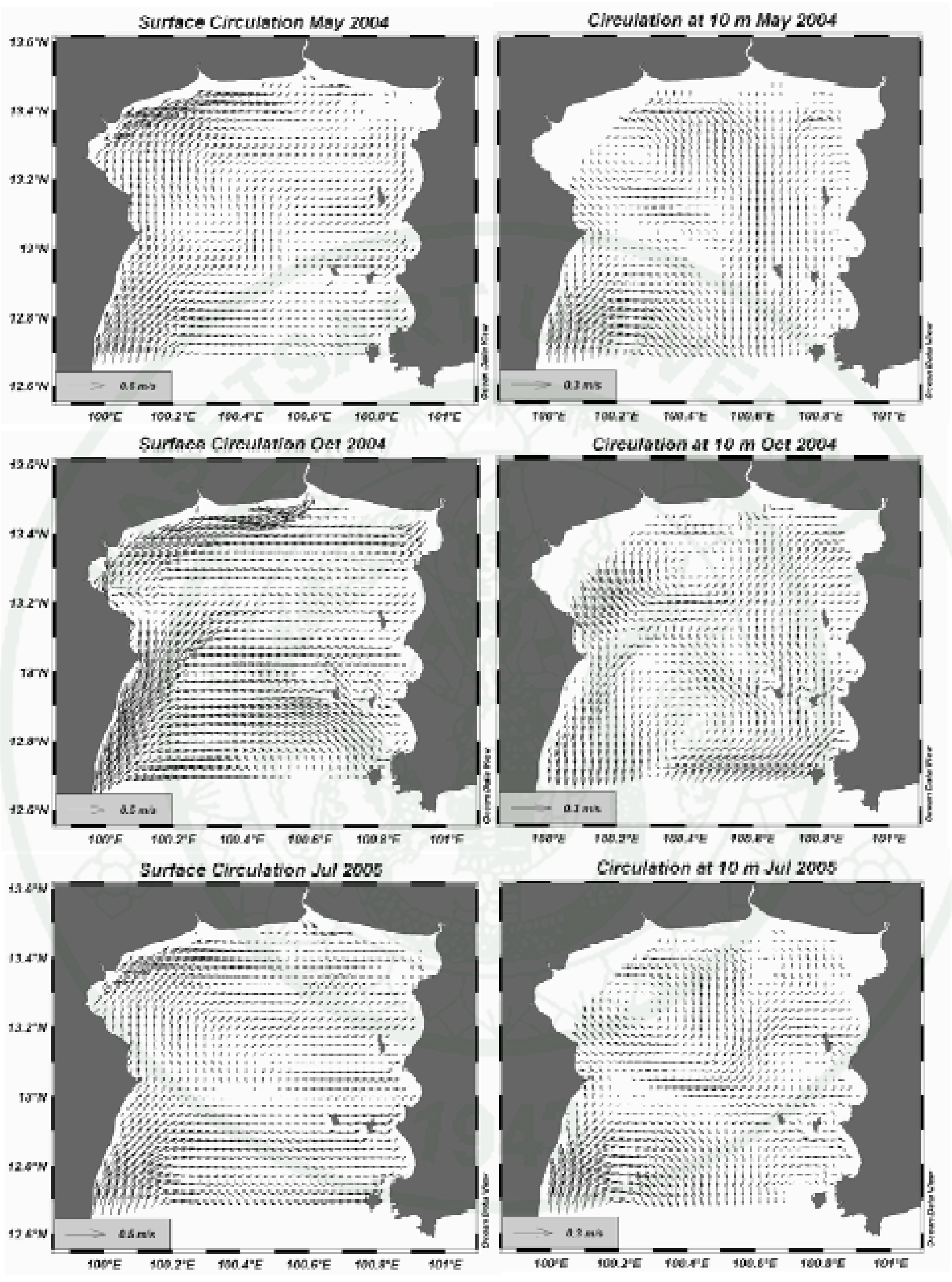
Circulation at 10 m Dec 2003

Surface Circulation Jan 2004

Circulation at 10 m Jan 2004

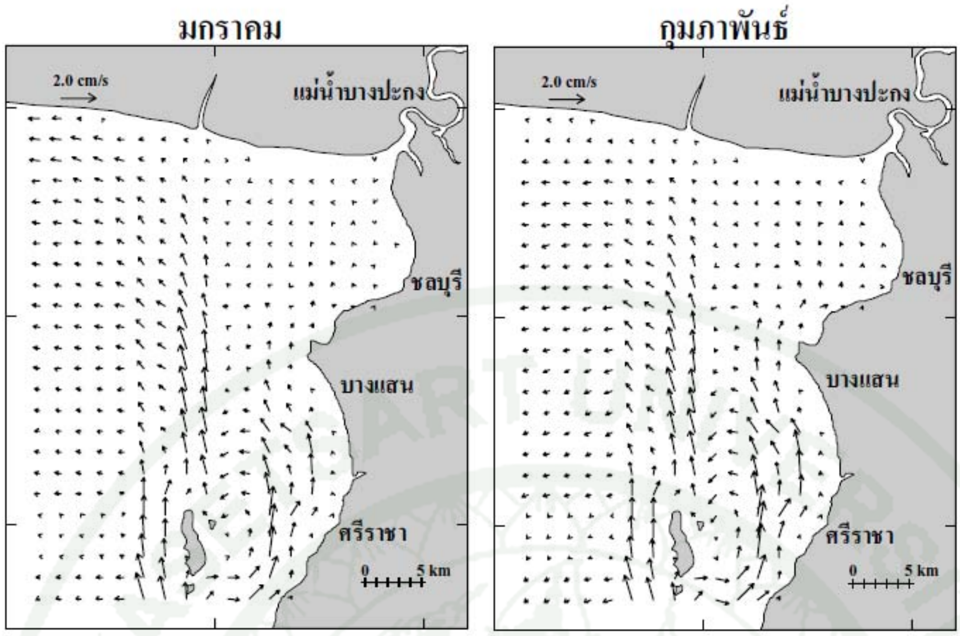
Appendix Figure 1 Monthly mean horizontal circulation at sea surface and 10 m depth, simulated using POM, in October, December 2003 