ปัจจัยที่มีผลต่อความหลากหลายและการเปลี่ยนแปลงแทนที่ในชุมชนแพลงก์ตอนพืช บริเวณชายฝั่งศรีราชา-สีชัง จังหวัดชลบุรี

นางสาวนิตยา สมทรัพย์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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FACTORS AFFECTING DIVERSITY AND SUCCESSION IN PHYTOPLANKTON COMMUNITIES IN THE COASTAL AREA OF SI RACHA-SI CHANG, CHON BURI PROVINCE

Miss Nittaya Somsap

A Dissertation Submitted in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy Program in Biological Sciences
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Thesis Title	FACTORS AFFECTING DIVERSITY AND SUCCESSION IN PHYTOPLANKTON COMMUNITIES IN THE COASTAL AREA OF SI RACHA-SI CHANG, CHON BURI PROVINCE
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Field of Study	Biological Sciences
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นิตยา สมทรัพย์ : ปัจจัยที่มีผลต่อความหลากหลายและการเปลี่ยนแปลงแทนที่ในชุมชนแพลงก์ตอนพืช บริเวณชายฝั่งศรีราชา-สีชัง จังหวัดชลบุรี (FACTORS AFFECTING DIVERSITY AND SUCCESSION IN PHYTOPLANKTON COMMUNITIES IN THE COASTAL AREA OF SI RACHA-SI CHANG, CHON BURI PROVINCE) อ. ที่ปรึกษาวิทยานิพนธ์หลัก : รศ.ดร. นันทนา คชเสนี, อ. ที่ปรึกษาวิทยานิพนธ์ร่วม : รศ.ดร. อัจฉราภรณ์ เปี่ยมสมบูรณ์, 129 หน้า.

การศึกษานี้ประกอบด้วย 3 ส่วนคือ 1) ความหลากหลายและความอุดมสมบูรณ์ของแพลงก์ตอนพืชซึ่งสัมพันธ์กับปัจจัยทางสิ่งแวดล้อม 2) การเปลี่ยนแปลงแทนที่ในชุมชนแพลงก์ตอนพืชซึ่งสัมพันธ์กับปัจจัยทางสิ่งแวดล้อม และ 3) ความสัมพันธ์แบบอัลเลโลพาธิคระหว่างแพลงก์ตอนพืชกลุ่มเด่นสองชนิด พื้นที่ศึกษาตั้งอยู่ในบริเวณชายฝั่งศรีราชา-สีชัง จังหวัดชลบุรี การศึกษาส่วนที่หนึ่งดำเนินการในเดือนตุลาคม 2551 ถึงเดือนพฤษภาคม 2552 ในช่วงเปลี่ยนมรสุม (ตะวันตกเฉียงใต้-ตะวันออกเฉียงเหนือ SW-to-NE และตะวันออกเฉียงเหนือ-ตะวันตกเฉียงใต้ NE-to-SW) ฤดูมรสุมตะวันออกเฉียงเหนือ (NE) และฤดูมรสุมตะวันตกเฉียงใต้ (SW) พบว่าการเปลี่ยนแปลงตามฤดูกาลมีอิทธิพลต่อคุณภาพน้ำทะเลซึ่งส่งผลต่อความหลากหลายและความหนาแน่นของแพลงก์ตอนพืช โดยอุณหภูมิ ความเข้มข้นสารอาหารฟอสเฟต (DIP) และสารอาหารซิลิเกต (DSi) มีค่าสูงในช่วงที่น้ำทะเลมีความเค็มต่ำใน NE-to-SW และ SW และความเข้มข้นสารอาหารอนินทรีย์ไนโตรเจน (DIN), DIP และ DSi มักมีค่าสูงบริเวณสถานีด้านตะวันออกเฉียงเหนือของเกาะสีชังซึ่งอยู่ใกล้กับปากแม่น้ำบางปะกง ชุมชนแพลงก์ตอนพืชขนาดไมโครแพลงก์ตอนกลุ่มเด่นใน SW-to-NE และ NE-to-SW คือไดอะตอม ขณะที่กลุ่มเด่นใน NE และ SW คือไซยาโนแบคทีเรีย โดย *Oscillatoria* มีความหนาแน่นเฉลี่ยของสูงสุด (84%) ใน SW ช่วงที่น้ำทะเลมีค่า DIN:DIP ที่ไม่สมดุล = 2:1 (สมดุลของ N:P ~ 16:1, Redfield ratio) การศึกษาส่วนที่สองใน NE (ธันวาคม 2553-กุมภาพันธ์ 2554) และ SW (พฤษภาคม-ตุลาคม 2554) พบว่า DIN, DIN:DIP และ DSi มีค่าสูงในช่วงที่น้ำทะเลมีความเค็มต่ำใน SW ซึ่งตรงกันข้ามใน NE แพลงก์ตอนพืชกลุ่มเด่นที่พบใน NE และ SW คือ ไดอะตอมและไซยาโนแบคทีเรีย ตามลำดับ การเปลี่ยนแปลงแทนที่ของแพลงก์ตอนพืชใน NE เปลี่ยนจาก *Bacteriastrum* และ *Chaetoceros* ในเดือนธันวาคมไปเป็น *Oscillatoria* ในเดือนกุมภาพันธ์ ขณะที่ DIN:DIP = 90:1 และในช่วงต้น SW (พฤษภาคม) *Oscillatoria* และ *Chaetoceros* พร้อมกับการเพิ่มจำนวนของ *Noctiluca scintillans* (DIN:DIP = 24:1) ถูกแทนที่ด้วย *Skeletonema costatum* ในเดือนสิงหาคม (DIN:DIP = 36:1) และ *Oscillatoria* ร่วมกับ *Ceratium furca* ในเดือนกันยายนและเดือนตุลาคม (DIN:DIP = 33:1 และ 20:1 ตามลำดับ) การเปลี่ยนแปลงแทนที่ของแพลงก์ตอนพืชเหล่านี้สัมพันธ์กับความผันแปรของ DIN, DIP และ DIN:DIP ที่ไม่สมดุล การศึกษาส่วนที่สามในความสัมพันธ์แบบอัลเลโลพาธิคระหว่างไดโนแฟลกเจลเลต *Ceratium furca* และไดอะตอม *Chaetoceros curvisetus* ซึ่งทดลองโดยเติมน้ำทะเลที่กรอง *C. furca* ออก (filtrate) ที่ความเข้มข้นต่างกัน (0%, 0.1%, 1%, 10% และ 100%) ลงในระบบเลี้ยงไดอะตอม *C. curvisetus* ในอาหาร f/2+Si พบว่าที่ filtrate = 100 % ยับยั้งการเจริญเติบโตของ *C. curvisetus* ขณะที่ filtrate = 0.1 % กระตุ้นการแบ่งเซลล์ของ *C. curvisetus* ผลการศึกษาทั้งสามส่วนแสดงให้เห็นว่าปัจจัยที่มีผลต่อความหลากหลายและการเปลี่ยนแปลงแทนที่ของแพลงก์ตอนพืช คือ ปริมาณสารอาหารอนินทรีย์ละลายน้ำ โดยเฉพาะ DIN:DIP ที่ไม่สมดุล และความสัมพันธ์แบบอัลเลโลพาธิคระหว่างแพลงก์ตอนพืชต่างชนิดในชุมชนแพลงก์ตอนพืช

สาขาวิชา วิทยาศาสตร์ชีวภาพ ลายมือชื่อนิสิต..............................

ปีการศึกษา 2554 ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก..............................

ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์ร่วม..............................

5073833923 : MAJOR BIOLOGICAL SCIENCES
KEYWORDS : PHYTOPLANKTON / DIVERSITY / SUCCESSION / ALLOLOPATHY / GULF OF THAILAND

NITTAYA SOMSAP : FACTORS AFFECTING DIVERSITY AND SUCCESSION IN PHYTOPLANKTON COMMUNITIES IN THE COASTAL AREA OF SI RACHA-SI CHANG, CHON BURI PROVINCE. THESIS ADVISOR : ASSOC. PROF. NANTANA GAJASENI, Ph.D., THESIS CO-ADVISOR : ASSOC. PROF. AJCHARAPORN PIUMSOMBOON, Ph.D., 129 pp.

This study comprises three parts including 1) Diversity and abundance of phytoplankton in relation to the environmental factors; 2) Succession of phytoplankton communities in relation to the environmental factors; and 3) Allelopathic relationship between two dominant phytoplankton. The study site located in the coastal area of Si Racha and Ko Si Chang, Chon Buri province where the first study was conducted from October 2008 to May 2009 in two inter-monsoon seasons (southwest to northeast: SW-to-NE and northeast to southwest: NE-to-SW) and the northeast (NE) and the southwest (SW) monsoons. The results indicated the significant influence of seasonal variation on environmental parameters affecting phytoplankton diversity and density. The high seawater temperature, dissolved inorganic phosphorus (DIP) and dissolved silicate-silicon (DSi) but low in salinity were observed in the NE-to-SW inter-monsoon and the SW monsoon periods. The highest concentrations of DIN, DIP and DSi always found at the stations located in the NE part of Ko Si Chang closed to Bang Pakong river mouth. Consequently, the dominant phytoplankton groups in both inter-monsoons were diatoms while the dominant groups in the NE and the SW monsoons were cyanobacteria with *Oscillatoria* contributed to high percentage of total count (84%) in the SW monsoon with the unbalanced DIN:DIP ratio = 2:1 (balanced N:P ~ 16:1, Redfield ratio). Furthermore, the second study in both the NE monsoon (December 2010 to February 2011) and the SW monsoon (May to October 2011) was conducted. The results showed that there were significantly high values of DIN, DIN:DIP ratio, DSi and low salinity in the SW monsoon, while it found opposite in the NE monsoon. The dominant groups of phytoplankton in the NE and the SW monsoons were diatoms and cyanobacteria, respectively. It also found that succession pattern of phytoplankton during the NE monsoon changed from *Bacteriastrum* and *Chaetoceros* in December to *Oscillatoria* in February with the value of DIN:DIP = 90:1. In the early SW monsoon (May), *Oscillatoria* and *Chaetoceros* with a bloom of *Noctiluca scintillans* (DIN: DIP = 24:1) were replaced by the bloom of *Skeletonema costatum* in August (DIN:DIP = 36:1) and *Oscillatoria* - *Ceratium furca* in September and October (DIN:DIP = 33:1 and 20:1, respectively). These successions of phytotoplankton related to the variations in DIN and DIP concentrations, particularly in the unbalanced DIN:DIP ratio. The third study on the allelopathic effect between a dinoflagellate *Ceratium furca* and a diatom *Chaetoceros curvisetus* was also performed using *C. curvisetus* grown in f/2+Si medium with the addition of 0%, 0.1%, 1%, 10% and 100% filtrate from *C. furca*. The inhibition of diatom growth was noticed in *C. curvisetus* grew in 100% filtrate since cell density decreased from the beginning of the experiment. The result from 0.1% filtrate stimulated cell division of *C. curvisetus*. In conclusion, these studies indicated that factors affecting diversity and succession of phytoplankton were dissolved inorganic nutrients especially in the unbalanced DIN:DIP ratio and the allelopathic relationship between different phytoplankton.

Field of Study : Biological Sciences Student's Signature ....

Academic Year : 2011 Advisor's Signature ....

Co-advisor's Signature ....

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CHAPTER I
INTRODUCTION

1.1 Justification of research

With the recent situation in the Gulf of Thailand, the decline of coastal fisheries and the deterioration of water quality are important problems in the upper gulf, due to the expansion of industrialization and community development in the coastal zone in order to achieve a national economic development. Consequently, it has caused considerable environmental changes that also obviously created a stress on the marine environments as well as provoked habitat degradation (Cheevaporn and Menasveta, 2003). Moreover, not only the above mentioned development but also the maritime activities within many commercial ports have stimulated the environmental impacts to the marine ecosystem in the Upper Gulf of Thailand (UGoT). Based on the beautiful beach and islands in the eastern coastal zone in the gulf, it becomes the tourist attraction so touristic and recreation activities are also very important for the local and national economy that cannot be overlooked (Buranapratheprat, 2002).

Regarding the human activities along and within the coastal areas, the utilizations of the natural resources in coastal areas also induce the direct and indirect environmental impacts on marine ecosystems and resulted in the decline of coastal fisheries and the deterioration of water quality as indicated by the increasing frequency of eutrophication and phytoplankton bloom (ARRI, 2009). Some evidences show that most conspicuous and widespread pollution impacts on the marine environment of the gulf is perhaps related to eutrophication due to the dynamics of nutrient availability in the ecosystem. Consequently, it causes the massive blooms of phytoplankton and/or red tide phenomenon that usually indicate the imbalance in diversity and abundance in phytoplankton communities. This red tide phenomenon also causes some health impacts to people as well as ecological impacts to marine life.

Interestingly, the coastal zone of the eastern of the UGoT is highly industrialized not only chemical industry and automation industry but also hotel and tourism which currently encounters with various types of environmental pollutions such as water pollution, air pollution and so on. Particularly, Chon Buri province is also facing on those environmental problems such as the red tide phenomenon has caused a serious coastal environmental and health problem and long been scientifically interested (Rungsupa *et al*., 2003). The red tide normally occurs year around but in different locations-along the western coast and the northeast corner of the UGoT during the northeast and the southwest monsoons, respectively (Buranapratheprat *et al*., 2009).

The marine ecosystem at Si Racha-Si Chang, Chon Buri province is selected as the study area because of its location at one of busy maritime route of international shipping or marine transport in Thailand as well as the fishery boats and tourist activities. With this regard, it is seemed that the human activities have been occurred directly or indirectly in this marine ecosystem caused many environmental changes in terms of water pollution, ecosystem disturbance, etc. There are still many research issues that are unsolved and proved properly. Therefore, it is highly justified for conducting the study that is also interested mainly in the diversity, abundance and succession of phytoplankton in relation to environmental factors due to seasonal variation. To understand the relationships between nutrient availability and phytoplankton blooms, thus the knowledge of phytoplankton community dynamics and succession in certain condition is necessary. Then, the knowledge of the succession of phytoplankton will be taken for further study on allelophatic relationship of two dominant species under specific condition in order to understand the effects of both species. Moreover, this study will provide a better information and knowledge that is possibly benefit for algal bloom control particularly the red tide phenomenon as well as the appropriate management strategy for the coastal zone of Si Racha-Si Chang area.

1.2 Study site

Geographical characteristics of the Upper Gulf of Thailand are a semi-enclosed sea and located in the tropical region in the Southeast Asia at latitude 13°30′N to 12°60′N and longitude 100°00′E to 101°00′E. It has a square-liked dimension surrounded by land in the eastern, northern and western coastal zones, and is open to the Lower Gulf of Thailand via the southern side. It has an approximate area of 10^4 km^2. The average depth is 20 m with the maximum depth of 40 m at the south eastern area. There are four main rivers approaching into the upper gulf namely Mae Klong, Tha Chin, Chao Praya and Bang Pakong Rivers from the west to the east, respectively (Buranapratheprat, 2006). The area is under the climatic influence of the two-monsoon system annually as the dry northeast (November to January) and the wet southwest monsoon (May to August). The northeast monsoon brings cool and dry air from Siberia, while the southwest monsoon brings moist air from the Indian Ocean into Thailand (Sojisuporn, 1994). The UGoT has been intensively used for several purposes such as coastal fisheries, aquaculture especially mussel and oyster husbanding, maritime and recreation (Buranapratheprat, 2006).

Study area is located between Si Racha coastal zone and Ko Si Chang in Chon Buri province in the UGoT. Chon Buri province has been developed as one of economic development area in the eastern part of Thailand called "Eastern Seaboard Area". It also has many islands where has been diversified in terms of tourism, fishery industry, automation industry, marine transport, agriculture, etc. Particularly, Ko Si Chang is one of the largest island in the UGoT, its importance includes both historical aspect and economic aspects: fisheries, tourism, recreation and marine transportation. The locality of Ko Si Chang is opposite the coastal area called Si Racha district in Chon Buri province where the Laem Chabang marine port located there.

Interestingly, the location of Si Racha-Si Chang channel imposes limited water circulation to the outer part of the Gulf of Thailand and trapping of water runoff from Bang Pakong river. While Si Racha is one district in Chon Buri province, it is very important in terms of local and national economy from international maritime transportation, fishery business, tourism, etc. Therefore, this specific geographical characteristics of study area will be a suitable for conducting the study in responsible to the proposed hypothesis and objectives.

1.3 Research hypotheses

The hypothesis of this study is raising that

"Phytoplankton diversity and succession patterns depend on environmental factors especially dissolved inorganic nutrients and allelopathy"

1.4 Research objectives

Regarding the research interest and hypothesis, it is clear that objectives are;

1. To determine diversity and succession patterns in phytoplankton communities along Si Racha–Si Chang coastal area, Chon Buri province.
2. To determine the relationships between phytoplankton diversity and succession with physico-chemical parameters.
3. To study the allelopathic relationships between phytoplankton.

1.5 Conceptual framework

Figure 1.1 shows the schematic conceptual framework of this study, which is composed of five main themes; (i) research hypotheses and objectives, (ii) literature review from primary and secondary sources, other three themes emphasised on the field survey and experimental laboratory that are (iii) diversity and abundance of phytoplankton communities in relation to environmental factors, (iv) succession of phytoplankton communities in relation to the environmental factors, (v) allelopathic relationship between phytoplankton.

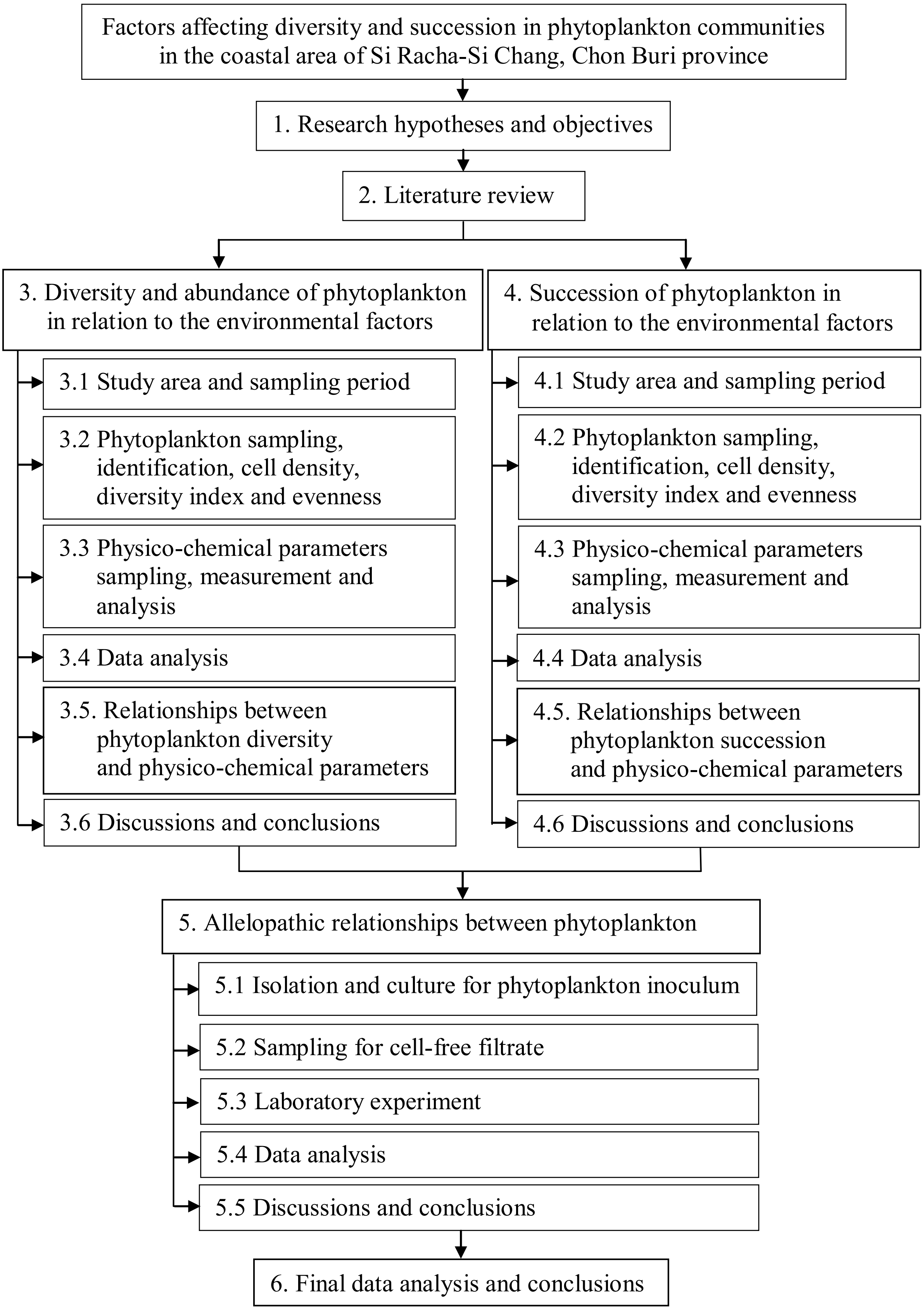


Figure 1.1 Conceptual framework of the research.