and January 2004 in the upper Gulf of Thailand.

Source: Buranapratheprat *et al*. (2009)

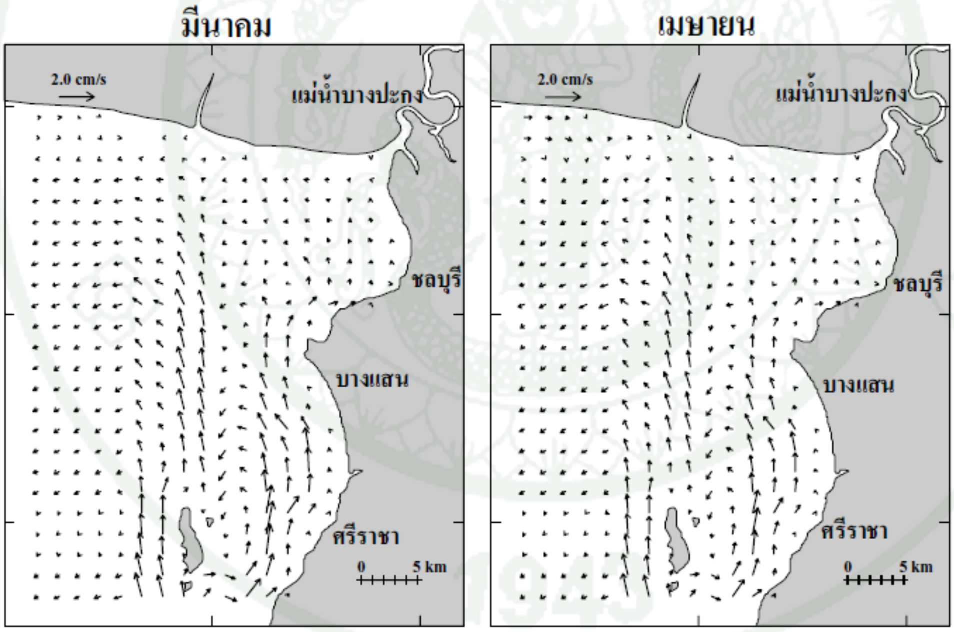


Appendix Figure 2 Monthly mean horizontal circulation at sea surface and 10 m depth, simulated using POM, in May, October, and July 2004 in the upper Gulf of Thailand.