1.6 Expected outcomes

The outcomes expected from this research are:

1. The result on phytoplankton diversity and abundance can be used as baseline information on marine biodiversity of Si Racha–Si Chang area.

2. The knowledge of factors affecting phytoplankton succession can be used as guideline for proper management of the coastal zone as well as the guideline for the monitoring of coastal ecosystems as well as the application of bio-indicator to the monitoring scheme.

3. The knowledge of allelopathic phytoplankton species will benefit for algal bloom control and appropriate management.

1.7 Dissertation structure

This dissertation is organized into six chapters in the formality of paper base approach which includes namely;

Chapter I presents the introduction of the study as the above mentioned.

Chapter II presents the literature review from primary and secondary sources in relation to the situation of the Upper Gulf of Thailand, particularly the situation of western part at Si Racha-Si Chang in Chon Buri province. By the reviews, it is emphasis on the respective research on diversity, succession, both relationships with physico-chemical parameters and allelopathic relationship between phytoplankton.

Chapter III presents the first scientific paper on the topic "Diversity and abundance of phytoplankton communities in relation to environmental parameters in the coastal area of Si Racha-Si Chang, Chon Buri province".

Chapter IV presents the second scientific paper on the topic "Succession of phytoplankton communities in relation to environmental parameters in the coastal area of Ko Si Chang, Chon Buri province".

Chapters V presents the third scientific paper on the topic "Allelopathic relationship between two dominant phytoplankton: dinoflagellate (*Curatium furca*) and diatom (*Chaetoceros curvisetus*) in the coastal area of Ko Si Chang, Chon Buri province".

Chapters VI presents conclusions of the overall study and recommendations that will provide some ideas for the further study.

CHAPTER II
LITERATURE REVIEW

2.1 The Gulf of Thailand

Geographically, the Gulf of Thailand (GoT) is a large marine ecosystem (Pauly and Chuenpagdee, 2003), a semi-enclosed tropical sea located in the South China Sea (Pacific Ocean) and bordered with Malaysia, Thailand, Cambodia and Vietnam. The approximate area is 3.2 x 10^5 km^2 which can be divided into two parts; Upper Gulf and Lower Gulf (Wattayakorn, 2006).

The Upper Gulf of Thailand (UGoT), the innermost area located at latitude 13^oN and longitude $100^o30'E$. It has an inverted U-shape, surrounded by three sides of land in the eastern, northern and western boundaries and open to the Lower Gulf in the south. It covers roughly 10^4 km^2 which is a shallow gulf with the maximum and average depth at 40 m and 20 m, respectively (Buranapratheprat, 2008).

The UgoT is characterized as the catchment basin from four main rivers on the northern side namely Mae Klong, Tha Chin, Chao Praya and Bang Pakong from west to east, respectively. These rivers discharge freshwater and sediment into the head of the UgoT. Among them, Chao Phraya discharges the greatest freshwater runoff in term of volume followed by the Mae Klong. It is estimated that a considerable amount of nutrients is also discharged from these two rivers promoting primary productivity in the Gulf (Buranapratheprat, 2006; Wattanayakorn, 2006).

The GoT area is under climatic influence of the two-monsoon wind system, the dry northeast (November to January) and the wet southwest monsoon (May to August). The northeast monsoon brings cool and dry air from Siberia, while the southwest monsoon brings moist air from the Indian into Thailand (Sojisuporn, 1994).

The GoT is considered as a major marine economic area for Thai people for a long time. Recently, the coastal and marine ecosystems have been disturbed and destroyed from the rapid development of industrialization and community. The most serious problems are untreated industrial wastewater, eutrophication, and trace metals contamination (Cheevaporn and Menasveta, 2003).

Furthermore, because of industrial growth in Thailand, maritime activities are rapidly stimulated. Therefore, there are many commercial ports located around the UgoT, it creates more environmental problems. Nevertheless, the rapid development of tourism and recreation activities along the coastal area of UGoT also push more pressure to the environment, the significant economy are also important and cannot be overlooked (Buranapratheprat, 2002).

2.2 Si Racha-Si Chang Area

Si Racha is a district (amphoe) of Chon Buri province, Thailand. It located at the eastern part of UGoT. It is in a heavy industrial zone consisting of various types of manufacturing and shipping industries, supported by the sprawling port of Laem Chabang (20^{th} largest port in the world). With the location of Laem Chabang port is next to Chon Buri Mueang district and connect to the north of Pattaya and Bang Lamung township, it becomes the economic zone of the Eastern Seaboard of Thailand. This area is the fast growing economic zone that is the second to only Bangkok in population and wealth. Due to the well-developed infrastructure, Laem Chabang and the Eastern Seaboard in general is the major hub for international exports, which have become the underpinning of the Thai economy.

Ko Si Chang or Si Chang Island, one district of Chon Buri province, located in the UGoT, 12 km away from the western shore of Si Racha district. It consists of the island of Ko Si Chang and its adjoining islands.

Ko Si Chang is an important economic island based on tourism for natural attraction, fishing and diving as well as a historical site where the summer palace, Phra Chuthathut palace, of King Rama V is located. Geographically, the location of Ko Si Chang and adjacent island is suitable for anchoring so it is important in term of marine transportation (ARRI, 2009).

Benjatheprasamee (2008) reported that in the past about 70 % of people who lived on Ko Si Chang were fishermen, but nowadays the number of fishermen has reduced due to the declining of marine resources. The rapid growth of deep seaport construction nearby the coastal areas and the population immigration due to high demand of tourism pressure have affected land use change on Ko Si Chang and surrounding area. Consequently from the mentioned pressures, there are lots of garbage, waste water, hot water and engine oil drained from ship to the sea and dust from tapioca and coal transportation have contaminated to the water quality of Ko Si Chang (ARRI, 2009).

Onkol (2007) found that total petroleum hydrocarbon (TPH) valued in the seaport area of Ko Si Chang of 0.774 μg/L was higher than in the residential area (0.657μg/L). Nevertheless, Ko Si Chang has been influencing by Bang Pakong river's effluent by receiving wastewater and organic matter contamination which also have been affected by internal-circulated current and caused water pollution, eutrophication, red tide, and the decrease of phytoplankton density (ARRI, 2009).

2.3 Phytoplankton communities in the GoT

According to the previous studies of phytoplankton diversity in the GoT, it found that the dominant phytoplankton often were diatoms and cyanobacteria particularly genus *Chaetoceros* and *Oscillatoria*, respectively. The phytoplankton density inshore is always greater than offshore.

Boonyaphiwat *et al*., (1998) recorded dominant phytoplankton in the GoT in northeast monsoon season were *Oscillatoria*, *Chaetoceros*, *Coscinodiscus*, *Proboscia* and *Thalassionema*. Khwaiphan (2005) also reported that in the area of Bang Pakong river mouth in dry and wet season, diatoms were the most diverse group and the most frequent phytoplankton genera appeared were *Thalassiosira* and *Oscillatoria*. While Saosee (2004) found that *Oscillatoria* and *Chaetoceros* were the higher abundance in the coastal area of Bang Pra in Chon Buri province.

There also were many researchers studied the diversity of phytoplankton in the coastal area of Ko Si Chang, Ratanamongkon (2007) reported that the dominant phytoplankton at Had Sai Kaew were diatoms especially *Chaetoceros*, *Thalassionema* and *Bacteriastrum*. In 2007, at Had Tha Bon there were 17 genera of phytoplankton which dominant genera were *Bacteriastrum*, *Chaetoceros* and *Eucampia* (Puttarn, 2007). At Had Thum Pang, Wichairahad (2007) found that the dominant groups at inshore and offshore were the diatoms of *Chaetoceros, Nitzschia* and *Rhizosolenia* and phytoplankton density at offshore stations was lower than the inshore ones. Junkaew (2009) also found that the dominant phytoplankton were diatoms in genus *Chaetoceros* which accounted for 79.2 % of total phytoplankton density. In the areas of Had Tha Bon, Had Thum Pang and Tha Yai Tim, Kaewngen (2008) also found the highest density of *Chaetoceros* in all three areas. At inshore and offshore in the area of Tha Wang, the major groups of phytoplankton were diatoms, dinoflagellates and cyanobacteria, respectively, which *Chaetoceros*, *Nitzschia*, *Rhizosolenia* were dominant genera and the phytoplankton density at inshore was greater than offshore (Late, 2007). In the area of Leam Ngu in 2007 at inshore and offshore, Purgsaard (2007) found that the dominant phytoplankton were *Chaetoceros*, *Nitzschia* and *Lauderia* respectively which the phytoplankton density at inshore was found higher than offshore. At Assadang bridge and Tha Panurungsi, Wongsuwan (2008) found that diatoms were dominant which consisted of *Eucampia*, *Chaetoceros*, *Bacteriastrum*, and *Nitzschia*.

2.4 Red tides

Red tides are water colour changes due to the rapid growth of marine microscopic organisms, irrespective of the colour, and often cause mass mortalities of marine animals (Okaichi, 2003). Due to the increasing of nutrients contamination from freshwater and marine farming located near the shore, it is one of major course that leads to the increasing of phytoplankton bloom or red tides, the depletion of dissolved oxygen, food poisoning and other pollution effects. In Thailand, the red tide occurrence evidently was first reported in 1957. Nowadays, the frequency of this phenomenon has been increasing, especially in the UGoT.

From the survey of the Aquatic Resources Research Institute (ARRI), Chulalongkorn University (2003) reported that since 1957 till 2001 there were 97 red tide occurrences in the GoT. The dominant species of blooming phytoplankton were *Noctiluca scintillans* and *Trichodesmium erythraeum*,which caused the change of colour water from discoloured into dark green and yellow green, respectively. Although both blooming species are non-toxin and harmless to fish and shellfish, due to the high concentration they could cause the decrease of dissolved oxygen and increase of ammonia concentration in the water column occurred, sometimes lead to mortality of fish (Wattayakorn, 2006).

Buranapratheprat (2008) reported that in Thailand, there was only one recorded occurrence of Paralytic Shellfish Poisoning (PSP) in May 1983. This event caused of 63 people becoming ill and one death after consuming contaminated green mussels (*Perna veridis*) in the red tide area of Pran Buri river mouth.

2.5 Relationships of physico-chemical parameters and phytoplankton

Nutrients are the major physico-chemical parameters reported as the cause of phytoplankton bloom as measured by phytoplankton abundance as well as phytoplankton biomass all over the world ocean.

Chen *et al*. (2006) who studied the physical forcing influence biogeochemical cycles in the water column of the South China Sea, reported the low chlorophyll concentrations (represented phytoplankton biomass) resulted from strong nutrient limitation condition. Paul *et al*. (2008) studied the seasonal dynamics of nutrient ratios and abundance of phytoplankton cells at Bengal bay found that high nutrient concentrations appeared to contribute to higher phytoplankton abundance. Shipe *et al*. (2008) also reported that the *Pseudo-nitzschia* sp. blooms along the North American west coast were associated with elevated nitrate, dissolved silicon and phosphate concentrations. The study on the effects of rainfall on phytoplankton community during spring and summer in Sagami Bay, Japan, also revealed that nutrient supply from river discharge is a main cue for strong bottom–up effects on algal bloom (Baek *et al*., 2009).

2.6 DIN: DIP ratio

Most nutrient limitation that is driving force in the ecosystem development are N or P (Koerselman and Meuleman 1996). There were many researches indicated that N: P ratio influenced on the growth of phytoplankton. Obernosterer and Herndl (1995) cultured *Chaetoceros affinis* under the different of N: P ratios. Their result showed that in P limitation (N: P = 100) and N limitation (N: P = 5), *C. affinis* produced higher (100 and 30%) phytoplankton extracellular release (PER) than in balanced N: P ratio treatment. This PER composed of dissolved monomeric (MCHO) and polymeric (PCHO) carbohydrate and dissolved free amino acid (DFAA) which significantly stimulated higher growth of bacteria in PER derived from unbalanced than balanced N: P ratio. Wood, *et al*. (2010) reported that the blooming of *Anabaena planktonica* corresponded with low DIN and the lowest of DIN: DIP. Carpenter

(1973) reported that nitrogen fixation by *Oscillatoria* appeared in the situation of low concentration of total nitrogen in the water column.

2.7 Succession in phytoplankton communities

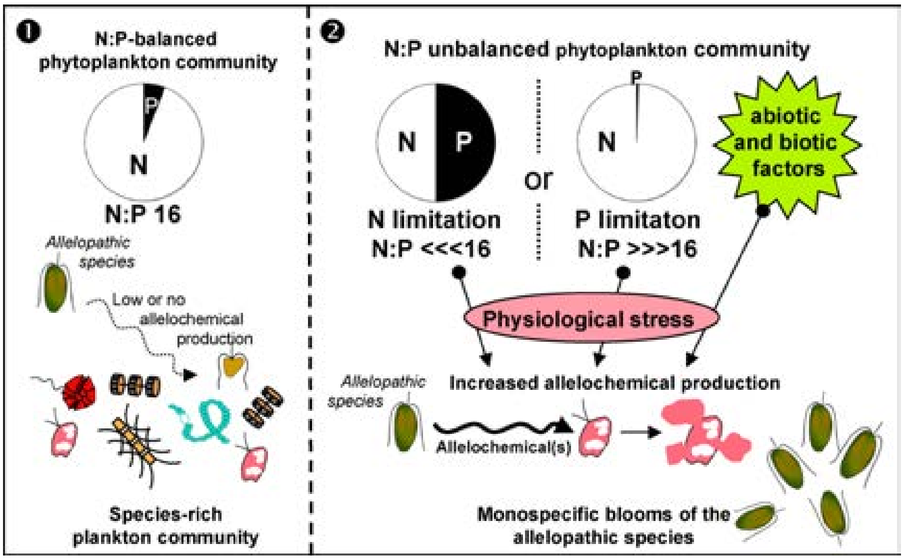
Succession refers to an orderly sequence of species observed in a habitat following a large disturbance that eliminates the local biota (Levinton, 1982). Phytoplankton succession depends on the influence of biotic and abiotic factors. Casas (1999) reported that seasonal succession of phytoplankton species on the coast of Coruna in the northwest Spain, occurred during upwelling events. Ubry *et al.* (2004) studied the appearance of phytoplankton over the years and found that the major limiting factors controlling phytoplankton growth in the Adriatic coastal system were light, temperature, and the strong influence of meteorological events. It was also referred that the change of nutrients would also affect the phytoplankton succession. There are many factors such as irradiance, temperature, turbulence, salinity and grazing reported to affect the occurrence of phytoplankton blooms, while phytoplankton succession would happen when nutrient ratios changed (Domingues *et al*., 2005; Liu *et al*., 2005). In red tide phenomenon, nutrient availability has frequently outweighed other factors on phytoplankton succession (Liu *et al*., 2005). Besides, the bottom-up control, Lopes *et al.* (2006) reported that phytoplankton succession may also depend on the grazing capacity of the pelagic community through top-down regulation.

2.8 Allelopathy

The International Allelopathy Society gave the definition of allelopathy as "any process involving secondary metabolites produced by plants, algae, bacteria, and fungi that influence the growth and development of agricultural and biological systems" (IAS, 1996). Therefore, allelopathy of phytoplankton is defined as the ability of certain harmful algal species to produce and release chemicals (allelochemicals) to inhibit the growth of co-occurring phytoplankton species (Graneli *et al*., 2008).

The production of allelochemicals by marine phytoplankton found in cyanobacteria, dinoflagellates and flagellates (Graneli and Pavia, 2006). Some reports suggested that allelochemicals were also produced in diatom and green algae (Graneli and Hansen, 2006).

It is clear that allelopathy is closely associated with competition condition during limiting nutrient resources. In experimental study, the nutrients filled to seawaters especially nitrogen (N) and phosphorus (P) always in unbalanced ratios (N: P~16, Redfield ratio), which causes of eutrophication and limit growth of phytoplankton (Cloern, 2001). Under the condition of growth-limiting nutrients, certain algal species with the ability to produce allelochemical substance have the potential to become dominant and form blooms (Figure 2.1).



Source: Graneli et al., 2008.

Figure 2.1 Two senarios showing how eutrophication might affect allelopathy.

The stress conditions imposed by the shifted nutrient supply ratios can, in some algae, stimulate production of allelochemicals that inhibit potential competitors. Thus, under cultural eutrophication, altered nutrient (N, P) ratios and limiting nutrient supplies can stimulate increased production of allelochemicals, including toxins, by some algal species and increase the adverse effects of these substances on other algae (Graneli *et al*., 2008).

By referring scientific reports related to allelopathy, the application of mixed batch cultures is recognized. The advantages of this method are the continuing production of allelochemicals by the toxic algae, and therefore it provides the opportunity of studying the toxic effects at "natural cell concentrations". However, potential competition for nutrients between the donor and the target, as well as other interspecific interactions can be avoided by using filtrates of allelopathic compounds. Filtrates are particularly useful in studies of potential toxic effects on natural planktonic communities (Graneli and Hansen, 2006; Graneli *et al.*, 2008; Tameishi *et al.*, 2009).

Allelopathy, as one pattern of chemical interactions is an important part of phytoplankton competition liked higher plants, is largely unknown in aquatic systems (Legrand *et al.*, 2003). Currently, the knowledge on allelopathic research is a relatively new topic in aquatic ecosystems, which most allelochemicals have not yet been isolated and structurally characterized. However, some researchers reported that organic substances that released from phytoplankton cells were carbohydrates (Myklestad, 1995) and fatty acid (Wu *et al.*, 2006 and Kubanek *et al.*, 2008). Myklestad (1995) also reported that during all phases of phytoplankton growth, it could secrete polysaccharides, sometimes reached to 80–90% of the total extracellular release.

The current publications (Graneli *et al.*, 2008) mainly show how the allelochemical production effects on other phytoplankton (Table 2.1). Wang *et al.* (2006) reported that in bi-algal culture of dinoflagellates *Prorocentrum donghaiense* and *Alexandrium tamarense*, although the initial cell density of *A. tamarense* was lower than *P. donghaiense*, it could suppress growth of *P. donghaiense.* Whereas, in filtrate culture, the lower initial cell density of *P. donghaiense* promoted growth of *A. tamarense.* Pouvreau *et al*. (2007) reported that marennine, a blue-green polyphenolic pigment released from diatom *Haslea ostrearia*, could inhibit growth of *Skeletonema costatum*, *Nitzschia closterium*, *H. crucigera* and *Entomoneis pseudoduplex*. However, at low concentration of marennine could promot growth of *H. ostrearia*. Kubanek *et al*. (2008) reported that the red tide caused by a dinoflagellate *Karenia brevis* exhibited an allelopathic effect of suppressing growth of 9 of 12 co-occurring phytoplankton. Moreover, the extracellular filtrates or lipophilic extracts from *K. brevis* also inhibited six of these nine species. Tameishi *et al*. (2009) studied the allelopathic relationships between dinophyte *Prorocentrum minimum* and the bacillariophyte *Skeletonema costatum*, the results showed that in bi-algal culture, *P. minimum* always inhibited growth of *S. costatum*, comparison to higher cell density of *S. costatum* suppressed growth of *P. minimum*. Moreover, low concentration of *P. minimum* cell-free filtrate significantly promoted growth of *S. costatum.* While the ultrafiltration of *P. minimum* culture which consisted of polysaccharide(s) significantly suppressed growth of *S. costatum.* Moreover, Wu *et al*. (2006) reported that some free fatty acid could kill phytoplankton by damaging phytoplankton cell membrane.