Source: Buranapratheprat *et al*. (2009)



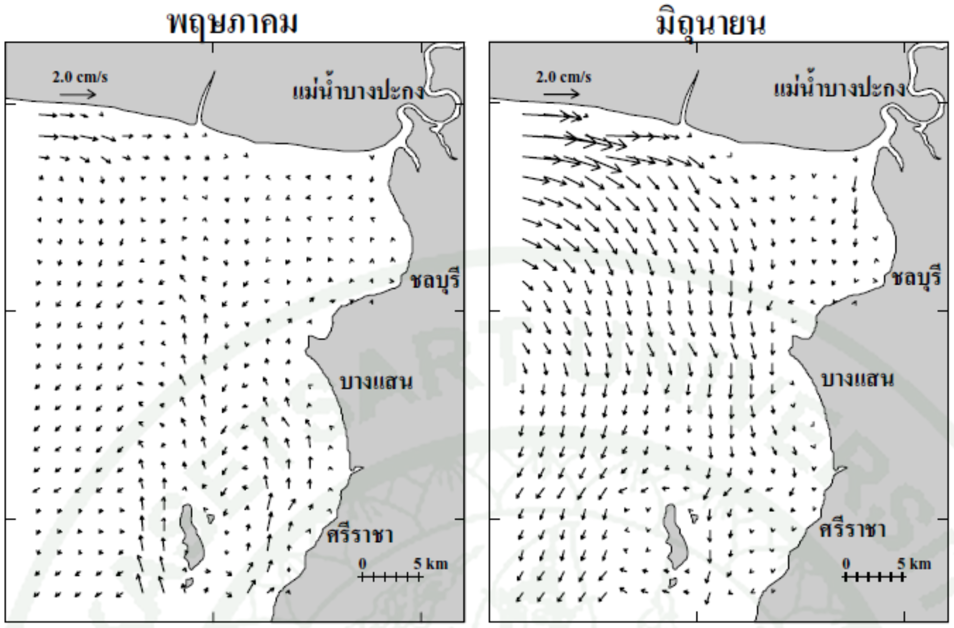
January February



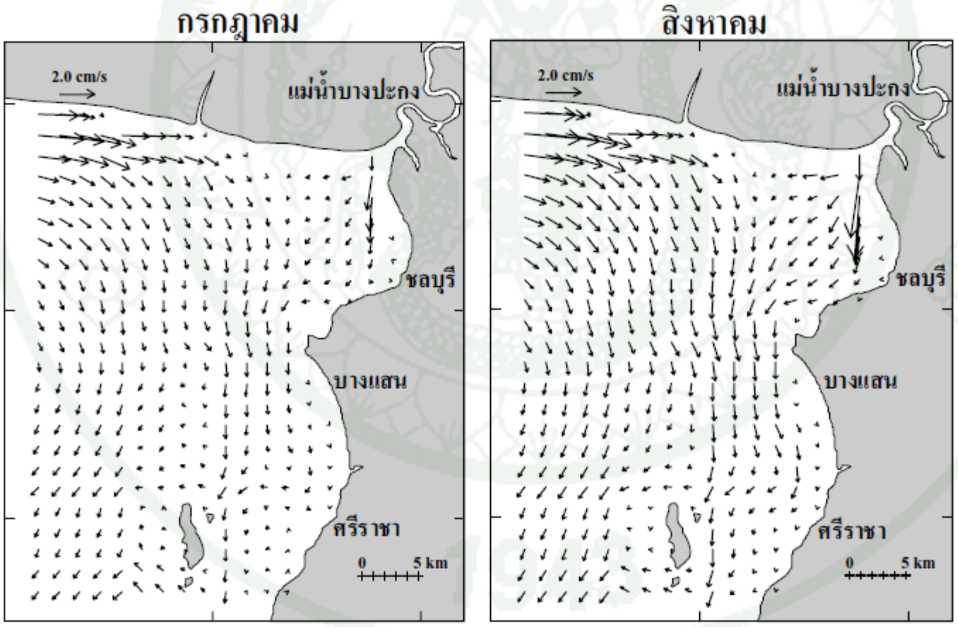
March April

Appendix Figure 3 Monthly mean circulation at sea surface in Bang Pakong River Mouth and Chonburi coastal areas, January to April.