However, Granéli *et al*. (2008) suggested that the level of allelopathic effects depend on cell densities of allelopathic donor and target species. Sol (2005) reported that growth curve of non-toxic phytoplankton *Heterocapsa triquetra* significantly affected by only the high concentration of allelopathic species *Chrysocromulina polylepis*. Roy (2009) reported that the increasing of toxin-producing (allelochemicals) phytoplankton caused the decreasing of phytoplankton diversity.

Table 2.1 Allelopathic harmful algae species, their allelochemicals and allelopathic effect.

Species	Allelochemicals[a]	Effect[b]	Reference
Cyanophyceae			
Anabaena sp.	U	GI, GS	Suikkanen et al. (2005)
A. cylindrica	EP	GI	Legrand et al. (2003)
A. flos-aquae	HX, A, M, U	GI, IS , D	Murphy et al. (1976), Kearns and Hunter (2000), Kearns and Hunter (2001), Legrand et al. (2003)
A. lemmermannii	U	GI	Suikkanen et al. (2004)
Aphanizomenon sp.	U	FS	Suikkanen et al. (2005)
A. flos-aquae	U	GI	de Figueiredo et al. (2004); Suikkanen et al. (2004), Suikkanen et al. (2006)
A.gracile	U	GI, D	Legrand et al. (2003)
Cylindrospermopsis raciborskii	U	PI	Figueredo et al. (2007)
Gomphosphaeris aponina	U	GI	Legrand et al. (2003)
Hapalosiphon fontinalis	Hapalindole A	D	Moore et al. (1984)
Fisherella sp.	U	GI, PI	Bagchi and Marwah (1994)
Fisherella muscicola	Fisherellin	PI, GI, D	Gross et al. (1991), legrand et al. (2003)
Microcystis sp.	U, Micorcystin	GI, PI, D	Sukenik et al. (2002), Vardi et al. (2002)
Nodularia spumigena	U	GI, GS	Suikkanen et al. (2004, 2005), Suikkanen et al. (2006)
Nostoc sp.	U	GI, D	Schageri et al. (2002), Legrand et al. (2003)
Nostoc spongiaeforme	Nostocine	GI	Hirata et al. (1996), Hirata et al. (2003)
Oscillatoria sp.	FA	PI	Chauhan et al (1992)
Oscillatoria spp.	U	GI, PI, D	Legrand et al (2003)
Oscillatoria laetevirens	U	GI	Ray and bagchi (2001)
Bacillariophyceae			
Pseudo-nitzschia pungens	U	GI	Legrand et al. (2003)
Skeletonema costatum	U	GI	Yamasaki et al (2007)
Coscinodiscophyceae			
Rhizpsplenia alata	U	GI	Legenad et al. (2003)
Dinophyceae			
Alexandrium catenella	U	GI, D	Arzul et al. (1999)
A. minutum	U	GI, D	Arzul et al. (1999), Fistarol et al. (2004a)
A. ostenfeldii	U	IM, CP	Tillmann et al. (2007)
A. tamarense	U	GI, GS, CP, D	Arzul et al. (1999), Fistarol et al. (2004b), Fistarol et al. (2004a), Wang et al. (2006)
Amphidinium klebsii	U	GI	Sugg and VanDolah (1999)
Ceratium sp.	U	GI	Legrand et al. (2003)
Coolia monotis	U	GI	Sugg and VanDolah (1999), Legrand et al. (2003)
Gambierdiscus toxicus	U	GI, D	Sugg and VanDolah (1999)
Karenia brevis (Gymnodinium	U	GI, GS	Kubanek et al. (2005)
breve)	U	GI, CP, D	Uchida et al. (1999), Fistarol et al. (2004b)
K. mikimotoi (Gymnodinium	U	GI, D	Sugg and VanDolah (1999)
mikimotoi)	U	GI, D	Rengefors an dlegrand (2001)
Ostreopsis lenticularis	U	GI, D	Sugg and VanDolah (1999)
Peridinium aciculiferum			
Prorocentrum lima			
Haptophyceae			
Chrysochromulina polylepis	U	GI, CP, D	Myklestad et al. (1995), Schmidt and Hansen (2001), Fistarol et al.
Phaeocystis pouchetii	U, PUA	GI, D, H	(2004b)
Prymnestium parvum	U, Prymnesin	D, RG	Hansen et al. (2004), Hansen and Eilertsen (2007), van Rijssel et al. (2007)
			Igarashi et al. (1998), Fistarol et al. (2003), Granéli and Johansson (2003),
			Berreiro et al. (2005), Fistarol et al. (2005)
Raphidophyceae			
Chattonella antiqua	U	GI	Matsuyama et al. (2000) cited in Gross (2003)
Heterosigma akashiwo	U	GI, GS	Matsuyama et al. (2000) cited in Gross (2003); Pratt (1996); Yamasaki et al. (2007)

[a] A, anatoxin; EP, extracellular peptide; F, fatty acid; HX, hydroxamate chelator; M, microsystin; OA, okadaic acid; PUA, polyunsatuarated aldehyde; U, unknown.
[b] CP, cyst promotion; D, death; GI, growth inhibitor; GS, growth stimulation; H, haemolysis; IM, immobilization; IS, induced setting; PI, phytosysthesis inhibition; RG, reduced grazing

Source: Graneli et al., 2008.

CHAPTER III

DIVERSITY AND ABUNDANCE OF PHYTOPLANKTON COMMUNITIES IN RELATION TO THE ENVIRONMENTAL FACTORS IN THE COASTAL AREA OF SI RACHA - SI CHANG, CHON BURI PROVINCE

Abstract

The diversity and abundance of phytoplankton in relation to the environmental factors was studied in the coastal area of Si Racha and Ko Si Chang, Chon Buri province from October 2008 to May 2009. Field samplings were conducted for four periods; two periods in the inter-monsoon seasons (southwest to northeast or SW-to-NE and northeast to southwest or NE-to-SW), the northeast (NE) and the southwest (SW) monsoons. Seawater samples were collected from eleven sites at surface, middle and bottom depths. Temporal variations of environmental parameters were significantly ($p < 0.05$) with high values of seawater temperature, dissolved inorganic phosphorus (DIP) and dissolved silicate-silicon (DSi) but low value of salinity observed in the NE-to-SW inter-monsoon and the SW monsoon periods. The highest concentrations of dissolved inorganic nutrients always found at the stations located in the northeastern part of Ko Si Chang closed to Bang Pakong river mouth. Diatoms together with cyanobacteria were the dominant phytoplankton groups found in this study except in the SW monsoon period where the dominance of cyanobacteria was far greater than the diatoms. Fifty six genera of phytoplankton were identified with *Oscillatoria* contributed to high percentage of total count. Phytoplankton density, Shannon-Wiener diversity index (H') and Pielou evenness index (J') were significant differences ($p < 0.05$) in different study periods and sites. In the SW monsoon, the highest phytoplankton density but lowest H' and J' were recorded. While in the NE monsoon, phytoplankton communities were characterized by the lowest density with the highest J'. Phytoplankton density in the stations between Ko Si Chang and the coastal area of Si Racha tended to be higher than the density in the stations located on the western part of Ko Si Chang.

3.1 Introduction

The Upper Gulf of Thailand (UGoT), is long known for its economically important marine environment for Thai people (Cheevaporn and Menasveta, 2003). The UGoT had been recognized for its fishery fertility due to nutrient input from freshwater discharge by major rivers namely Mae klong, Tha Chin, Chao Praya and Bang Pakong rivers (Buranapratheprat, 2006; Wattanayakorn, 2006). Nowadays, the rapid growths of industrialization, maritime activities such as commercial ports, communities, tourists and recreation activities along the coastal area of the UGoT resulted in deterioration of marine ecosystem such as eutrophication and algal bloom (Buranapratheprat, 2002).

Si Racha, Chon Buri province is an economic zone located in the eastern part of the UGoT. Due to the supporting of Laem Chabang port nearby Si Racha, there are many types of manufacturing and shipping industries. Ko Si Chang, located in the eastern part of UGoT. It also is an important economic island due to the activities of tourism and marine transportation. Consequently, it is followed by the contamination of seawater from garbage, waste water, hot water and engine oil drained from ship to the sea and dust from tapioca and coal transportation (ARRI, 2009). Onkol (2007) reported that the total petroleum hydrocarbon (TPH) valued in the seaport area of Ko Si Chang (0.774 µg/L) was higher than in the residential area (0.657µg/L). Benjatheprasamee (2008) also reported that due to the reduction of marine resources resulted in the reduction of the number of native fishermen there.

Phytoplankton, microalgae living in the water column, can be used as an indicator of seawater quality. As qualitative indicator, phytoplankton diversity and dominant taxa in the UGoT were studied by many researchers (Boonyaphiwat *et al*., 1998; Saosee, 2004; Khwaiphan, 2005; Purgsaard, 2007; Ratanamongkon, 2007; Wichairahad, 2007; Kaewngen, 2008; Wongsuwan, 2008; Junkaew, 2009). The dominant phytoplankton often found in the UGoT included diatoms (*Chaetoceros, Thalassionema* and *Bacteriastrum*) and cyanobacteria (*Oscillatoria*). Quatitatively, the inshore phytoplankton density was often higher than in offshore areas (Late, 2007; Wichairahad, 2007).

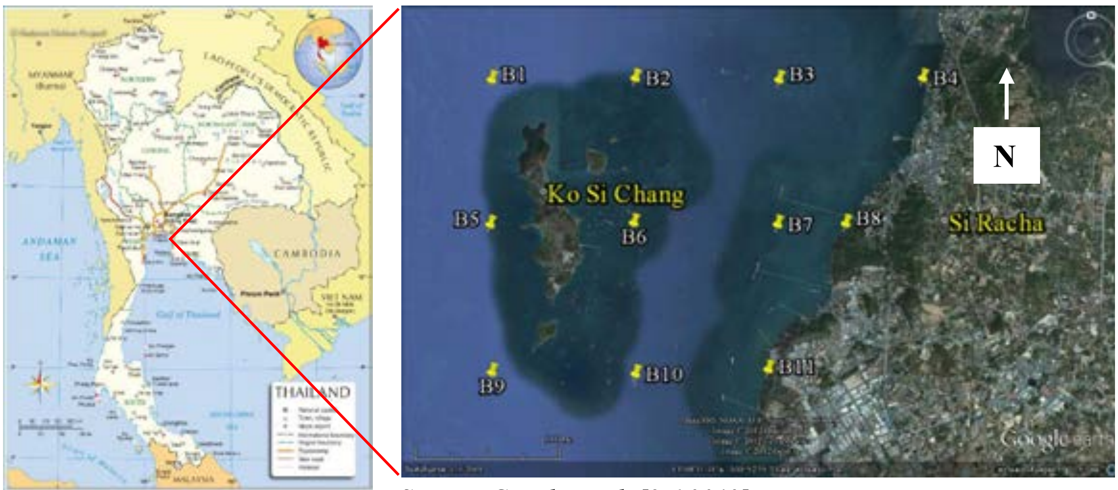
According to the problems of marine ecosystem in the coastal area of Si Racha-Si Chang as mentioned. So the aims of this study were to: (i) investigate the environmental parameters in the SW-to-NE, NE, NE-to-SW and SW monsoons in the UGoT; (ii) identify phytoplankton communities and also distribution and abundance;

(iii) analyze the relationships between phytoplankton communities and environmental factors. This study is an essential strategy for monitoring and proper management of the coastal zone.

3.2 Methodology

3.2.1 Study area and sampling period

Si Racha coastal area and Ko Si Chang located on the west coast of Chon Buri province, the Inner Gulf of Thailand respectively. Eleven sampling sites were set up along 3 transect lines from Si Racha coast to the west coast of Si Chang with the first transect line at the latitude above the north-end of Si Chang, the second one in the middle of Si Chang and the last one toward the south end of Si Chang (Figure 3.1 and Table 3.1). Field samplings were conducted for 4 times during 2008-2009 period; 1) the inter-monsoon (southwest to northeast, SW-to-NE) period in October 2008; 2) the northeast (NE) monsoon in December 2008; 3) the inter-monsoon (northeast to southwest, NE-to-SW) in March 2009; and 4) the southwest (SW) monsoon in May 2009.



Source:http://www.nationsonline.org/one world/map/thailand _map2.htm [26 7 2009].

Source: Google earth [9 6 2012].

Figure 3.1 Eleven sampling sites in the coastal area of Si Racha-Si Chang, Chon Buri province.

Table 3.1 The locations of each sampling site in the coastal area of Si Racha-Si Chang, Chon Buri province.

Stations	Latitude (N)	Longitude (E)	Locations
B1	13° 11’ 27.6”	100° 47’ 24”	The northwest coast of Si Chang
B2	13° 11' 27.6"	100° 50' 9.5"	The north coast of Si Chang
B3	13° 11' 23.9"	100° 52' 55.2"	The east coast of Si Chang (channel)
B4	13° 11' 23.9"	100° 55' 40.7"	The coastal area of Si Racha
B5	13° 8' 45.6"	100° 47' 20.4"	The west coast of Si Chang (Had Tum Pung)
B6	13° 8' 45.6"	100° 50' 5.9"	The east coast of Si Chang (Si Chang port)
B7	13° 8' 41.9"	100° 52' 51.6"	The east coast of Si Chang (channel)
B8	13° 8' 41.9"	100° 54' 10"	The north of Ao Udom
B9	13° 5' 59.9"	100° 47' 20.4"	The southwest of Si Chang (Ko Kang Kao)
B10	13° 5' 56.4"	100° 50' 5.9"	The southwest of Si Chang (Ko Kang Kao)
B11	13° 5' 59.9"	100° 52' 39.0	The north of Laem Chabang (PTT port)

3.2.2 Collection and analysis of phytoplankton samples

A) Phytoplankton sampling

Quantitative phytoplankton samples were collected by using a piston pump water sampler at each station from 2-3 different depths, depended on the total depth of seawater, usually surface sample at 0.5 m depth, 2nd sample at ~ 2.0-2.5 m depth and the bottom sample at 10–15 m depth, depending on the depth of seawater. In each depth, 2 replications of water samples were collected. Water samples usually 10-20 l were filtered onto a 20 μm phytoplankton net. The cells retained by this net were preserved with 1 % (v/v) neutralized formalin (Sournia, 1978).

B) Phytoplankton diversity and abundance

Phytoplankton assemblages were identified down to genus level based on the reference of Tomas (1996). Cell density in the unit of cell l^{-1} of each genus was calculated from the count using Sedgewick-Rafter slide under a compound microscope (Lobban *et al*., 1988).

3.2.3 Physico-chemical parameters

A) Physico-chemical parameters measurement

At each station, *in situ* water temperature, salinity, dissolved oxygen and pH were measured using SCT meter (YSI model 30), DO meter (YSI model 55) and pH meter, respectively.

B) Sampling and analyses of dissolved inorganic nutrients and chlorophyll *a* content

Water samples for analysis of ammonia-nitrogen were collected by a stainless bottle sampler. Then kept in 100 ml plastic bottle and frozen at -20 °C until analysis in laboratory by spectrophotometric method followed Parsons *et al*. (1984).

At each station, water samples for analyses of nitrate-nitrogen, nitrite-nitrogen, phosphate-phosphorus and silicate-silicon were sampled from the same depth as phytoplankton samples. Then the water samples were filtered through 200 µm-meshed net to remove suspended particles and GF/C filter. The filtrates were kept frozen in 500 ml of cleaned plastic bottle at -20 °C for the further analyses as referred by Parsons *et al*. (1984).

About 1-2 l of seawater were sampled and kept cool in a 500 ml of plastic bottles, filtered onto a GF/F filter (Whatmann, UK) and kept the filter paper were frozen at -20 °C for spectrophotometric analysis of total chlorophyll *a* (Parsons *et al*., 1984).

3.2.4 Data analysis

A) Phytoplankton diversity index and evenness index

Diversity index (H') and evenness index (J') of phytoplankton were calculated using the equations of Shannon-Wiener (Shannon and Weaver, 1949) and Pielou (1966) respectively

$$H' = -\sum_{i=1}^{S} Pi \log_2 Pi \qquad J' = H' / \log_2 S$$

where $Pi = Ni/N$, Ni is number of individual of the genus organisms, N is number of total individual, S is total genus at any depth level.

B) Significant differences of physic-chemical and biological parameters in different stations and seasons

A two-way ANOVA was used to test for significant differences in phytoplankton density, diversity index, evenness index and environmental parameters (temperature, salinity, dissolved oxygen, pH, ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen, phosphate-phosphorus, DIN: DIP ratio, silicate-silicon and total chlorophyll *a*) within each monsoon, station and depth and between different monsoons, stations and depths using SPSS statistic package version 16.

C) The relationships between phytoplankton and environmental parameters

The relationships between dominant phytoplankton and environmental parameters were tested by Canonical Correspondence Analysis (Lepš and Šmilauer, 1999) using CCA; CANOCO program for window version 4.5.

3.3 Results and Discussions

3.3.1 Environmental parameters

A) Seawater temperature

Mean temperatures of seawater showed seasonal variation with the highest values in the SW monsoon season and the lowest values in the NE monsoon period. During the SW-to-NE inter-monsoon of October 2008, an average seawater temperature was 28.76 $\pm$ 0.18 ^{o}C with the temperature range between 28.50 ^{o}C and 29.27 ^{o}. In the NE monsoon (December 2008), seawater temperature had a mean of 27.36 $\pm$ 0.49 ^{o}C with the variation of temperature between 26.28 ^{o}C and 28.18 ^{o}C. The NE-to-SW inter-monsoon period of March 2009, the minimum and maximum values of seawater temperature were 26.84 ^{o}C and 30.20 ^{o}C, respectively with a mean temperature of 29.78 $\pm$ 0.73 ^{o}C. In the SW monsoon (May, 2009), seawater temperature ranged from 30.5 ^{o}C to 31.1 ^{o}C with a mean value of 30.68 $\pm$ 0.18 ^{o}C (Figure 3.2). There were significant differences ($p < 0.05$) of seawater temperatures among sampling stations within each monsoon and between different monsoons.

The studied of Sojisuporn (2009) reported that, in the NE monsoon, mean of temperature in the adjacent area of Ko Si Chang (Ko Tai Kangkao) was 27.07 ^{o}C, corresponded with this study. Moreover, mean of temperature in the NE-to-SW inter-monsoon in this study was similar to the studied of Butwong (2008) in the coastal area of Ko Si Chang and Buranapratheprat *et al.*, (2010) in the UGoT. Moreover, the result of mean temperature in the SW monsoon which was warmer than in the NE monsoon, also agreed well with Buranapratheprat *et al.*, (2008) and Sriwoon *et al.*, (2008).

B) Salinity

During the SW-to-NE inter-monsoon mean salinity was 31.81 $\pm$ 0.15 psu and range of variation was from 31.46 psu to 32.01 psu, there was no significant difference ($p > 0.05$) in salinity between sampling stations (Figure 3.2). No significant difference ($p > 0.05$) in salinity of different stations was also found in the NE monsoon where a mean salinity was 30.78 $\pm$ 0.10 psu with a minimum and a maximum of 30.56 psu and 30.92 psu, respectively. During the NE-to-SW inter-monsoon, salinity ranged from 28.21 psu to 31.08 psu with a mean of 29.51 $\pm$ 0.85 psu. While in the SW monsoon, the mean salinity was about 26.17 $\pm$ 0.52 psu with a range of 25.4 psu and 27.0 psu. The differences within the NE-to-SW inter-monsoon and the SW monsoon were significant ($p < 0.05$). Moreover, between the different four monsoons, the differences among sampling stations also were significant ($p < 0.05$).

The result of salinity concentration in the NE-to-SW inter-monsoon corresponded well with Kobwed (2008) who reported that range of salinity in the coastal area of Ko Si Chang was 29.00-33.00 ppt. Moreover, salinity concentration in this study during the SW monsoon which was lower than during the NE monsoon, also agreed with Buranapratheprat *et al.*, (2002a; 2002b; 2008), Sriwoon *et al.*, (2008) and Bubphamala *et al.*(2010). This lowest salinity in the SW monsoon was influenced by the precipitation and freshwater discharge into the UGoT. Buranapratheprat (2009) also found that monsoonal wind systems and water discharge resulted in seasonal variations in circulation in Bang Pakong river mouth and the coastal area of Si Racha.