Source: Buranapratheprat (2009)



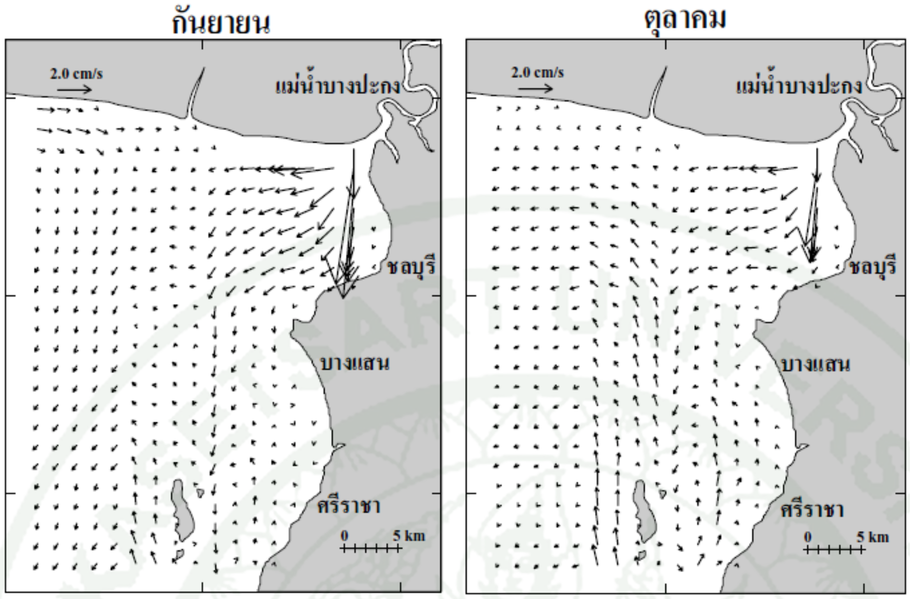
May June



July August

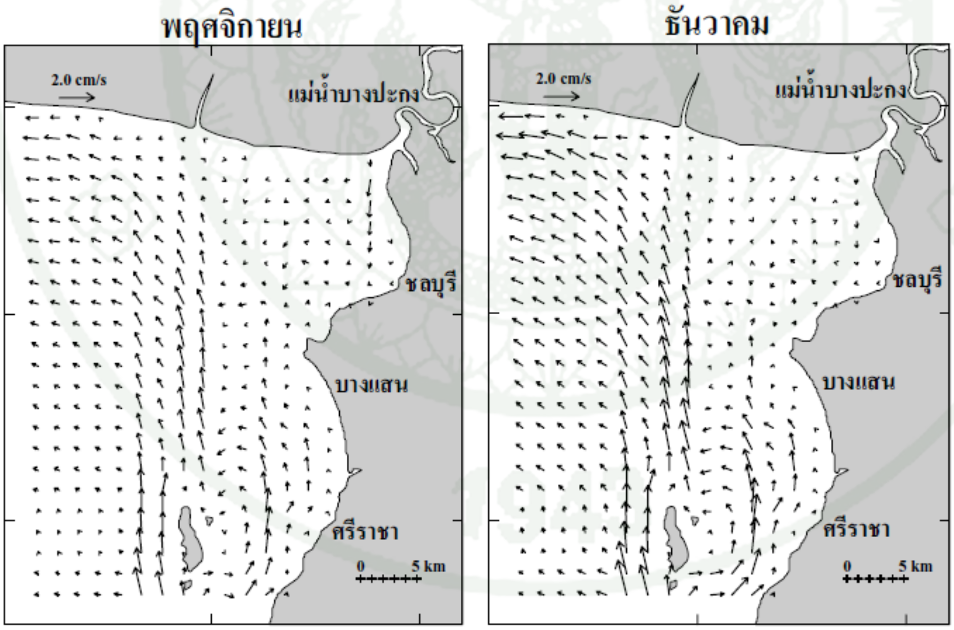
Appendix Figure 4 Monthly mean circulation at sea surface in Bang Pakong River Mouth and Chonburi coastal areas, May to August.