C) Dissolved oxygen

Dissolved oxygen concentration (Figure 3.2) in the SW-to-NE inter-monsoon (mean = 4.79 $\pm$ 0.78 ppm) ranged between 4.24 ppm and 5.35 ppm with no significant difference ($p > 0.05$). During the NE monsoon, there was a significant difference ($p < 0.05$) in DO concentration which the lowest and the highest values were 4.87 ppm and 5.60 ppm, respectively with a mean of 5.22 $\pm$ 0.23 ppm. While in the NE-to-SW inter-monsoon, a mean DO was 4.97 $\pm$ 0.25 ppm with a range of 4.59 ppm and 5.40 ppm. In the SW monsoon, there was a mean DO value of 5.43 $\pm$ 0.23 ppm with a minimum and a maximum of 5.1 ppm and 5.78 ppm, respectively. No significant differences ($p > 0.05$) were found within the NE-to-SW inter-monsoon and the SW monsoon. However, when comparing the difference among sampling stations among four different monsoons, a significant difference ($p < 0.05$) was found.

The result of mean DO in the NE-to-SW inter-monsoon, corresponded well with the study of water quality in the coastal area of Ko Si Chang by Butwong (2008). Moreover, the situation of high DO concentrations in the SW monsoon found in this study was also previously reported by Buranapratheprat *et al.*, (2010) which may due to the increasing density of phytoplankton (photoautotroph) and hence increase in photosynthetic activity and oxygen evolution. Levinton (1982) reported that oxygen distribution in the ocean is controlled through the exchange with the atmosphere and the biological process of photosynthesis (increasing oxygen). Smith and Piedrahita (1988) also suggested that the concentrations of dissolved oxygen in fish pounds could be raised by increasing algal growth.

D) pH

The pH value (Figure 3.2) in the SW-to-NE inter-monsoon (mean = 8.05 $\pm$ 0.04) ranged from 8.01 to 8.13 with a significant difference ($p < 0.05$). In the NE monsoon, no a significant difference ($p > 0.05$) was found from the pH value (mean of 8.11 $\pm$ 0.01) which the lowest and the highest values were 8.10 and 8.12, respectively. In the NE-to-SW inter-monsoon, pH value showed a significant difference ($p < 0.05$), this value ranged between 7.98 and 8.20 with a mean of 8.04 $\pm$ 0.06. In the SW monsoon, the difference was not significant ($p < 0.05$), pH value (mean = 8.07 ± 0.04) ranged from 8.03 to 8.17. When comparing among the different monsoons, there was a significant difference ($p < 0.05$) among sampling stations.

The result of pH value during the NE-to-SW inter-monsoon agreed well with Kobwed (2008), reported that range of pH in the coastal area of Ko Si Chang was 7.80-8.40.

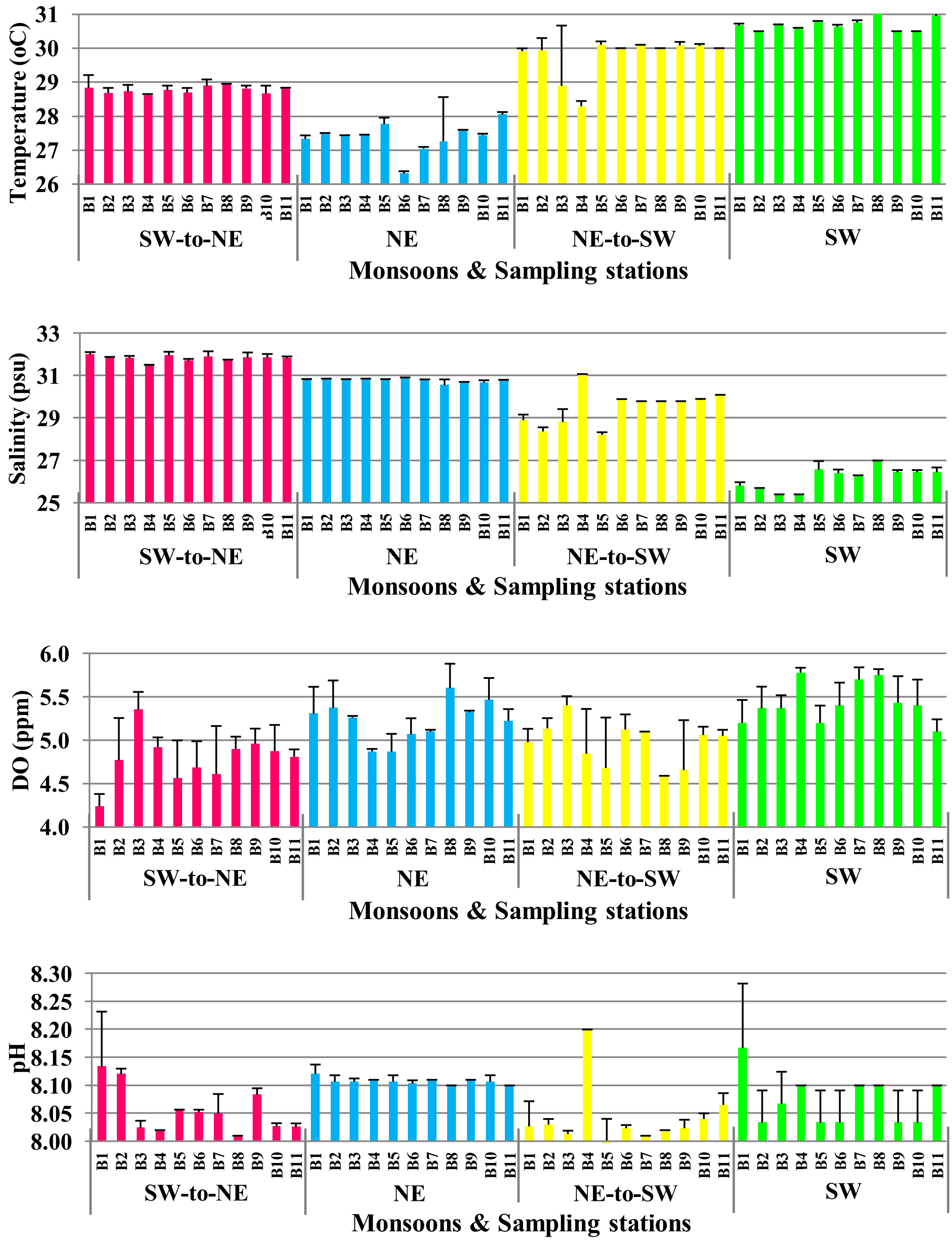


Figure 3.2 Means of temperature, salinity, dissolved oxygen and pH in each monsoon and sampling station in the coastal area of Si Racha-Si Chang, Chon Buri province during October 2008 to May 2009.

E) Dissolved inorganic nutrients

Ammonia-nitrogen

Ammonia-nitrogen concentration (Figure 3.3) in the SW-to-NE inter-monsoon (mean = 6.44± 3.50 µM) ranged between 1.88 µM and 13.89 µM. During the NE monsoon, this parameter had the lowest and the highest values of 2.62 µM and 4.47 µM, respectively with a mean of 3.67 ± 0.61 µM. In the NE-to-SW inter-monsoon, there was a mean ammonia-nitrogen of 1.16 ± 0.44 µM, with a range of 0.41 µM and 2.01 µM. During the SW monsoon, ammonia-nitrogen (mean = 1.37± 0.35 µM) ranged between 0.90 µM and 1.85 µM. There were significant differences ($p < 0.05$) among sampling stations within each monsoon as well as between different monsoons.

Nitrite-nitrogen and nitrate-nitrogen

Nitrite- and nitrate-nitrogen concentrations (Figure 3.3) in the SW-to-NE inter-monsoon ranged from 0.10 µM to 1.02 µM with a mean of 0.51 ± 0.30 µM. In the NE monsoon, mean of this parameter was 0.36 ± 0.28 µM with a range of 0.10 µM to 0.81 µM. In the NE-to-SW inter-monsoon, nitrite- and nitrate-nitrogen had the lowest and the highest values of 0.06 µM to 0.78 µM, respectively with a mean of 0.29 ± 0.25 µM. In the SW monsoon, nitrite- and nitrate-nitrogen (mean = 0.26 ± 0.14 µM) ranged from 0.11 µM to 0.51 µM. The differences among sampling stations within each monsoon and between different monsoons were significant ($p < 0.05$).

Dissolved Inorganic Nitrogen (DIN)

In the SW-to-NE inter-monsoon, mean of DIN (ammonia plus nitrite and nitrate) was 6.66 ± 3.45 (Figure 3.3) with a range of 0.51 to 15.23. In the NE monsoon, this value (mean = 4.01 ± 0.69) ranged between 2.73 and 5.28. In the NE-to-SW inter-monsoon, the lowest and the highest values of DIN were 0.47 and 2.36 with a mean of 1.50 ± 0.52. In the SW monsoon, DIN values ranged from 0.30 to 2.27 with a mean of 1.59 ± 0.50. Significant differences ($p < 0.05$) were found among sampling stations within each monsoon and between different monsoons.

Dissolved Inorganic Phosphate (DIP)

In the SW-to-NE inter-monsoon, DIP concentration (mean = 0.62 $\pm$ 0.42 µM) ranged between 0.19 µM to 1.26 µM (Figure 3.3). A mean of phosphate-phosphorus in the NE monsoon was 0.39 $\pm$ 0.59 µM with a range of 0.04 µM to 2.07 µM. During the NE-to-SW inter-monsoon, the lowest and the highest values of phosphate-phosphorus were 0.19 µM to 4.97 µM, respectively with a mean of 0.99 $\pm$ 1.40 µM. In the SW monsoon, phosphate-phosphorus concentration (mean = 0.87 $\pm$ 0.29 µM) ranged from 0.49 µM to 1.37 µM. The significant differences ($p < 0.05$) from different sampling stations were found within each monsoon and between different monsoons.

The high concentration of DIP in the SW monsoon corresponded with Buranapratheprat *et al.*, (2002a) and Sriwoon *et al.*, (2008).

DIN: DIP ratio

Mean values of DIN: DIP ratio in the inter-monsoon of SW-to-NE and NE monsoon, frequently higher than 15 to the extreme values over 100, were higher than those in other seasons. DIN: DIP values (Figure 3.4) in the SW-to-NE inter-monsoon ranged between 1.94 and 31.20 with a mean of 16.57 $\pm$ 10.27. During the NE monsoon, this value varied with a range of 2.54 and 102.54 with the mean value of 33.08 $\pm$ 30.52. The DIN:DIP which was higher than 16: 1 suggested the situation of phosphorous limitation of phytoplankton growth. A mean of DIN: DIP ratio in the NE-to-SW inter-monsoon and SW monsoon were 3.47 $\pm$ 2.86 (0.29 - 8.55) and 2.00 $\pm$ 0.65 (1.15 to 3.51), respectively. These low DIN:DIP ratios indicated high concentration of phosphate-phosphorous and nitrogen became the limiting factor for phytoplankton. Significant differences ($p < 0.05$) from different sampling stations were found within each monsoon and between different monsoons.

Dissolved Silicate (DSi)

The concentrations of silicate-silicon showed variation among the different period of study with the lowest value in the NE monsoon season than other seasons. In the SW-to-NE inter-monsoon, a mean of DSi in Figure 3.4 was 13.6 $\pm$ 3.41 µM with a range of 8.46 µM to 18.48 µM. Silicate-silicon concentration in the NE monsoon (mean = 1.92 $\pm$ 0.95 µM) ranged from 1.10 µM to 4.44 µM. During the NE-to-SW inter-monsoon, the lowest and the highest of silicate-silicon concentrations were 6.87 µM and 24.38 µM, respectively with a mean of 17.82 $\pm$ 5.45 µM. In the SW monsoon, silicate-silicon (mean = 13.95 $\pm$ 1.96 µM) ranged between 11.97 µM to 18.45. There were significant differences ($p < 0.05$) from different sampling stations within each monsoon and between different monsoons.

The value of DSi which showed high concentration during the SW monsoon, because freshwater river discharge enhanced DSi to the UGoT. Moreover, during the SW monsoon, the dominant genus was *Oscillatoria*, so DSi was unused by them and still occurred in seawater column (Buranapratheprat *et al.*, 2010). The high value of DSi during the SW monsoon corresponded with Sriwoon *et al.*, (2008).

By considering in the result of all dissolved inorganic nutrients concentrations from each station as reported, the high nutrient concentrations were frequently observed at station B2 and B4 which located on the northern side of Ko Si Chang and closer to Bang Pakong river mouth than other stations. Moreover, B4 also located in the coastal area of Si Racha which normally, the area of inshore always found higher nutrients than offshore. Then this station had more chance of receiving more nutrients.

F) Total chlorophyll *a*

A mean of total chlorophyll *a* (Figure 3.4) in the SW-to-NE inter-monsoon was 2.00 $\pm$ 1.12 mg m^{-3} with the lowest and the highest values of 0.64 mg m^{-3} and 4.22 mg m^{-3}, respectively. In the NE monsoon, this parameter (mean = 1.16 $\pm$ 0.65 mg m^{-3}) ranged from 0.36 mg m^{-3} and 2.92 mg m^{-3}. The minimum and maximum values of total chlorophyll *a* in the NE-to-SW inter-monsoon were 1.80 mg m^{-3} and 3.29 mg m^{-3}, respectively with a mean of 2.23 $\pm$ 0.54 mg m^{-3}. During the SW monsoon, total chlorophyll *a* (mean = 2.02 $\pm$ 2.04 mg m^{-3}) with a range of 0.71 mg m^{-3} and 7.21 mg m^{-3}. The significant differences ($p < 0.05$) from different sampling stations were observed within each monsoon and between different monsoons.

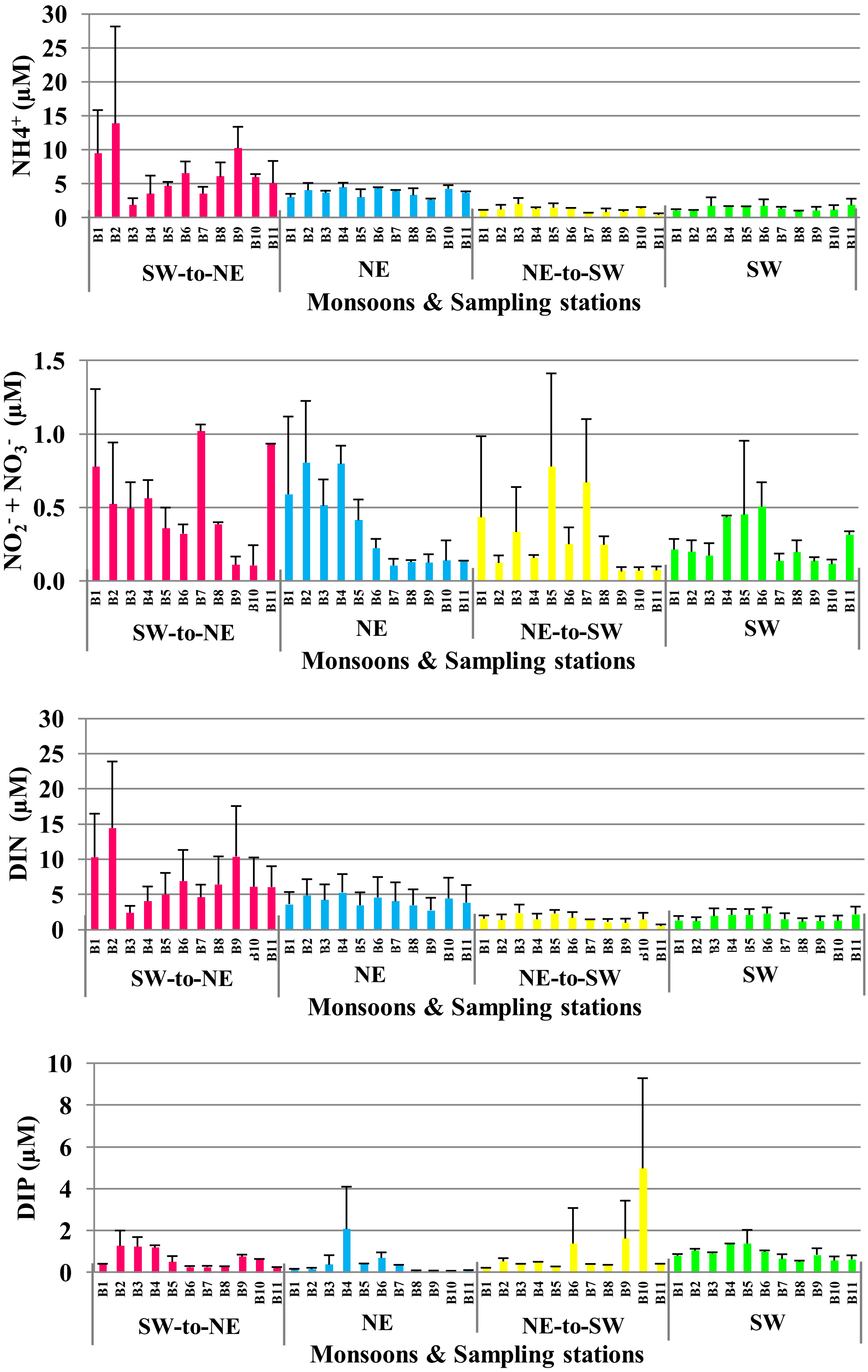


Figure 3.3 Means of ammonia-nitrogen, nitrite- and nitrate-nitrogen, DIN and DIP from each monsoon and sampling station in the coastal area of Si Racha-Si Chang, Chon Buri province during October 2008 to May 2009.

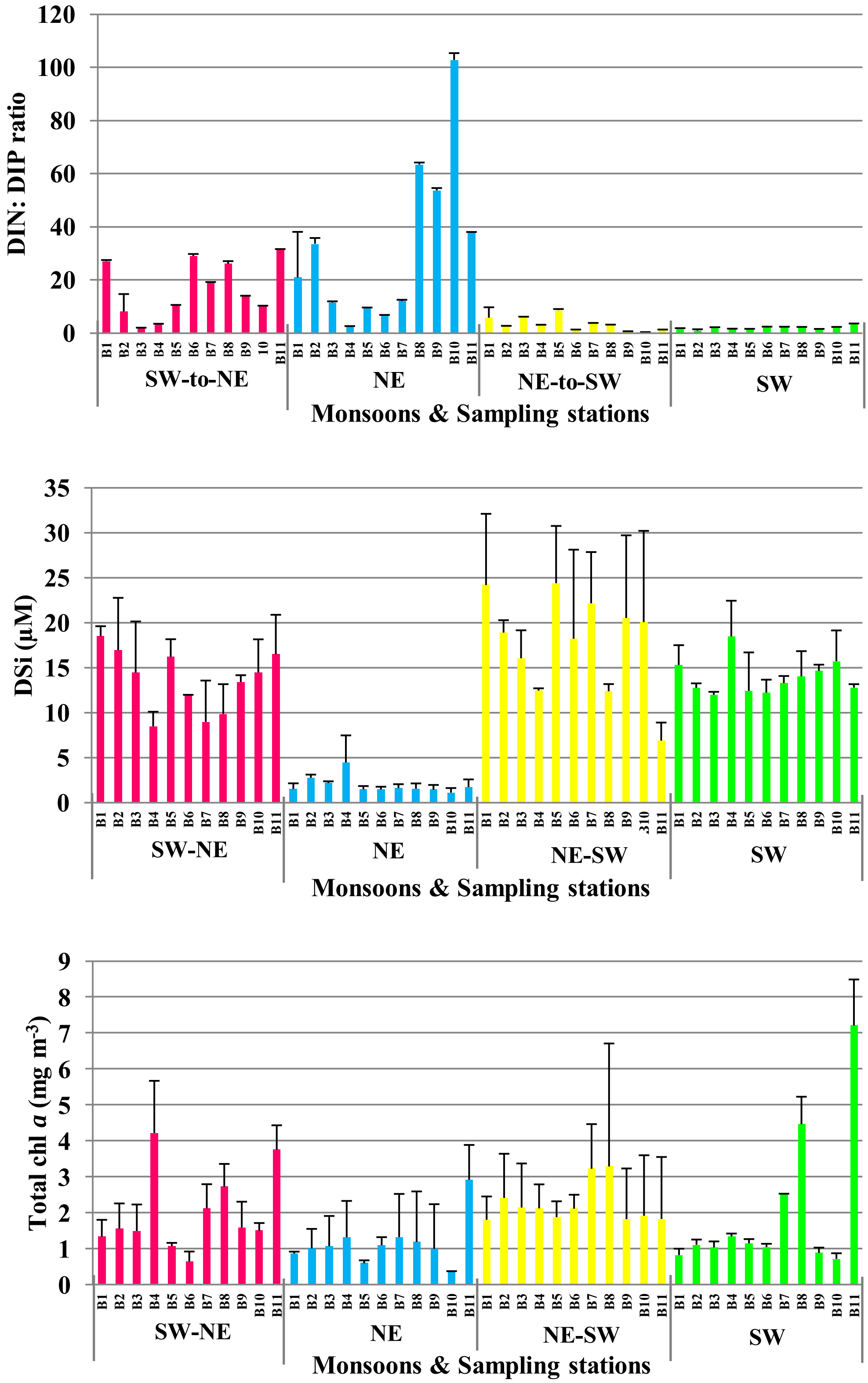


Figure 3.4 Means of DIN: DIP ratio, DSi and total chlorophyll *a* from each monsoon and sampling station in the coastal area of Si Racha-Si Chang, Chon Buri province during October 2008 to May 2009.

3.3.2 Phytoplankton

A) Phytoplankton communities

During October 2008 to May 2009, phytoplankton assemblage was identified to 56 genera (the SW-to-NE inter-monsoon = 50 genera, the NE monsoon = 46 genera, the NE-to-SW inter-monsoon = 53 genera and the SW monsoon = 45 genera; Table 3.2).

Figure 3.5 indicated that in the SW-to-NE inter-monsoon (October 2008), dominant phytoplankton group belonged to diatoms (32 genera, 50.39% of total density) followed by cyanobacteria (2 genera, 48.03%), dinoflagellates (15 genera, 1.53%) and a silicoflagellate (1 genus, 0.05%). During this period, the most dominated genus was *Oscillatoria* (45.42%). The other dominant genera were *Thalassionema* (34.39%; *T. frauenfeldii* = 22.97%, *T. nitzschioides* = 11.43%) and *Bacteriastrum* (7.64%; *B. hyalinum* = 5.99%, *B. delicatulum* =1.65%; Table 3.2 and Figure 3.6).

In the NE monsoon (December 2008), cyanobacteria (3 genera, 52.89% of total density) became dominant. Which followed by diatoms (30 genera, 46.41%), dinoflagellates (12 genera, 0.70%) and silicoflagellate (1 genus, 0.001%) (Figure 3.5). The dominant genera during the NE monsoon were *Oscillatoria* (40.97%), *Pseudanabaena* (11.14%), *Thalassionema* (14.61%; *T. frauenfeldii* = 7.59%, *T. nitzschioides* = 7.02%, *Pseudo-nitzschia* (8.22%), *Chaetoceros* (6.16%) and *Gyrosigma / Pleurosigma* (4.81 %) (Table 3.2 and Figure 3.7). This study corresponded with Khwaiphan (2005) who reported that *Oscillatoria* was dominant in the NE and the SW monsoon at Bang Pakong river mouth.

In NE-to-SW inter-monsoon (March 2009), the dominated groups were diatoms (33 genera, 50.41% of total density), cyanobacteria (3 genera, 41.58%), dinoflagellates (16 genera, 7.97%) and silicoflagellate (1 genus, 0.04%; Figure 3.5). This result corresponded with Late (2007), Ratanamongkon (2007), Wichairahad (2007), Wongsuwan (2008) and Junkaew (2009), who reported that diatoms were the most dominant in the coastal area of Ko Si Chang during this time. During the NE-SW monsoon, the dominant genera were *Oscillatoria* (34.57%), *Pseudo-nitzschia* (19.56%), *Pseudanabaena* (7.01%), *Chaetoceros* (6.39%) and *Thalassionema* (5.53%, *T. frauenfeldii* = 2.30 %, *T. nitzschioides* = 3.32 %; Table 3.2 and Figure 3.8). This study corresponded with the results of Purgsaard (2007), Puttarn (2007) and Kaewngen (2008) who found similar dominant phytoplankton in the coastal area of Ko Si Chang.

In the SW monsoon (May 2009), cyanobacteria (2 genera, 84.03% of total density) occupied the most area, which followed by diatoms (28 genera, 13.24%), dinoflagellates (14 genera, 2.73%) and silicoflagellate (1 genus, 0.001%) (Figure 3.5). During this time *Oscillatoria* (82.83%) reached to the highest density with the lower densities of *Thalassionema* (5.66%; *T. frauenfeldii* = 2.53 %, *T. nitzschioides* = 3.13 %) and *Chaetoceros* (3.88 %) (Table 3.2 and Figure 3.9). This result corresponded with Saosee (2004) reported that *Oscillatoria* was frequently found during the SW monsoon in the coastal area of Bang Pra, Chon Buri province. Boonyaphiwat (1997) and Boonyaphiwat *et.al*, (1998) also found that *Oscillatoria* was the dominant genus during this period.

A cyanobacterium *Oscillatoria* had the highest density during the unbalanced DIN: DIP = 2 (N limitation, but high P). This may due to the ability of this cyanobacterium to fix nitrogen since Capone (2001) had reported that ocean nitrogen fixation was likely controlled by ion and phosphorus. Beside, *Oscillatoria* is reported to be capable of nitrogen fixation under the situation of low concentration of total nitrogen in the water column (Carpenter, 1973). Marine *Oscillatoria* could fix nitrogen by the differentiated cells located at the middle of the colony (Carpenter and Price, 1976). This study also agreed well with the study by Wood *et.al.* (2010) who reported the concurrent of the bloom of a cyanobacterium *Anabaena planktonica* and the low concentration of DIN and the lowest of DIN: DIP ratio in a temperate, eutrophic reservoir

Table 3.2 Phytoplankton genera recorded in the coastal area of Si Racha-Si Chang, Chon Buri province during October 2008 to May 2009 showing the relative contribution (%) to the total count by monsoons, stations and depths and diversity values.

Phytoplankton genera	Mean of cell density		Monsoons				Stations											Depths		
	(10^3cell/l)	(%)	SW-NE (%)	NE (%)	NE-SW (%)	SW (%)	B1 (%)	B2 (%)	B3 (%)	B4 (%)	B5 (%)	B6 (%)	B7 (%)	B8 (%)	B9 (%)	B10 (%)	B11 (%)	Surface (%)	Middle (%)	Bottom (%)
Oscillatoria	**42.669**	**63.8**	**45.4**	**41.0**	**34.6**	**82.8**	**87.4**	**84.0**	**44.5**	**13.7**	**70.9**	**69.8**	**54.6**	**17.3**	**69.1**	**74.5**	**18.4**	**61.8**	**66.5**	**62.0**
Pseudanabaena	**1.7489**	**2.61**	**2.61**	**11.14**	**7.01**	**1.20**	**2.56**	**1.26**	**2.64**	**2.09**	**3.05**	**3.24**	**2.97**	**2.95**	**4.26**	**3.20**	**2.40**	**2.31**	**2.33**	**4.08**
Spirulina	0.020	0.03	0.00	0.79	0.00	0.00	0.00	0.00	0.00	0.47	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.03	0.00
Prorocentrum	0.1886	0.28	0.20	0.26	0.72	0.26	0.17	0.09	0.31	0.59	0.21	0.33	0.48	0.37	0.49	0.26	0.37	0.28	0.30	0.24
Dinophysis	0.1915	0.29	0.05	0.00	0.23	0.47	0.20	0.25	0.37	0.15	0.20	0.34	0.56	0.16	0.46	0.33	0.21	0.26	0.28	0.36
Ornithocercus	0.0008	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Phalacroma	0.0127	0.01	0.00	0.00	0.05	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.02	0.02	0.02	0.01	0.01	0.02
Gymnodinium	0.0015	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Gyrodinium	0.0022	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Noctiluca	0.2309	0.35	0.01	0.00	3.24	0.05	0.18	0.29	0.53	0.17	0.17	0.40	1.23	0.78	0.22	0.21	0.08	0.29	0.34	0.50
Ceratium	0.8382	1.25	0.99	0.24	0.58	1.62	0.72	0.35	1.34	7.47	0.43	0.31	1.28	1.23	0.62	0.36	4.32	1.28	1.48	0.61
Alexandrium	0.0058	0.01	0.00	0.00	0.07	0.00	0.01	0.00	0.01	0.00	0.01	0.02	0.01	0.03	0.01	0.01	0.00	0.01	0.01	0.01
Gonyaulax	0.0226	0.03	0.01	0.00	0.10	0.04	0.05	0.01	0.06	0.03	0.06	0.03	0.01	0.03	0.04	0.03	0.04	0.03	0.04	0.03
Pyrocystis	0.0017	0.00	0.00	0.03	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Pyrophacus	0.0233	0.03	0.02	0.02	0.03	0.05	0.04	0.01	0.05	0.07	0.04	0.04	0.02	0.02	0.06	0.05	0.00	0.03	0.03	0.05
Scrippsiella	0.1579	0.24	0.00	0.00	2.40	0.00	0.10	0.09	0.02	0.01	0.09	1.24	0.12	0.08	0.56	0.24	0.04	0.23	0.30	0.09
Diplopsalis	0.0018	0.00	0.00	0.00	0.03	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Podolampas	0.0001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Protoperidinum	0.1654	0.25	0.25	0.14	0.49	0.21	0.12	0.16	0.31	0.74	0.16	0.12	0.31	0.61	0.21	0.11	0.53	0.24	0.29	0.16
Dictyocha	0.0132	0.02	0.05	0.00	0.04	0.00	0.02	0.03	0.01	0.05	0.04	0.01	0.01	0.01	0.01	0.02	0.00	0.02	0.02	0.02
Cyclotella	0.0317	0.05	0.08	0.04	0.17	0.00	0.03	0.02	0.07	0.15	0.07	0.04	0.03	0.10	0.01	0.03	0.07	0.05	0.04	0.07
Lauderia	0.1031	0.15	0.16	0.04	0.77	0.04	0.12	0.11	0.19	0.15	0.23	0.11	0.04	0.25	0.04	0.23	0.31	0.16	0.11	0.26

Phytoplankton genera	Mean of cell density		Monsoons				Stations											Depths		
			SW-NE	NE	NE-SW	SW	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	Surface	Middle	Bottom
	(10^3cell/l)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Planktoniella	0.0077	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Skeletonema	0.0068	0.01	0.00	0.00	0.04	0.01	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.08	0.00	0.01	0.00	0.02	0.00	0.01
Thalassiosira	0.8480	1.27	1.18	0.84	3.38	0.96	0.67	0.78	2.03	2.66	1.24	1.33	1.56	2.56	1.14	0.69	1.70	1.14	1.18	1.79
Melosira	0.3255	0.49	0.00	0.00	0.48	0.84	0.06	0.28	0.41	0.15	1.59	0.54	0.39	1.36	0.16	0.05	1.57	0.29	0.41	1.19
Palaria	0.0278	0.04	0.00	0.24	0.15	0.03	0.02	0.02	0.04	0.01	0.03	0.04	0.05	0.11	0.03	0.04	0.16	0.02	0.04	0.08
Corethron	0.0018	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01
Coscinodiscus	0.0457	0.07	0.06	0.15	0.23	0.04	0.06	0.03	0.08	0.08	0.10	0.10	0.05	0.11	0.07	0.06	0.10	0.06	0.06	0.13
Asterolampra	0.0001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rhizosolenia	0.1841	0.28	0.12	2.64	1.37	0.01	0.14	0.11	0.30	0.33	0.41	0.31	0.16	0.30	0.27	0.22	1.03	0.28	0.23	0.38
Guinardia	0.0741	0.11	0.04	0.69	0.73	0.00	0.03	0.04	0.19	0.03	0.05	0.10	0.06	0.27	0.06	0.09	0.59	0.10	0.10	0.17
Dactyliosolen	0.0025	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Ceratualina	0.0007	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
Climacodium	0.0151	0.02	0.00	0.41	0.08	0.00	0.02	0.01	0.03	0.00	0.02	0.04	0.06	0.00	0.01	0.03	0.03	0.02	0.02	0.05
Eucampia	0.0598	0.09	0.00	0.01	0.82	0.02	0.02	0.04	0.19	0.08	0.04	0.04	0.08	0.57	0.08	0.03	0.17	0.10	0.05	0.14
Hemiaulus	0.0497	0.07	0.06	0.44	0.09	0.05	0.06	0.05	0.10	0.06	0.08	0.14	0.04	0.03	0.14	0.11	0.02	0.08	0.05	0.11
Bacteriastrum	**1.9544**	**2.92**	**7.64**	**2.67**	**1.30**	**0.14**	**0.42**	**2.55**	**3.56**	**6.97**	**3.54**	**6.51**	**2.94**	**2.83**	**0.70**	**2.85**	**1.96**	**4.41**	**2.24**	**0.90**
Chaetoceros	**2.4972**	**3.73**	**2.49**	**6.16**	**6.39**	**3.88**	**1.66**	**3.06**	**4.57**	**12.13**	**3.52**	**2.16**	**2.94**	**5.35**	**6.30**	**2.44**	**3.23**	**4.09**	**3.55**	**3.30**
Bellerochea	0.0000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ditylum	0.0133	0.02	0.05	0.04	0.00	0.00	0.01	0.01	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.08	0.00	0.02	0.02	0.03
Odontella	0.0313	0.05	0.06	0.18	0.12	0.01	0.02	0.01	0.04	0.07	0.04	0.02	0.04	0.14	0.04	0.06	0.17	0.05	0.04	0.06
Thalassionema	**10.594**	**15.8**	**34.39**	**14.61**	**5.53**	**5.66**	**4.09**	**5.32**	**16.9**	**46.1**	**10.6**	**10.3**	**23.6**	**46.8**	**13.9**	**12.7**	**37.0**	**17.4**	**15.9**	**11.8**
Thalassiotrix	0.054	0.08	0.02	0.73	0.44	0.01	0.06	0.03	0.10	0.04	0.14	0.09	0.08	0.11	0.15	0.06	0.15	0.07	0.07	0.14
Navicula	0.028	0.04	0.02	0.40	0.18	0.00	0.02	0.02	0.04	0.04	0.05	0.06	0.03	0.04	0.04	0.04	0.12	0.03	0.03	0.09
Bacillaria	1.2037	1.80	2.96	1.76	3.00	0.82	0.06	0.12	0.29	0.90	0.32	0.14	2.48	8.13	0.20	0.29	17.40	2.45	1.65	0.52
Cylindrotheca	0.0837	0.13	0.07	0.10	0.96	0.01	0.02	0.01	0.89	0.18	0.07	0.02	0.11	0.44	0.02	0.00	0.05	0.08	0.05	0.43

Phytoplankton genera	Mean of cell density (10^3cell/l)	(%)	Monsoons: SW-NE (%)	NE (%)	NE-SW (%)	SW (%)	Stations: B1 (%)	B2 (%)	B3 (%)	B4 (%)	B5 (%)	B6 (%)	B7 (%)	B8 (%)	B9 (%)	B10 (%)	B11 (%)	Depths: Surface (%)	Middle (%)	Bottom (%)
Fragilariopsos	0.0043	0.01	0.00	0.09	0.03	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.01	0.01	0.01
Pseudo-nitzschia	**1.5766**	**2.36**	**0.36**	**8.22**	**19.56**	**0.06**	**0.43**	**0.41**	**18.5**	**2.07**	**1.82**	**1.51**	**1.42**	**1.59**	**0.27**	**0.29**	**2.52**	**1.08**	**0.89**	**9.25**
Triceratium	0.0002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biddulphia	0.0002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diploneis	0.0000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gyrosigma/ Pleurosigma	0.6410	0.96	0.54	4.81	3.44	0.50	0.31	0.27	1.02	1.95	0.43	0.38	1.98	3.98	0.26	0.18	3.92	0.97	1.05	0.69
Amphora	0.0018	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.00
Nitzschia	0.0346	0.05	0.02	0.48	0.26	0.00	0.04	0.02	0.09	0.14	0.03	0.07	0.04	0.13	0.01	0.02	0.11	0.04	0.05	0.09
Entomoneis	0.0132	0.02	0.01	0.19	0.11	0.00	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.11	0.01	0.01	0.06	0.02	0.02	0.03
Surirella	0.1044	0.16	0.03	0.46	0.71	0.12	0.05	0.02	0.06	0.06	0.07	0.04	0.14	0.98	0.05	0.04	1.02	0.15	0.19	0.10
Campylodiscus	0.0001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total phytoplankton density (10^3cell/l)	23685																			
Number of genera	56		50	46	53	45	51	50	48	47	47	49	45	43	49	48	45	56	53	54
Mean cell density (10^3cell/l)	66.9		90.3	9.69	26.4	142.42	93.1	128	51.0	56.7	53.3	60.3	49.3	50.9	46.5	70.8	58.7	74.9	74.8	43.7
Standard deviation ($\pm$) of mean	85.7		49.1	3.23	23.8	124.97	137	156	41.6	67.3	61.0	54.3	51.3	35.4	41.7	88.7	35.8	81.5	99.2	64.1
Shannon-Wiener diversity index (H')	2.33		1.96	2.84	2.88	1.63	2.02	2.01	2.36	2.85	2.50	2.24	2.25	3.02	1.99	1.87	3.09	2.37	2.31	2.29
Standard deviation ($\pm$) of H'	0.91		0.54	0.60	0.68	1.01	1.04	1.08	0.74	0.30	1.02	0.89	0.79	0.54	0.74	0.82	0.54	0.89	0.94	0.89
Pielou evenness index (J')	0.48		0.41	0.61	0.56	0.35	0.41	0.40	0.49	0.59	0.52	0.46	0.48	0.62	0.42	0.39	0.64	0.48	0.48	0.48
Standard deviation ($\pm$) of J'	0.18		0.10	0.12	0.13	0.22	0.21	0.22	0.17	0.08	0.21	0.17	0.11	0.10	0.14	0.16	0.09	0.18	0.19	0.17

Note: the red letters indicated the dominant phytoplankton.

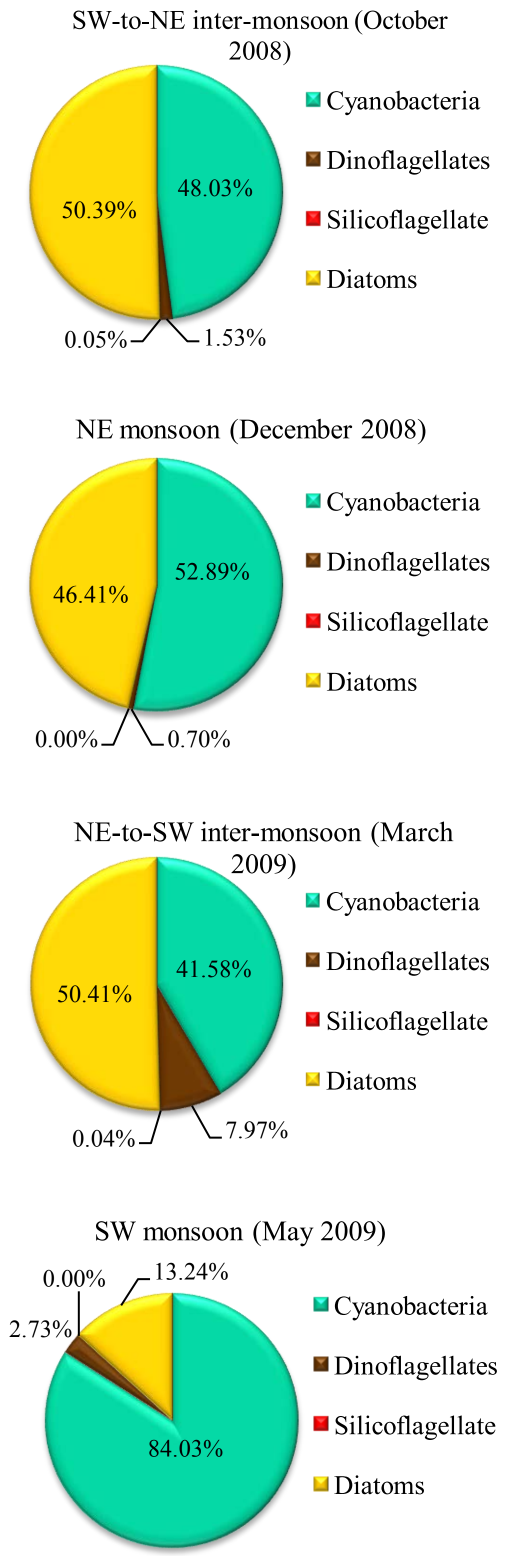
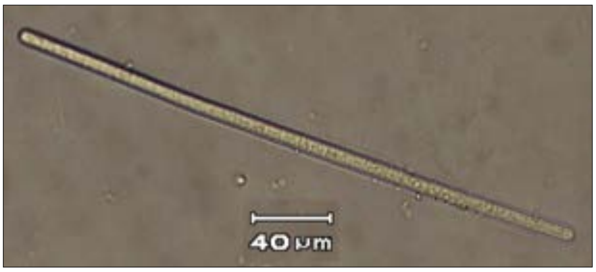
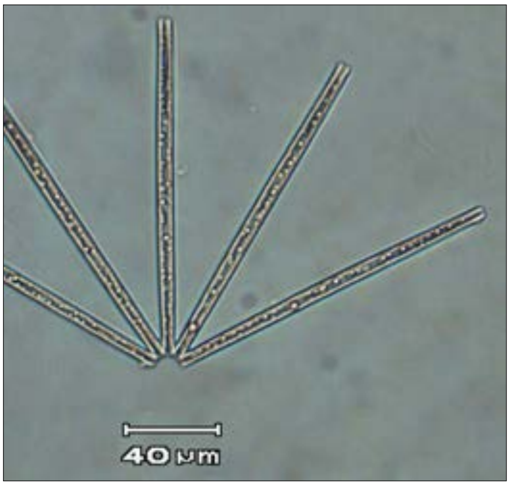


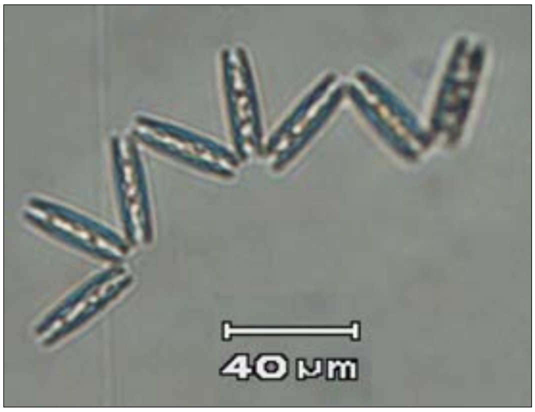
Figure 3.5 Phytoplankton genera recorded in the SW-to-NE inter-monsoon, the NE monsoon, the NE-to-SW inter-monsoon and the SW monsoon in the coastal area of Si Racha-Si Chang, Chon Buri province during October 2008 to May 2009.