Source: Buranapratheprat (2009)



September

October

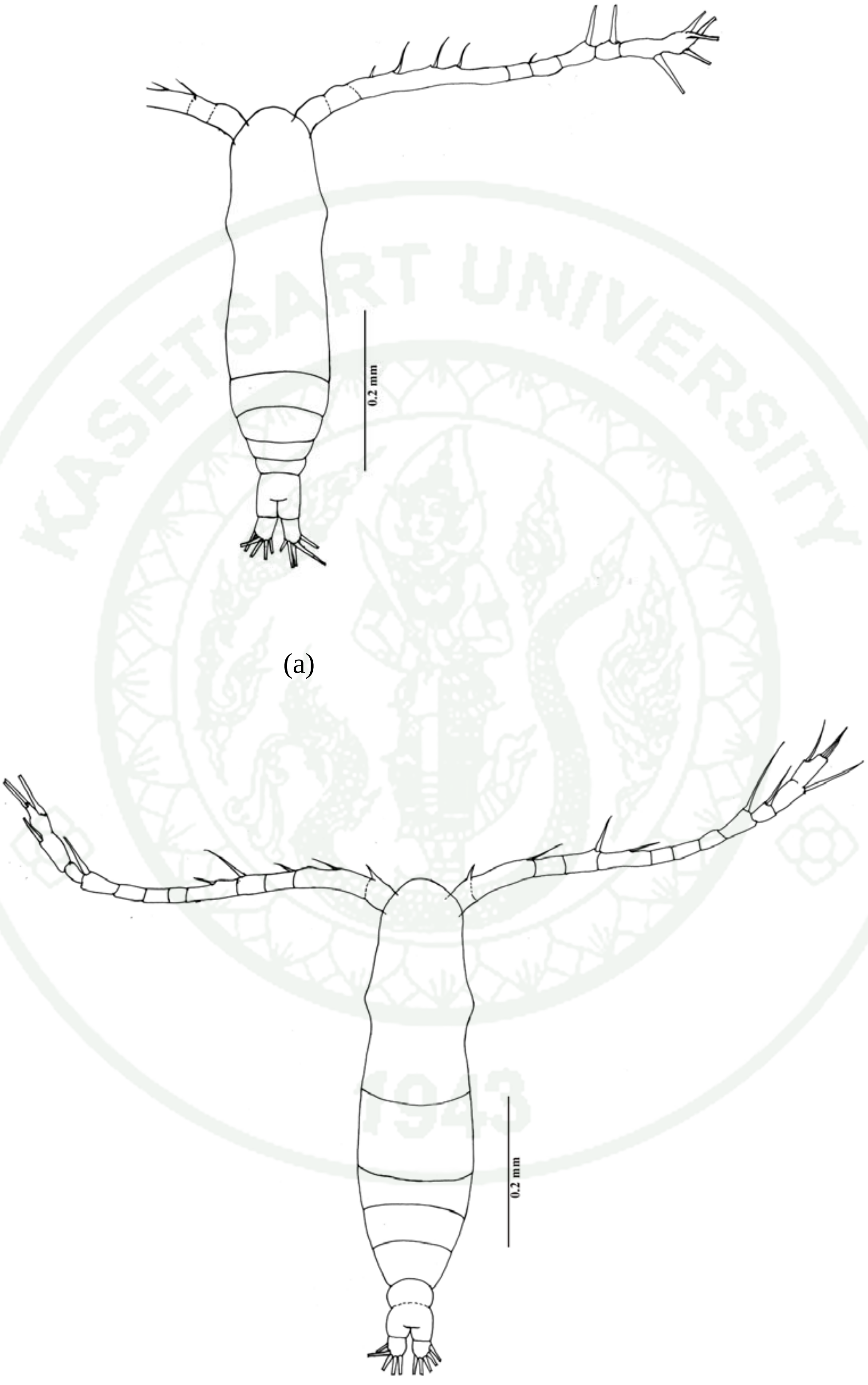


November

December

Appendix Figure 5 Monthly mean circulation at sea surface in Bang Pakong River Mouth and Chonburi coastal areas, September to December.

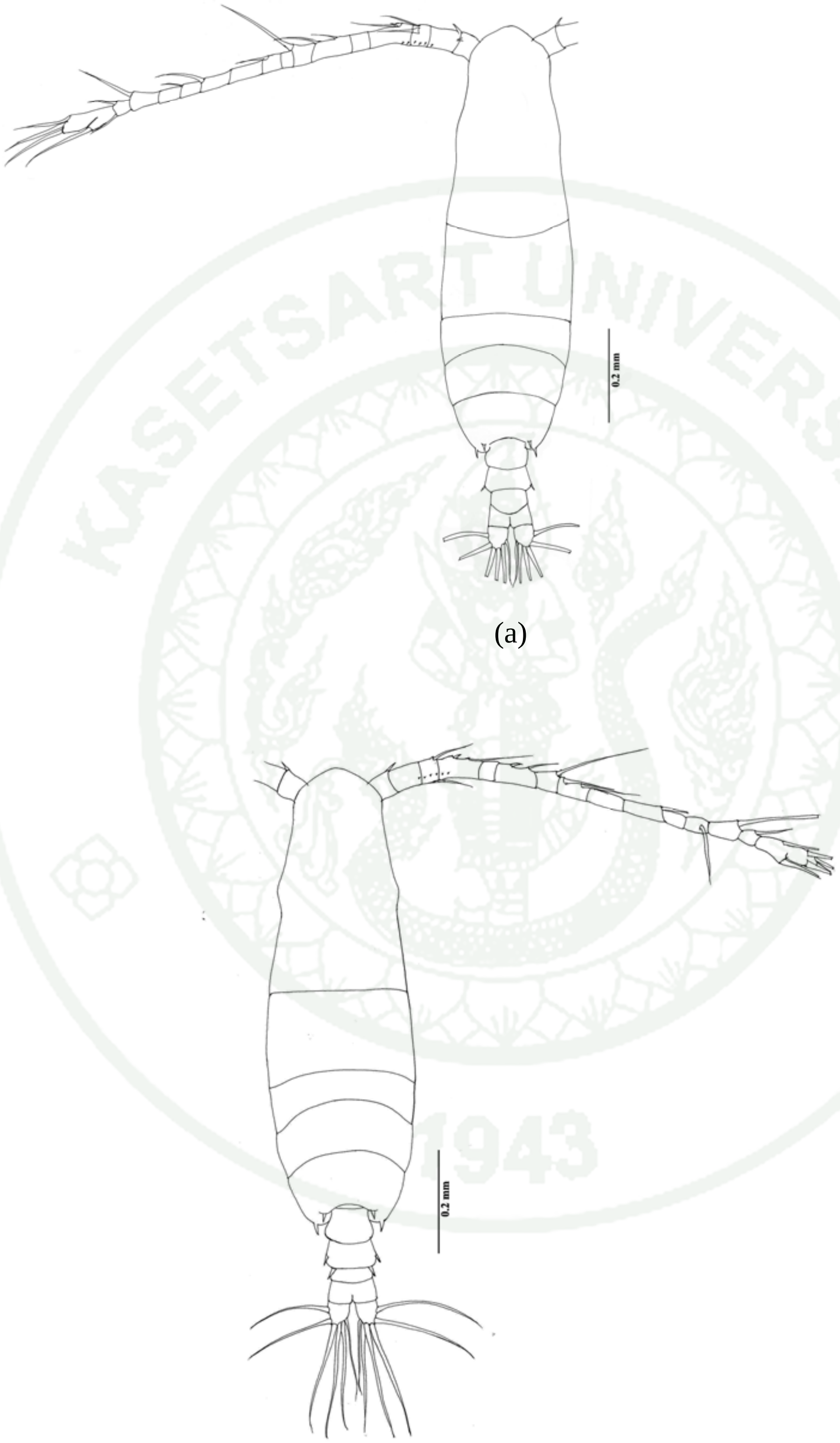
Source: Buranapratheprat (2009)



(a)

(b)