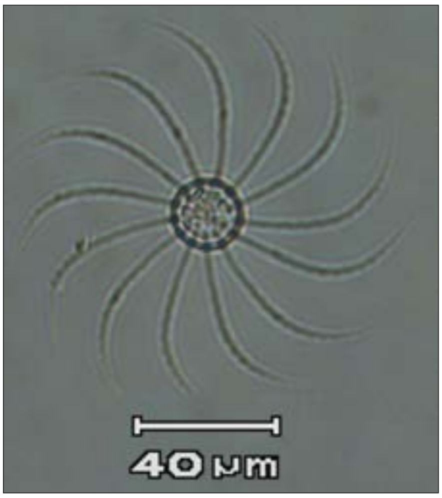
Oscillatoria sp.



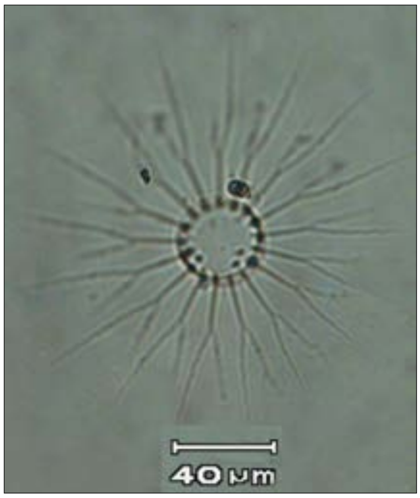
Thalassionema frauenfeldii



Thalassionema nitzschioides

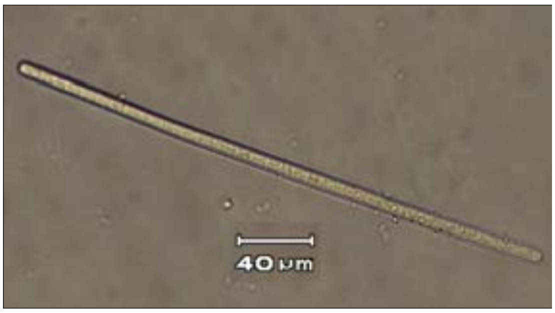


Bacteriastrum hyalinum

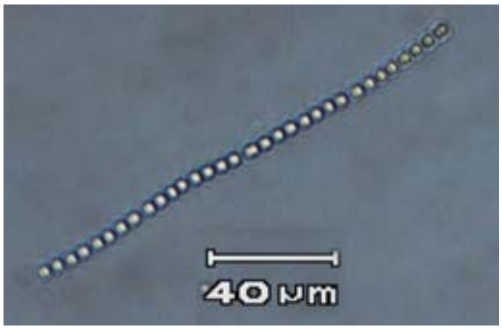


Bacteriastrum delicatulum

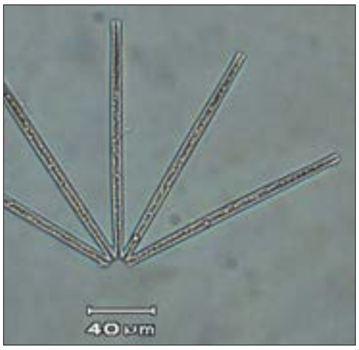
Figure 3.6 The dominant phytoplankton during the SW-to-NE inter-monsoon (October 2008) in the coastal area of Si Racha-Si Chang, Chon Buri province.



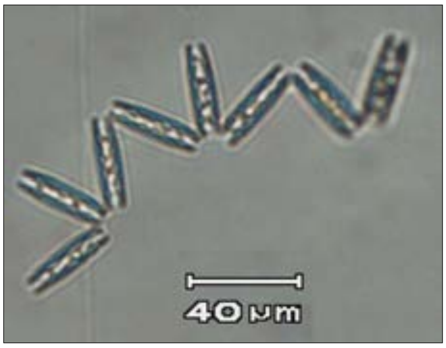
Oscillatoria sp.



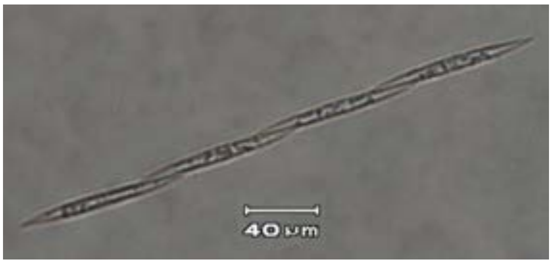
Pseudanabaena sp.



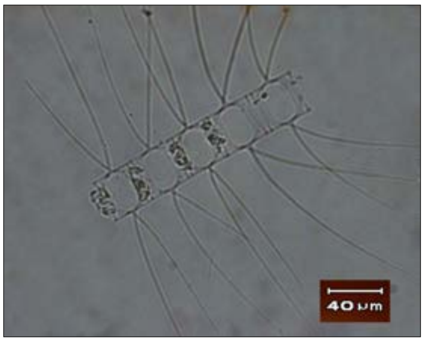
Thalassionema frauenfeldii



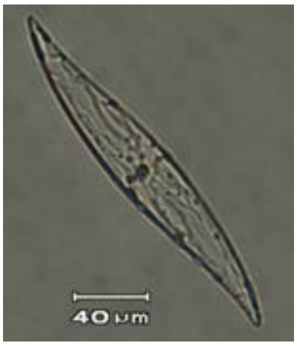
Thalassionema nitzschioides



Pseudo-nitzschia sp.

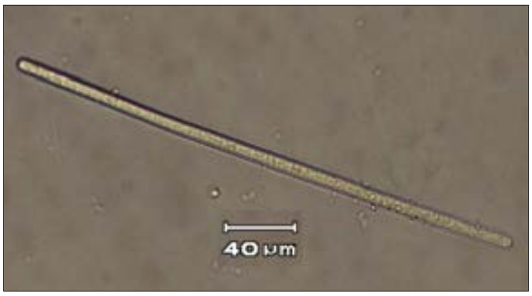


Chaetoceros sp.

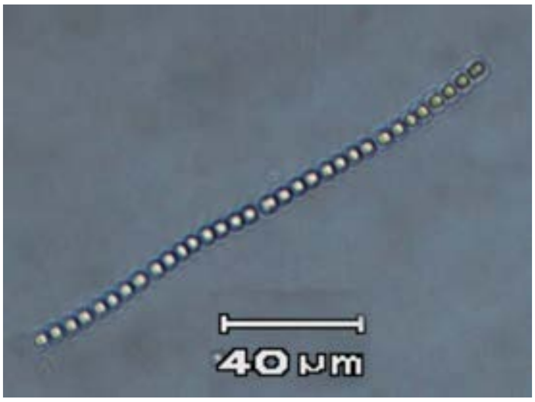


Gyrosigma / Pleurosigma sp.

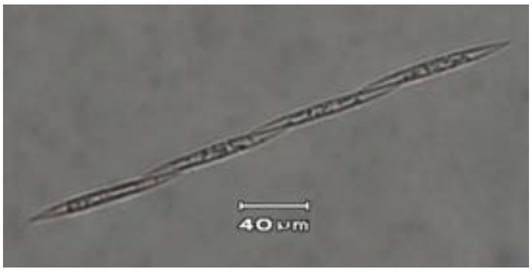
Figure 3.7 The dominant phytoplankton during the NE monsoon (December 2008) in the coastal area of Si Racha-Si Chang, Chon Buri province.



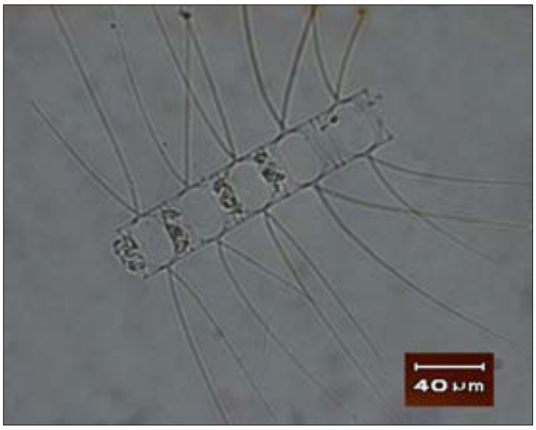
Oscillatoria sp.



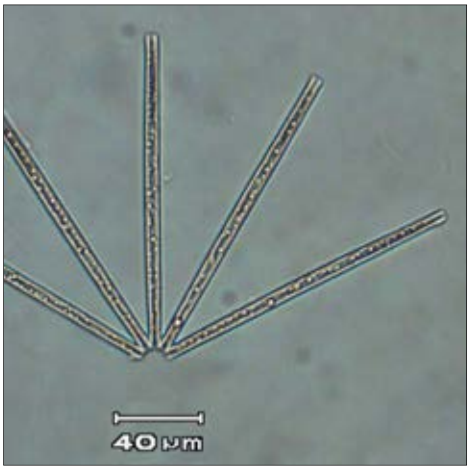
Pseudanabaena sp.



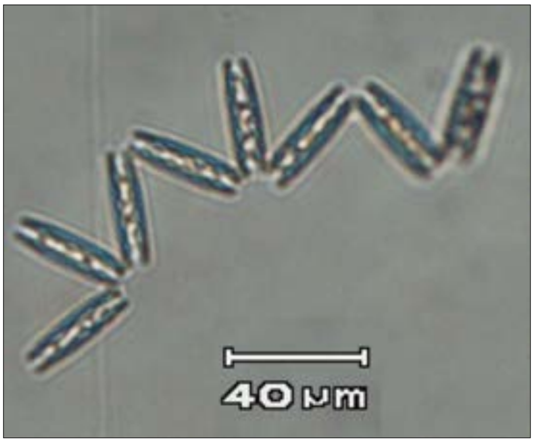
Pseudo-nitzschia sp.



Chaetoceros sp.

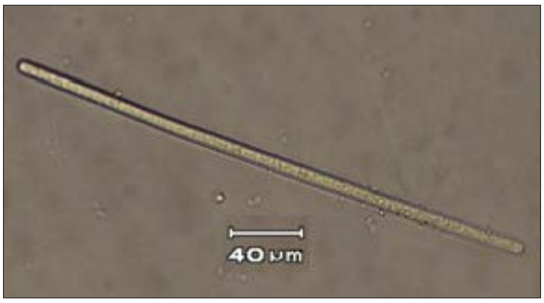


Thalassionema frauenfeldii

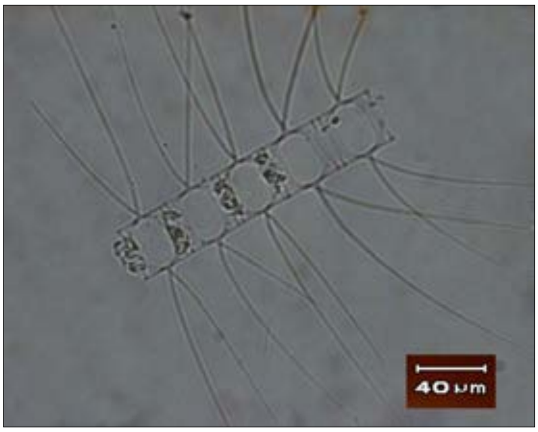


Thalassionema nitzschioides

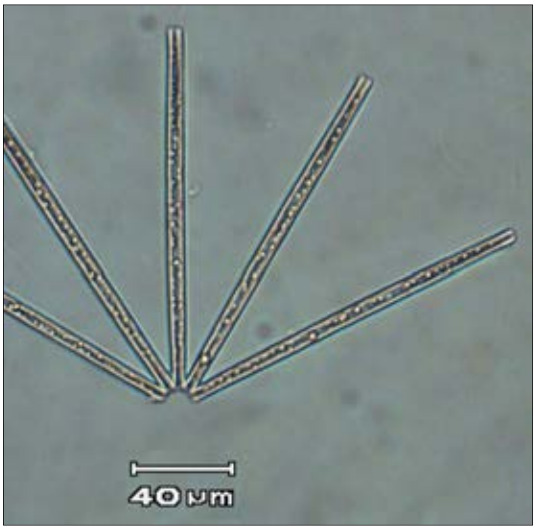
Figure 3.8 The dominant phytoplankton during the NE-to-SW inter-monsoon (March 2009) in the coastal area of Si Racha-Si Chang, Chon Buri province.



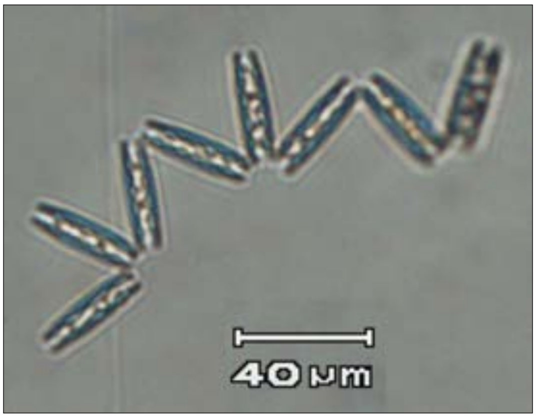
Oscillatoria sp.



Chaetoceros sp.



Thalassionema frauenfeldii



Thalassionema nitzschioides

Figure 3.9 The dominant phytoplankton during the SW monsoon (May 2009) in the coastal area of Si Racha-Si Chang, Chon Buri province.

B) Phytoplankton density, diversity index and evenness index.

Phytoplankton density

Means of phytoplankton density were ten-times higher in the SW monsoon and the SW-to-NE inter-monsoon periods in comparison to the NE monsoon and the NE-to-SW inter-monsoon periods (Figure 3.10). The mean density during the SW-to-NE inter-monsoon (October 2008) was 90.3 $\pm$ 49.1 x 10^3 cell l^{-1} with a range of 0.14 x 10^3 cell l^{-1} and 209.39 x 10^3 cell l^{-1}. In the NE monsoon (December 2008), these values ranged from 4.36 x 10^3 cell l^{-1} to 20.85 x 10^3 cell l^{-1} with a mean of 9.69 $\pm$ 3.23 x 10^3 cell l^{-1}. The NE-SW monsoon (March 2009), the minimum and maximum values of phytoplankton density were 10.50 x 10^3 cell l^{-1} and 147.27 x 10^3 cell l^{-1}, respectively with a mean of 26.4 $\pm$ 23.8 x 10^3 cell l^{-1}. During the SW monsoon (May 2009), a mean density was 142.42 $\pm$ 124.97 x 10^3 cell l^{-1}. Which B5 at B level showed the lowest density (23.57 x 10^3 cell l^{-1}) and B2 at M level had the highest density (542.52 x 10^3 cell l^{-1}).There were significant differences ($p < 0.05$) from the different sampling stations within each monsoon and between different monsoons.

Phytoplankton densities during the SW-to-NE inter-monsoon as well as the NE monsoon season tended to accumulated near surface (S). While in the NE-to-SW inter-monsoon and SW monsoon periods, high densities of phytoplankton occurred at greater depths i.e. mid-depth (M) or bottom layer (B) as seen in Figure 3.11. In the SW-to-NE inter-monsoon the mean densities at S, M and B levels were 116.05 $\pm$ 48.06 x 10^3 cell l^{-1}, 97.84 $\pm$ 38.72 x 10^3 cell l^{-1} and 39.60 $\pm$ 23.21 x 10^3 cell l^{-1}, respectively with a significant difference ($p < 0.05$) among different depths. During the NE monsoon, the densities at S, M and B levels were 9.91 $\pm$ 2.91 x 10^3 cell l^{-1}, 10.20 $\pm$ 3.68 x 10^3 cell l^{-1} and 8.70 $\pm$ 2.88 x 10^3 cell l^{-1}, respectively. While the values in the NE-to-SW inter-monsoon were 26.16 $\pm$ 13.00 x 10^3 cell l^{-1}, 23.07 $\pm$ 10.80 x 10^3 cell l^{-1} and 32.02 $\pm$ 43.80 x 10^3 cell l^{-1}, respectively. In the SW monsoon, the densities at each depth were 143.83 $\pm$ 106.30 x 10^3 cell l^{-1} (S), 168.10 $\pm$ 148.55 x 10^3 cell l^{-1} (M) and 99.86 $\pm$ 515.79 x 10^3 cell l^{-1} (B). There were not significant differences ($p > 0.05$) from the different sampling depths within the NE monsoon, the NE-to-SW inter-monsoon and the SW monsoon. However, a significant difference ($p < 0.05$) was found among the different monsoon periods.

Phytoplankton diversity index

Phytoplankton diversity index or Shannon–Wiener diversity index in the SW-to-NE inter-monsoon ranged between 0.30 and 3.04 with a mean of 1.96± 0.54 (Figure 3.10). While this index in the NE monsoon (mean = 2.84 ± 0.60) ranged from 1.37 to 3.73. During the NE-to-SW inter-monsoon (mean = 2.88 ± 0.68), the lowest and the highest indices were 1.40 and 3.99, respectively. The minimum and maximum diversity indices in the SW monsoon were 0.16 and 3.31, respectively with a mean of 1.63 ± 1.00. Significant differences ($P < 0.05$) were found from the different sampling stations within each monsoon and between different monsoons.

Diversity index at S, M and B depth levels in the SW-to-NE inter-monsoon were 2.06 ± 0.51, 1.95 ± 0.49 and 1.75 ± 0.73, respectively (Figure 3.11) with a significant difference ($P < 0.05$) between the indices from different depths. In the NE monsoon, these indices were 2.98 ± 0.53, 2.78 ± 0.69 and 2.73 ± 0.52, respectively. During the NE-to-SW inter-monsoon there were diversity indices of 2.77 ± 0.70 (S), 2.97 ± 0.66 (M) and 2.91 ± 0.69 (B). While in the SW monsoon, these indices were 1.58 ± 1.05 (S), 1.56 ± 1.04 (M) and 1.81 ± 0.95 (B). No significant differences ($P >$ 0.05) were found from the different three depths within the NE monsoon, the NE-to-SW inter-monsoon and the SW monsoons. When comparing between the different four monsoons, a significant difference ($P < 0.05$) was found.