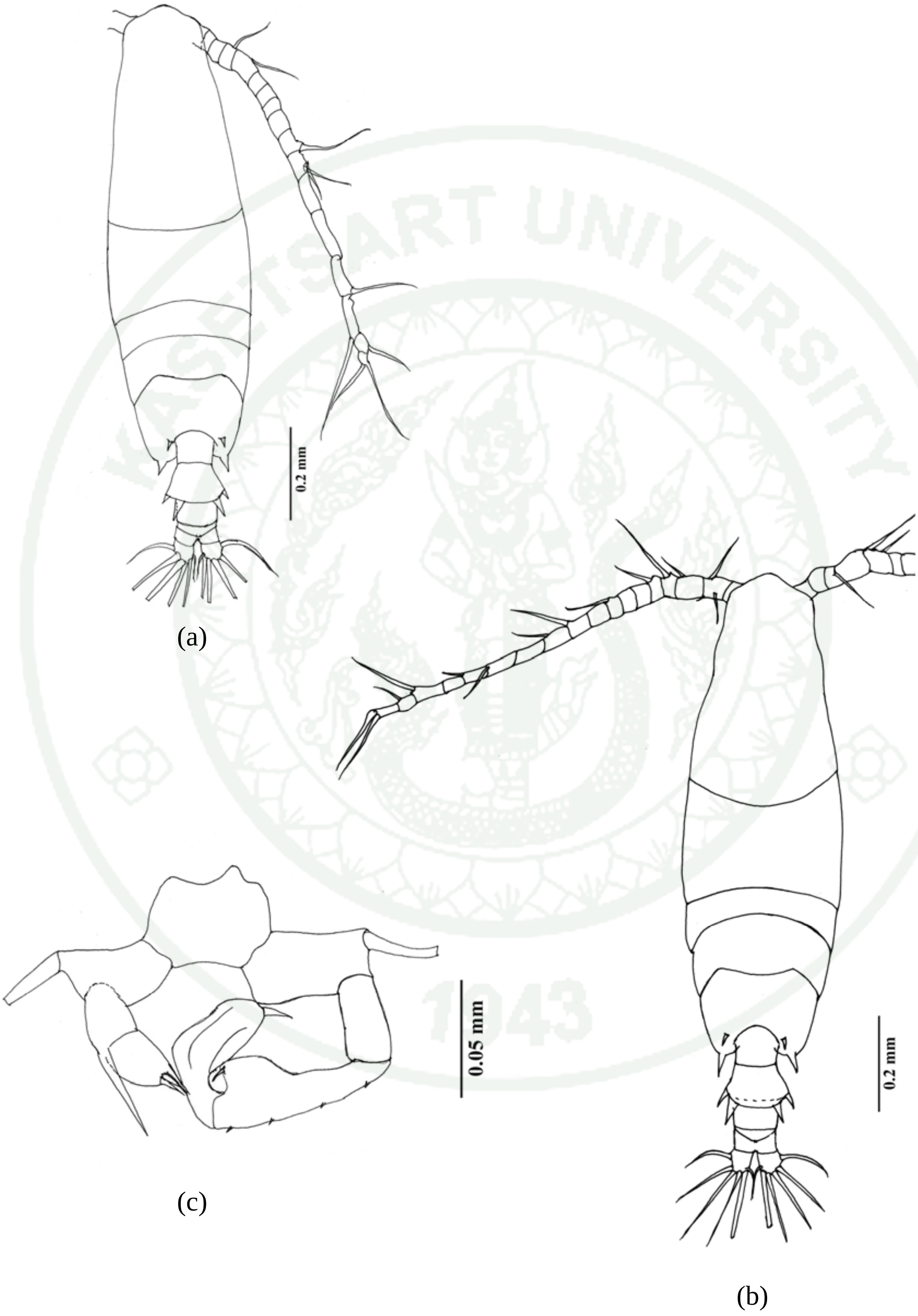
Appendix Figure 6 *Acartia erythraea* Giesbrecht: copepodid stage I (a); II (b).



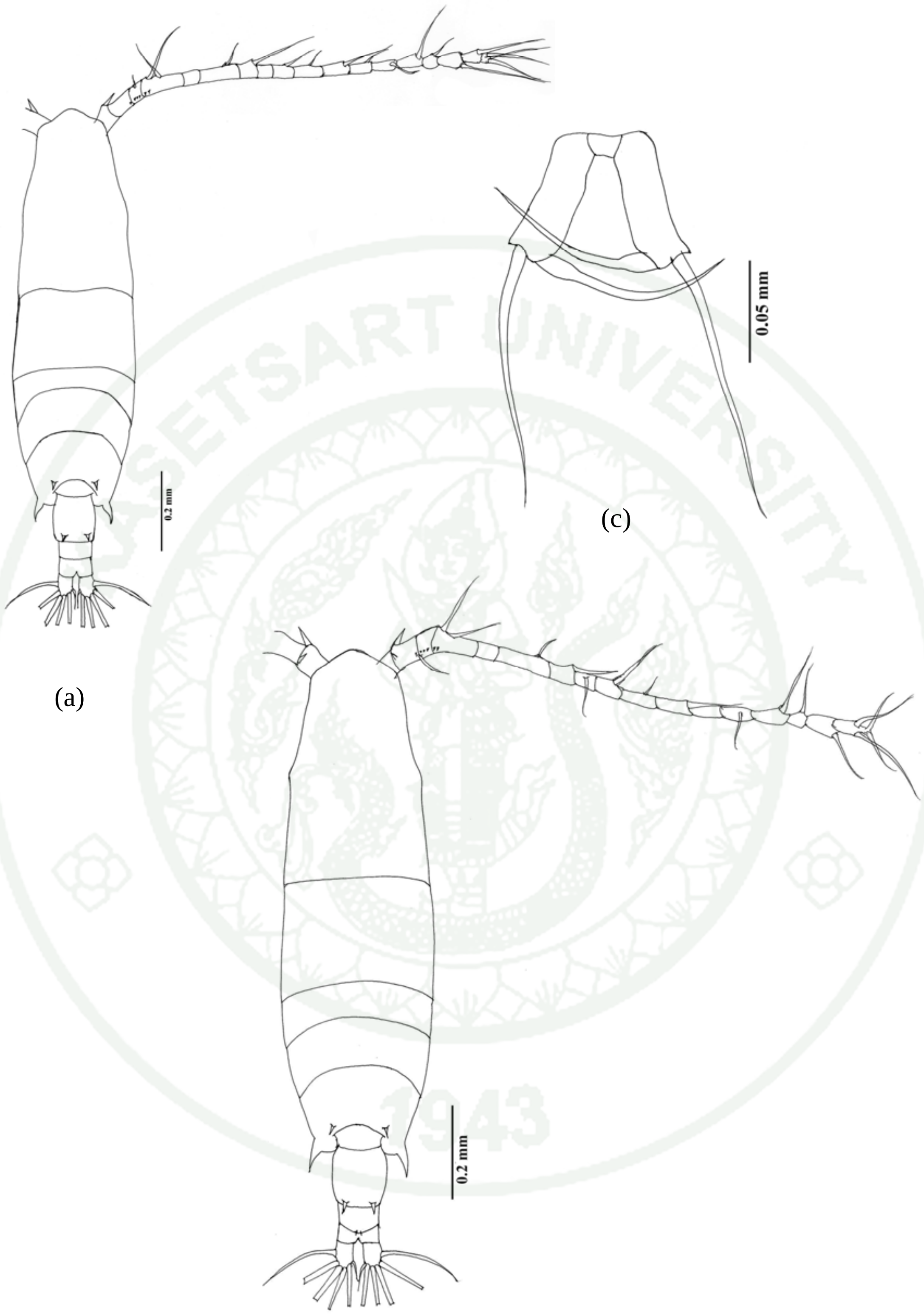
(a)

(b)

Appendix Figure 7 *Acartia erythraea* Giesbrecht: copepodid stage III (a); IV (b).



Appendix Figure 8 *Acartia erythraea* Giesbrecht male: copepodid stage V (a); adult (b); 5th legs (c).



(a)

(c)

(b)

Appendix Figure 9 *Acartia erythraea* Giesbrecht female: copepodid stage V (a); adult (b); 5th legs (c).

CURRICULUM VITAE

NAME : Mrs. Pailin Jitchum

BIRTH DATE : August 23, 1974

BIRTH PLACE : Bangkok, Thailand

EDUCATION :

YEAR	**INSTITUTUE**	**DEGREE**
1996	Kasetsart Univ.	B. Sc. (Fisheries)
1999	Kasetsart Univ.	M.S. (Marine Science)

POSITION/TITLE : Lecturer
WORK PLACE : Faculty of Fisheries, Kasetsart University
SCHOLARSHIP/AWARDS : Thai Government Scholarship 2006-2009