Phytoplankton evenness index

Phytoplankton evenness index or Pielou evenness index in the SW-to-NE inter-monsoon (mean = 0.41 ± 0.10) ranged from 0.19 to 0.61 (Figure 3.10). In the NE monsoon (mean = 0.61 ± 0.12), there were the lowest and the highest evenness indices of 0.32 and 0.79, respectively. While a mean of evenness index in the NE-to-SW inter-monsoon was 0.56 ± 0.13 with a minimum of 0.27 and a maximum of 0.77, respectively. During the SW monsoon, evenness index ranged between 0.07 and 0.73 with a mean of 0.35 ± 0.2. The differences from different sampling stations within each monsoon and between different monsoons were significant ($P < 0.05$).

Phytoplankton evenness indices at S, M and B levels (Figure 3.11), in the SW-to-NE inter-monsoon were 0.42 ± 0.10, 0.41 ± 0.10 and 0.39 ± 0.12, respectively. In the NE monsoon, there were evenness indices of each depth; S = 0.63 $\pm$ 0.10, M = 0.60 $\pm$ 0.14 and B = 0.58 $\pm$ 0.11. While these indices at each depth in the NE-to-SW inter-monsoon were 0.54 $\pm$ 0.13 (S), 0.58 $\pm$ 0.12 (M) and 0.57 $\pm$ 0.14 (B). During the SW monsoon found that the evenness indices at S, M and B levels were 0.33 $\pm$ 0.22, 0.34 $\pm$ 0.23 and 0.39 $\pm$ 0.19, respectively. There were not significant differences (P > 0.05) from different sampling depths within each monsoon. However, a significant difference (P < 0.05) was found when comparing between different monsoons.

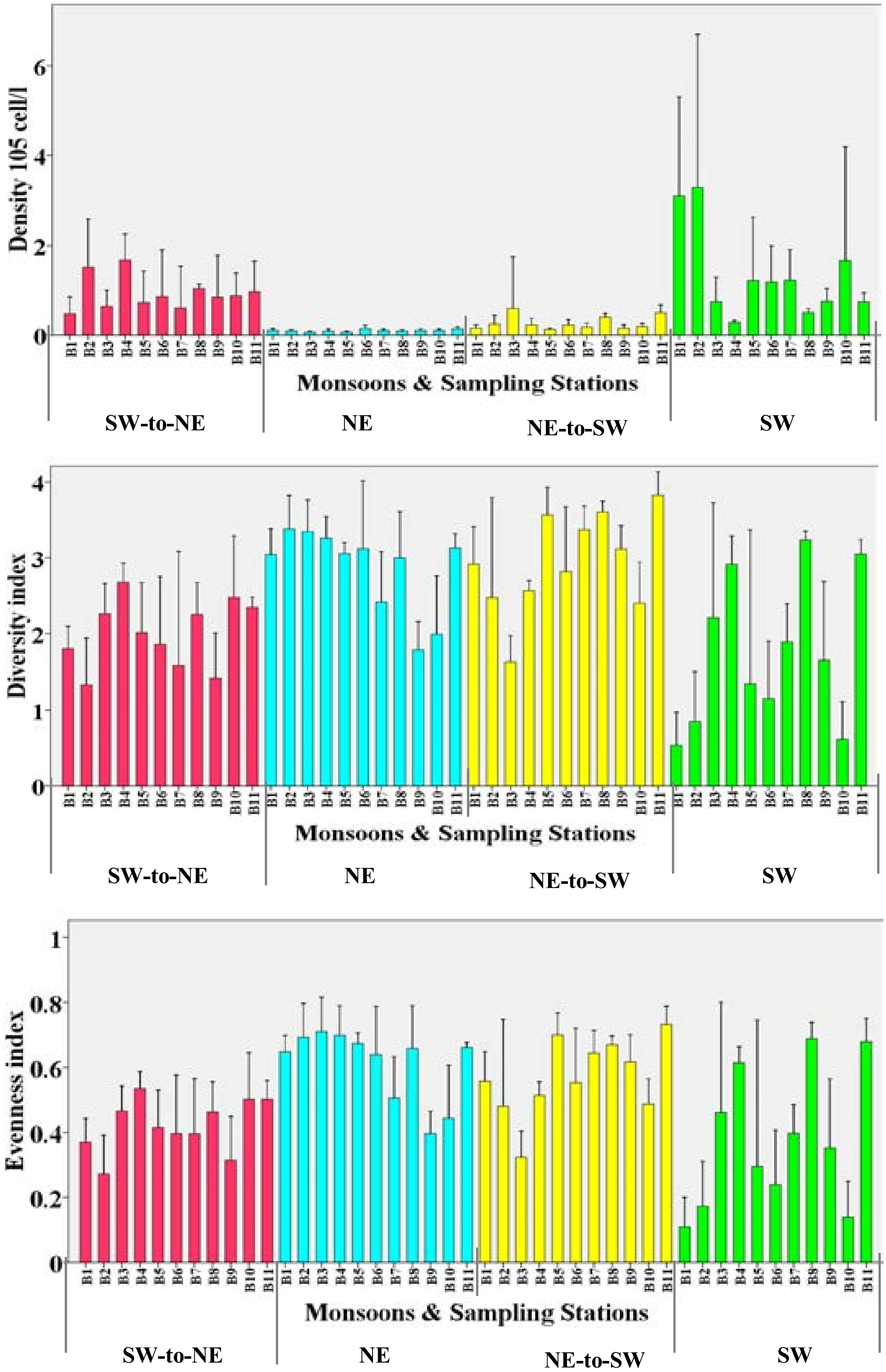


Figure 3.10 Means of phytoplankton density, diversity index and evenness index in each monsoon and sampling station in the coastal area of Si Racha-Si Chang, Chon Buri province during October 2008 to May 2009.

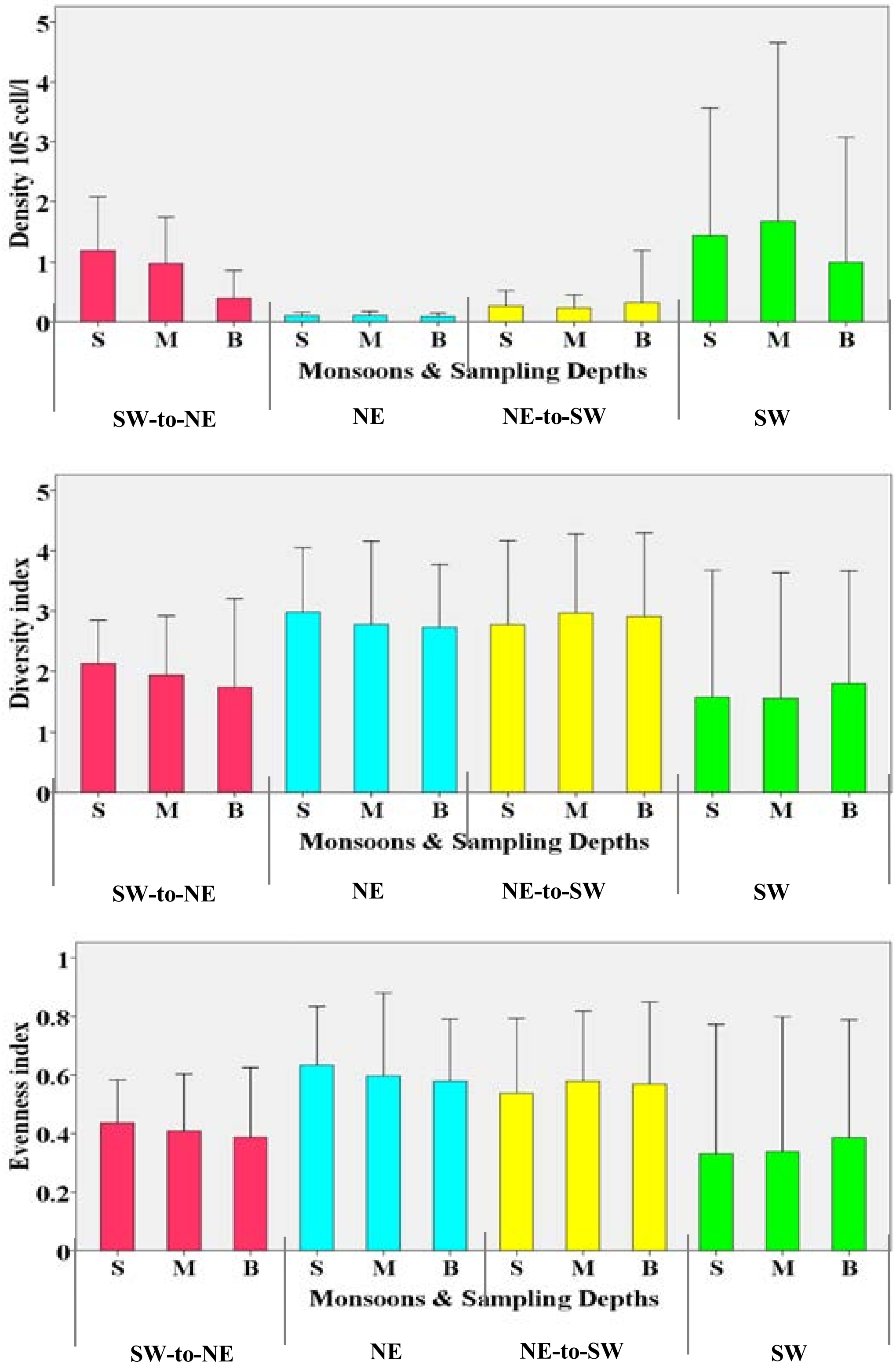


Figure 3.11 Means of phytoplankton density, diversity index and evenness index in each monsoon and sampling depth in the coastal area of Si Racha-Si Chang, Chon Buri province during October 2008 to May 2009.

C) The relationships between abundance of dominant phytoplankton and environmental factors

The correlations between density of dominant phytoplankton and environmental factors were investigated by Canonical Correspondence Analysis (CCA, Figure 3.12). The ordination diagram indicated that, in the SW-to-NE inter-monsoon (October 2008), high densities of *Bacteriastrum* corresponded with high salinity, high concentrations of dissolved inorganic nitrogen DIN, DIN: DIP molar ratio and DSi. While in the NE monsoon (December 2008) and the NE-to-SW inter-monsoon periods, the density of *Pseudo-nitzschia* together with *Thalassionema*, *Pseudanabaena* showed the tendency to follow the concentrations of salinity, DIN and DIN: DIP ratio. In the NE-SW monsoon (March 2009), the density of *Pseudo-nitzschia*, *Pseudanabaena* increased in response to high values of temperature, DIP, DSi and total- chlorophyll *a*. In the SW monsoon (May 2009), *Oscillatoria*, *Thalassionema* and *Chaetoceros* had the positive relationship with temperature, DO, DIP, DSi and total- chlorophyll *a*. Although, there were significant differences ($P < 0.05$) of diversity values within and between sampling stations, however, *Oscillatoria* frequently showed the highest density in each sampling station.

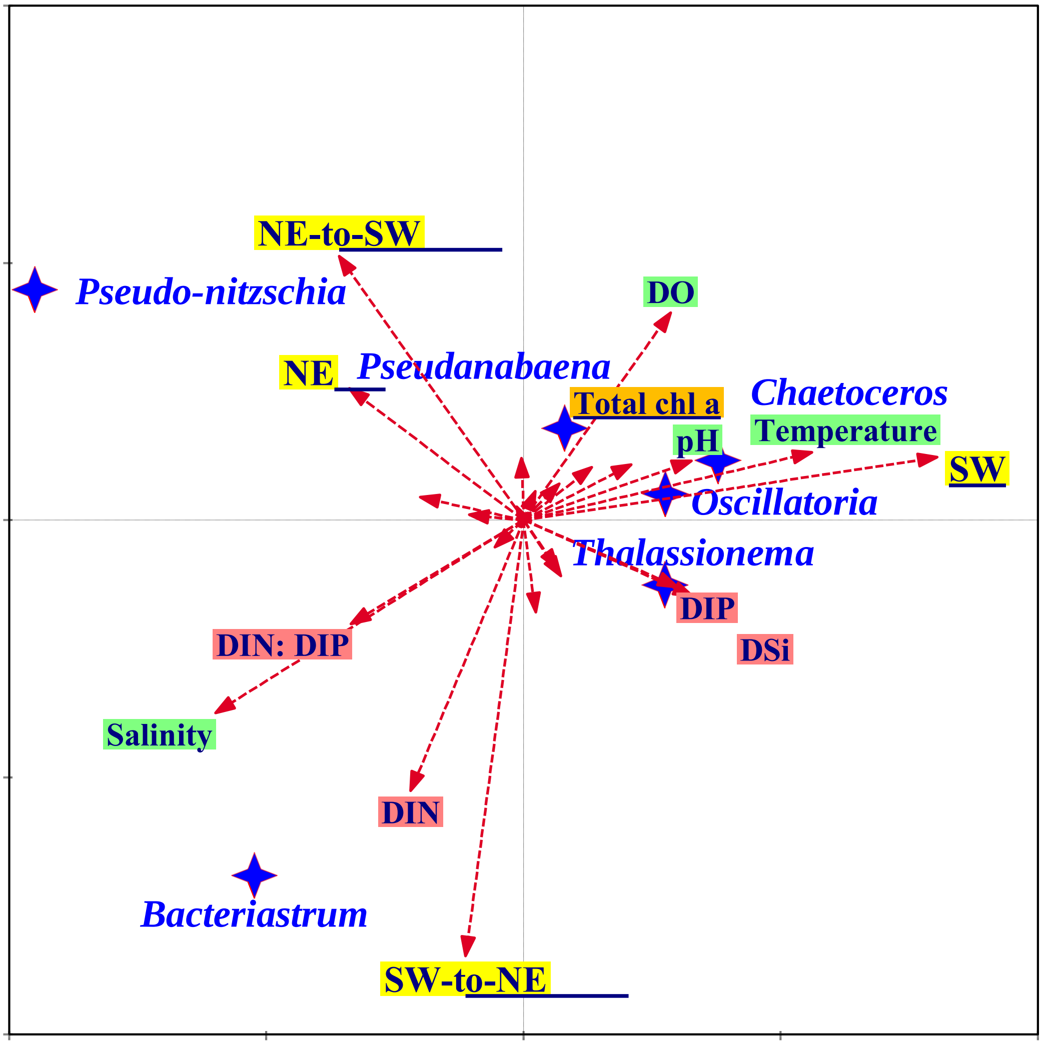


Figure 3.12 Ordination diagram displaying the first two axes of a redundancy analysis for the effect of environmental parameters on abundance of dominant phytoplankton in the coastal area of Si Racha-Si Chang, Chon Buri province during October 2008 to May 2009.

3.4 Conclusions

The study on environmental parameters showed that high values of seawater temperature, DO, pH, DIP and DSi trended to the NE-SW and the SW monsoon. While high concentrations of salinity and DIN were profound in the SW-to-NE inter-monsoon and the NE monsoon and were the most important factors controlling phytoplankton community structure. Moreover, high concentrations of nutrients frequently found in the stations which located near Bang Pakong rivermouth (B1 and B2). However, ANOVA showed significant ($p < 0.05$) in temporal variations of all environmental parameters.

Fifty six genera of phytoplankton were identified which diatoms were the most diverse group during the SW-NE and the NE-SW monsoons. The dominant diatoms genera comprised *Thalassionema*, *Chaetoceros*, *Bacteriastrum* and *Pseudo-nitzschia*. While the most dominated group in the NE and the SW monsoons were cyanobacteria. A cyanobacterium *Oscillatoria* had the highest percentage of total count in each monsoon and all monsoons. The density of *Oscillatoria* depended on the values of DIN and DIP.

Phytoplankton densities showed the lowest and the highest values in the NE and the SW monsoons, respectively. This value corresponded with DIN: DIP ratio. Phytoplankton at station B9 (the southwest of Ko Si Chang) had the lowest density while at B2 had the highest. The lowest and the highest densities also were observed at seawater bottom and seawater surface, respectively.

Phytoplankton diversity index (Shannon-Wiener diversity index, H') had the lowest value in the SW monsoon indicating the bloom of certain species of phytoplankton while the higher values found in the NE-to-SW inter-monsoon and the NE monsoon. Boonyaphiwat *et al.*, (1998) on the study of phytoplankton communities of the central Gulf of Thailand also suggested that H' was always higher in the NE monsoon than the SW monsoon. A minimum H' also was observed at B10 (the southwest of Ko Si Chang). Whereas a maximum H' was found at B11 (the coastal area of Leam Chabang), corresponded with Boonyaphiwat (1997) suggested that highest value of H' always found in the coastal area. Moreover, the highest H'

values were recorded from the communities inhabited near surface rather than at depth.

Phytoplankton evenness index (Pielou evenness index, J') had the lowest value in the SW monsoon and had the highest value in the NE monsoon, corresponded with Boonyaphiwat *et al.*, (1998). Boonyaphiwat (1997) also reported that J' always had the highest value in the coastal area.

Temporal variations of phytoplankton density, diversity and evenness indices also showed significant ($p < 0.05$).

This knowledge of phytoplankton diversity and abundance and also environment factors can be used as baseline information on marine biodiversity and water quality in the coastal area of Si Racha-Si Chang as well as the guideline for the monitoring of coastal ecosystems. Moreover, the result showed that high concentrations of nutrients frequently found in the stations which located near Bang Pakong river mouth and the coastal area of Si Racha which caused high density of phytoplankton. Consequently, this knowledge can be used as guideline for proper management of the coastal zone such as wastewater control from industry, livestock and household is required.

CHAPTER IV

SUCCESSION OF PHYTOPLANKTON COMMUNITIES IN RELATION TO THE ENVIRONMENTAL FACTORS IN THE COASTAL AREA OF KO SI CHANG, CHON BURI PROVINCE

Abstract

The study on succession of phytoplankton in relation to the environmental parameters in the coastal area of Ko Si Chang, Chon Buri province was carried out 10 times in the northeast (NE) monsoon from December 2010 to February 2011 and 24 times in the southwest (SW) monsoon from May to October 2011. A fixed station sampling site was set up and water as well as phytoplankton samples were collected once a week from three different depths: surface, middle and bottom. Due to the influence of seasonal variations and freshwater discharge from Bang Pakong river, the environmental parameters presented temporal variations with significantly high values of DIN, DIN: DIP ratio and DSi in the low salinity period of the SW monsoon in comparison to the high salinity period of the NE monsoon. The different environmental set up influenced significant differences in diversity and density of phytoplankton communities. That could indicate the succession stage. The NE monsoon phytoplankton communities were comprised mainly of diatoms (66%) and cyanobacteria (34%). While in the SW monsoon, the major phytoplankton groups were cyanobacteria (59%), dinoflagellates (25%) and diatoms (16%). Mean cell density in the NE monsoon was lower than those in the SW monsoon, while diversity index and evenness index showed greater values. In the early NE monsoon with the characterized high values of salinity, DO and DIP, phytoplankton community was dominated by diatoms *Bacteriastrum* and *Chaetoceros* (approx. 60% of total phytoplankton density) and increasing density of a cyanobacterium *Oscillatoria.* Total phytoplankton densities decreased during the period of *Thalassionema* and *Oscillatoria* dominated communities in the mid NE monsoon period where the high pH and DIN were recorded. The second and greater peak of phytoplankton abundance due to a cyanobacterium genus *Oscillatoria* (about 49% of total density) was noticed in late NE monsoon season together with the unbalanced DIN: DIP ratio (90: 1). In

the SW monsoon, the dominant phytoplankton genera were *Oscillatoria* and *Chaetoceros* with a bloom of *Noctiluca scintillans* at the beginning of this season with the unbalanced DIN: DIP ratio of 24: 1. The abundance of a diatom *Skeletonema costatum* occurred later in August with the unbalanced DIN: DIP ratio (36: 1). In late SW monsoon in September, phytoplankton communities were dominated by the co-occurrence of *Oscillatoria* and *Ceratium furca* that lasted until the period of early inter monsoon month of October 2011 with the unbalanced DIN: DIP of 33: 1 and 20: 1, respectively. The succession pattern of phytoplankton communities in this SW monsoon was related with the variation in DIN and DIP concentrations with the concurrence of *Oscillatoria* dominated phytoplankton community with high DIN: DIP molar ratios. The inter-specific relationship among phytoplankton species were also recognized such that the existence of *Ceratium furca* was usually showed an inverse relationship with the abundance of diatoms such as *Chaetoceros* spp. and *Bacteriastrum* sp. While a positive correlation between the diatom *Chaetoceros* spp. with another bloom forming dinoflagellate *Noctiluca scintillans* was significant.

4.1 Introduction

The Upper Gulf of Thailand (UGoT), a large semi-enclosed tropical sea, innermost area which located between latitude 13°30′N to 12°60′N and longitude 100°00′E to 101°00′E, and covers an area about 10000 km^2. It is characterized as the catchment basin from four main rivers on the northern side namely Mae Klong, Tha Chin, Chao Praya and Bang Pakong from west to east coast (Boonyatumanond *et al.*, 2007; Buranapratheprat, 2006; Wattayakorn, 2006).The UGoT area is under climatic influence of the two-monsoon wind system, the dry northeast (NE) from November to January and the wet southwest (SW) monsoon from May to August (Sojisuporn, 1994). The rapid development of industrialization and urbanization in the coastal area around UGoT have grown rapidly causing the deterioration of the coastal and marine ecosystems. The most serious problems are untreated industrial wastewater, eutrophication, and contamination of trace metals (Cheevaporn and Menasveta, 2003).

Ko Si Chang, located in the eastern part of UGoT, is an economically important island based on tourism and marine transportation. Consequently, the water qualities around Ko Si Chang were contaminated with garbage, waste water, hot water and engine oil drained from ships, dust from tapioca and coal transportations (ARRI, 2009).

The studies on oceanographic conditions and water qualities in the Eastern UGoT indicated the influence of monsoon system, freshwater discharge from Bang Pakong River in the SW monsoon season in particular, on the environmental parameters in water column with emphasis on the variations of salinity and algal nutrients (ARRI, 2009; Buranapratheprat *et al.*, 2002a). In the NE monsoon, the environmental conditions were characterized by low temperature values (Buranapratheprat *et al.*, 2008; Sriwoon *et al.*, 2008) but high values of salinity (Buranapratheprat *et al.*, 2002a; 2002b; 2008; Sriwoon *et al.*, 2008) and oxygen concentrations (Buranapratheprat *et al.*, 2010). Whereas algal nutrients; ammonia-nitrogen (Buranapratheprat *et al.*, 2002a), nitrite- and nitrate nitrogen (Sriwoon *et al.*, 2008), dissolved inorganic phosphate or DIP (Buranapratheprat *et al.*, 2002a; Sriwoon *et al.*, 2008) and dissolved silicate or DSi (Sriwoon *et al.*, 2008) were low in concentrations. Consequently, phytoplankton biomass in the NE monsoon also was lower than in the SW monsoon (Sriwoon *et al.*, 2008).

According to the previous studied of phytoplankton diversity in the UGoT, the results showed that the dominant phytoplankton always be diatoms (*Chaetoceros*, *Thalassionema*, and *Bacteriastru*m) and a cyanobacterium *Oscillatoria* (Boonyaphiwat, 1997; Boonyaphiwat *et al*., 1998; Junkaew, 2009; Kaewngen, 2008; Khwaiphan, 2005; Late, 2007; Purgsaard, 2007; Puttarn, 2007; Ratanamongkon, 2007; Saosee, 2004; Sriwoon *et al*., 2008; Wichairahad, 2007; Wongsuwan, 2008). Furthermore, there were frequently recorded of red tides in the UGoT. Red tide or algal bloom, the phenomenon occurred from the rapid growth of phytoplankton, caused water color changes (Okaichi, 2003). The major course that enhanced rapid growth of phytoplankton, consequently, red tide and phytoplankton succession, is nutrients-enrichment in water column such as DIN, DIP, DSi (Baek *et al*., 2009; Buranapratheprat *et al*., 2002a; Chen *et al*., 2006; Domingues *et al*., 2005; Liu *et al*., 2005; Paul *et al.,* 2008; Shipe *et al*., 2008). A total of ninety-seven red tides were recorded from this area during the period from 1957 to 2001 (ARRI, 2003).The most frequent blooming phytoplankton groups were *Noctiluca scintillans* and *Trichodesmium erythraeum.* In addition to red tide phenomena, the depleting of dissolved oxygen and increasing of ammonia concentration in water column were detected which resulting in the mortality of fish (Wattayakorn, 2006). Other bloom-forming phytoplankton found in the UGoT consisted of the dinoflagellate *Ceratium furca* and many genera of diatoms (Lirdwitayaprasit *et al*., 2006).

Nowadays, the frequencies of red tide have been increasing, especially in the UGoT. So the aims of this study were to: (i) investigate and compare the environmental parameters in the less red-tide period of NE and the SW monsoon where red tides frequently occurr in the UGoT; (ii) identify phytoplankton communities and also distribution and abundance; (iii) elucidate the relationships between phytoplankton communities and environmental factors during the red-tide and non red-tide seasons. The final goal of this study is to find factors affecting phytoplankton succession. The overall knowledge can be used as baseline information on marine ecosystem, and also the proper management of the coastal zone.

4.2 Methodology

4.2.1 Study area and sampling period

Ko Si Chang locates on the west coast of Chon Buri province, the UGoT. A fixed-station sampling site was set up near the coast of Ko Si Chang at the latitude 13° 9' 32.6" N and the longitude 100° 49' 05.2" E (Figure 4.1). Field samplings were conducted in two different periods: the northeast (NE) monsoon from December 2010 to February 2011 and the southwest (SW) monsoon from May to October 2011. During each period, samples were collected once a week with the exception during the red tide phenomenon where samples were collected every 1-2 days.

Source: http://www.worldatlas.com/[30 11 2011]

Source: Google Earth.

Figure 4.1 Sampling site: the coastal area of Ko Si Chang, Chon Buri Province.

4.2.2 Collection and analyses of phytoplankton samples

A) Phytoplankton sampling

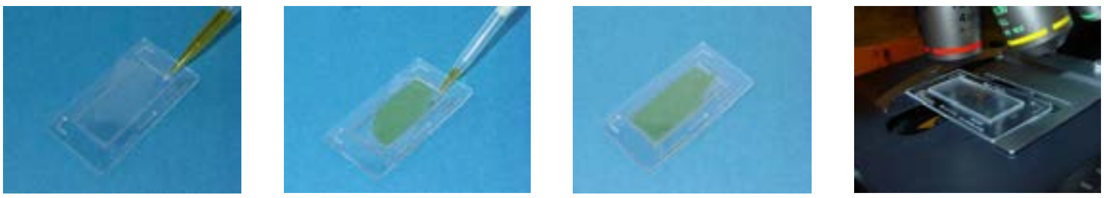
Quantitative phytoplankton samples were collected by a 1 l of Van Dorn water sampler for 3 different depths; 1) surface level (S) at 0.5 m depth; 2) mid depth (M) at 2.5-3.5 m depth; and 3) bottom level (B) at 5-7 m depth (Figure 4.2). Two replications of water samples were collected from each depth. About 10 l of water samples were filtered onto a 20 µm phytoplankton net. The cells retained by this net were preserved with 1 % (v/v) neutralized formalin (Sournia, 1978).

A B C

Figure 4.2 Phytoplankton sampling: A; Van Dorn bottle, B; 20 µm phytoplankton net and C; phytoplankton sampled was kept in plastic bottle.

B) Phytoplankton diversity and abundance

Phytoplankton samples were identified to genus level based on the references of Tomas (1996) and Round *et al.* (2007). Cell density in the unit of cell l^{-1} of each genus was calculated from the count by using Sedgewick Rafter slide under a compound microscope, at a magnification of 100 x (Lobban *et al.*, 1988) (Figure 4.3).



A B C D

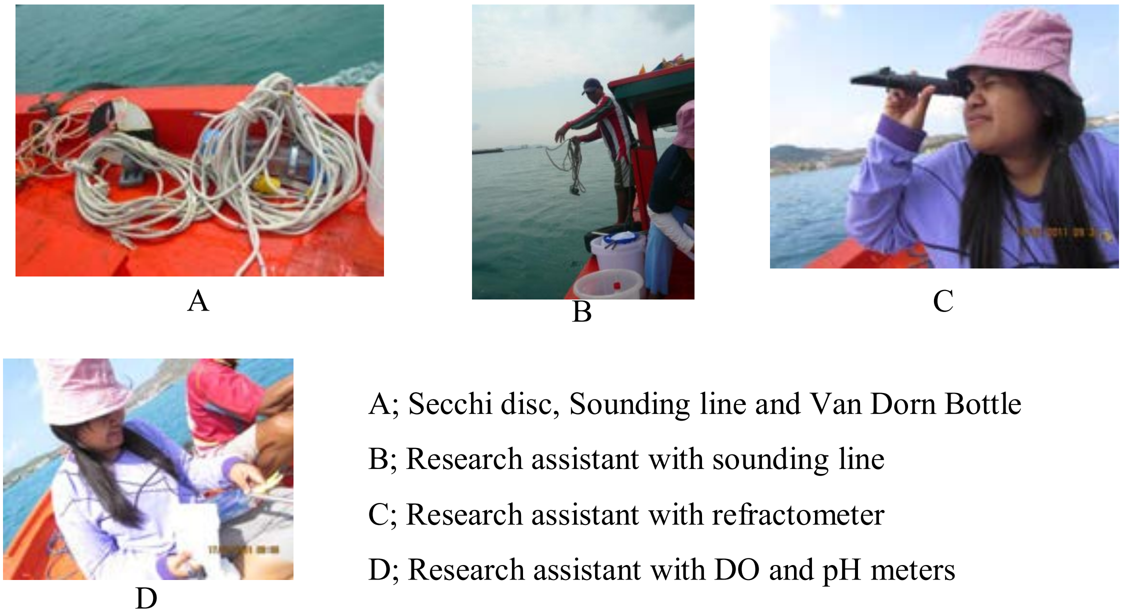
Source: http://www.afcd.gov.hk/english/fisheries/hkredtide/classroom/fun02.html [18 3 2011]

Figure 4.3 Phytoplankton counting : A-C; add phytoplankton samples into Sedgewick Rafter slides and D; Sedgewick Rafter slide under a compound microscope.

4.2.3 Physico-chemical parameters

A) Physico-chemical parameters measurement

At each station, the depth and transparency were determined prior to the sampling by a sounding line and a secchi disc, respectively. Salinity of water was measured by a refractometer, *in situ* water temperature and dissolved oxygen were measured by a DO meter (YSI model DO 200) and pH was measured by a pH meter (YSI model pH 100) (Figure 4.4)



A; Secchi disc, Sounding line and Van Dorn Bottle

B; Research assistant with sounding line

C; Research assistant with refractometer

D; Research assistant with DO and pH meters

Figure 4.4 Environmental parameters measurement.

B) Sampling and analyses of chlorophyll content and dissolved inorganic nutrients

Replicate seawater samples were withdraw from a designed depth using a Van Dorn bottle and filtered through a 200 µm-meshed net. The filtrates were kept cool in pre-cleaned plastic bottles. In laboratory, the portion of this pre-filtered seawater was filtered onto a GF/F filter paper (Whatman, UK) representing the total chlorophyll fraction (fraction < 200 µm). The second aliquot was first filtered through a 20 µm-mesh net (Figure 4.5) and then was filtered onto a GF/F filter paper. This represented the nano- plus picoplankton size class (0.7-20 µm fraction). All filter papers were kept frozen at -20 °C until the spectrophotometric analyses of chlorophyll *a*, *b* and *c* (Parsons *et al*., 1984) were performed and the pigment concentrations of microphytoplakton (20-200 µm or > 20 µm) and the smaller phytoplankton (0.7-20 µm or < 20 µm) were calculated.

A B C

Figure 4.5 Seawater serially filtered: A, 200 µm meshed net, B; 20 µm meshed net and C; seawater sample was kept in plastic bottle.

Seawater filtrate passing through GF/F filter paper was kept frozen at -20 °C in a 200 ml plastic bottle until analyzed in laboratory for nitrite-nitrogen, nitrate-nitrogen, phosphate-phosphorus and silicate-silicon by analytical methods referred by Parsons *et al*. (1984) (Figure 4.6).

A B

Figure 4.6 Spectrophotometric analysis: A; Seawater samples and B; seawater analysed using Spectrophotometer.

At the same sampling depths as water samples for ammonia-nitrogen analysis were collected by using a pre-cleaned stainless water sampler and kept frozen at -20

^{o}C in 60 ml plastic bottles until analyzed in laboratory by spectrophotometric method which followed Parsons *et al*. (1984).

4.2.4 Data analysis

A) Phytoplankton diversity index and evenness index

Phytoplankton diversity index (H') and evenness index (J') were calculated by following equation of Shannon-Wiener (Shannon and Weaver, 1949) and Pielou (1966) respectively:

$$H' = -\sum_{i=1}^{s} Pi \log_2 Pi$$

$$J' = H' / \log_2 S$$

where $Pi = Ni/N$, Ni is number of individual of the genus organisms, N is number of total individual, S is total genus at any depth level.

B) Significant differences of physic-chemical and biological parameters in different monsoons and depths

A two-way ANOVA was used to test for significant differences in phytoplankton density, diversity index, evenness index and environmental parameters (transparency, temperature, salinity, dissolved oxygen, pH, ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen, phosphate-phosphorus, silicate-silicon and chlorophyll *a*, *b*, and *c*) between different monsoons and among depths level using SPSS statistic package version 16.

C) The relationships between phytoplankton and environmental parameters

The relationships between dominant phytoplankton and environmental parameters were tested by using Canonical Correspondence Analysis (Lepš and Šmilauer, 1999) using CCA; CANOCO program for window version 4.5.

D) The relationships between phytoplankton

The relationships between dominant phytoplankton were analyzed by using Pearson's correlation (Vanichbancha, 2009) using SPSS statistic package version 16.

4.3 Results and Discussions

4.3.1 Environmental parameters

The variations in physical, chemical and biological features of seawater in the study period (December 2010 to October 2011) are shown in Appendix 4.1, summarized in Table 4.1 and illustrated in Figure 4.7-4.10. These results indicated the influence of monsoon seasons particularly of the freshwater discharge from Bang Pakong River in the SW monsoon period (Buranapratheprat, 2009), Appendix 4.2-4.3.

A) Transparency

In the NE monsoon (December 2010 to February 2011), mean transparency was about 3.15 $\pm$ 0.34 m with the values ranged from 3 m to 4 m. While in the SW monsoon (May to October 2011), the range of transparency was from 1.5 m to 4 m with a mean of 3.15 $\pm$ 0.63 m (Table 4.1). Significant differences ($p < 0.05$) were observed within each monsoon. However, no significant difference ($p > 0.05$) was found between these monsoons.

Table 4.1 Environmental parameters in the coastal area of Ko Si Chang, Chon Buri province.

Environmental parameters	December 2010-October 2011		Monsoon		Depth		
			Northeast	Southwest	Surface	Mid depth	Bottom
	Mean ± SD	Range	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Transparency (m)	3.15 ± 0.56	1.50-4.00	3.15 ± 0.34	3.15 ± 0.63			
Temperature (°C)	29.3 ± 1.16	27.1-31.7	27.8 ± 0.52	29.9 ± 0.73	29.3 ± 1.17	29.3 ± 1.17	29.3 ± 1.14
Salinity (ppt)	28.5 ± 4.79	10.0-35.0	32.6 ± 1.75	26.8 ± 4.64	27.9 ± 5.42	28.1 ± 5.25	29.5 ± 3.35
DO (ppm)	6.40 ± 1.10	2.69-8.70	6.96 ± 0.52	6.17 ± 1.19	6.71 ± 0.89	6.48 ± 1.05	6.01 ± 1.22
pH	8.28 ± 0.27	7.77-8.90	8.05 ± 0.27	8.37 ± 0.20	8.31 ± 0.27	8.30 ± 0.28	8.22 ± 0.25
NH_4^+ (µM)	2.69 ± 3.96	0.08-37.3	1.76 ± 0.92	3.07 ± 4.63	3.17 ± 5.94	2.45 ± 2.68	2.45 ± 2.18
NO_2^-(µM)	0.14 ± 0.25	0.01-1.76	0.05 ± 0.03	0.18 ± 0.28	0.09 ± 0.12	0.10 ± 0.15	0.23 ± 0.36
NO_3^- (µM)	0.89 ± 0.77	0.07-3.73	0.28 ± 0.13	1.15 ± 0.78	0.80 ± 0.70	0.80 ± 0.61	1.07 ± 0.93
DIN (µM)	3.72 ± 4.01	0.55-37.9	2.09 ± 0.95	4.40 ± 4.58	4.06 ± 5.90	3.34 ± 2.77	3.75 ± 2.46
DIP (µM)	0.43 ± 0.51	0.02-1.93	0.94 ± 0.64	0.21 ± 0.21	0.44 ± 0.54	0.41 ± 0.50	0.44 ± 0.50
DIN: DIP ratio	25.0 ± 32.9	0.37-252	14.1 ± 31.3	29.6 ± 32.5	28.8 ± 37.2	22.2 ± 22.8	24.1 ± 36.8
DSi (µM)	27.8 ± 22.6	1.69-106	7.31 ± 3.59	36.4 ± 21.7	30.0 ± 25.0	29.0 ± 24.0	24.6 ± 18.2

B) Seawater temperature

Seawater temperature in the NE monsoon ranged between 27.15 °C to 28.68 °C with a mean of 27.84 ± 0.52 °C. In the SW monsoon, mean temperature was 29.90 ± 0.73 °C with the values ranged from 28.95 °C to 31.50 °C (Table 4.1). Significant differences (p < 0.05) were found among sampling dates within each monsoon and between different monsoons. This result agreed with Sriwoon *et al.*, (2008). Buranapratheprat *et al.*, (2008) also reported that mean temperature in the UGot in January and May 2004 were 26°C and 31°C, respectively. However, mean temperature in the NE monsoon from this study was higher than in the previous studied from Sojisuporn who reported that mean temperature in the coastal area of Ko Si Chang during the NE monsoon of 2009 was 24.46°C (TRF, 2012).

Vertical profile of temperature during this NE monsoon period did not show drastic changes (Figure 4.7) with the mean temperature around 27-28 °C. Whereas in the SW monsoon, means temperature was around 29 °C. No significant differences (p > 0.05) were found among depths within each monsoon. However, a significant difference (p < 0.05) was found between different monsoons.

C) Salinity

In the NE monsoon, salinity values ranged from 30.33 ppt to 34.67 ppt. Mean value of salinity in this season was 32.55 $\pm$ 1.75 ppt. While in the SW monsoon, the values ranged between 15.67 ppt and 32.50 ppt with a mean value of 26.78 $\pm$ 4.64 ppt (Table 4.1). There were significant differences ($p < 0.05$) among sampling dates within each season and between different seasons. This result corresponded with Sojisuporn, who reported that salinity in January 2009 in the coastal area of Ko Tai KangKao nearby Ko Si Chang was 33.53 ppt (TRF, 2012). In the SW monsoon, precipitation and a large amount of freshwater discharge from a flooding in the central area of Thailand passed through Bang Pakong river (Appendix 4.2-4.3) to the UGoT and induced low salinity condition in the study area. This dilution of seawater concurrented with the study of water quality changes in Bang Pakong river (Pianjing, 2000) and also the reports of salinity values in the UGoT by Buranapratheprat *et al.*, (2002a; 2002b; 2008), Sriwoon *et al.*, (2008) and HAII (2012).

Means of salinity in the NE monsoon among sampling depths (Figure 4.7) showed no significant difference ($p > 0.05$). However, a significant difference ($p < 0.05$) was found among sampling depths in the SW monsoon with the lower salinity at surface layer and the maximum salinity values at bottom depth. When comparing means of salinity among sampling depths between the NE and the SW monsoons, a significant difference ($p < 0.05$) was observed.

D) Dissolved oxygen

The minimum and maximum values of oxygen concentration in the NE monsoon were 5.48 ppm and 7.69 ppm, respectively with a mean value of 6.96 $\pm$ 0.52 ppm (Table 4.1). In the SW monsoon, mean DO was 6.17 $\pm$ 1.19 ppm with the values ranged from 2.69 ppm to 8.95 ppm. Significant differences ($p < 0.05$) were observed among sampling dates within each monsoon and between these monsoons.

When comparing with the previous studied from Buranapratheprat *et al.*, (2010) and Sojisuporn (TRF, 2012), found the similar mean value of DO in the NE monsoon (January 2009). This result showed that mean value of DO in the SW monsoon was lower than in the NE monsoon, because of the frequency of red tides in the SW monsoon, it caused the depletion of dissolved oxygen (Wattayakorn, 2006).

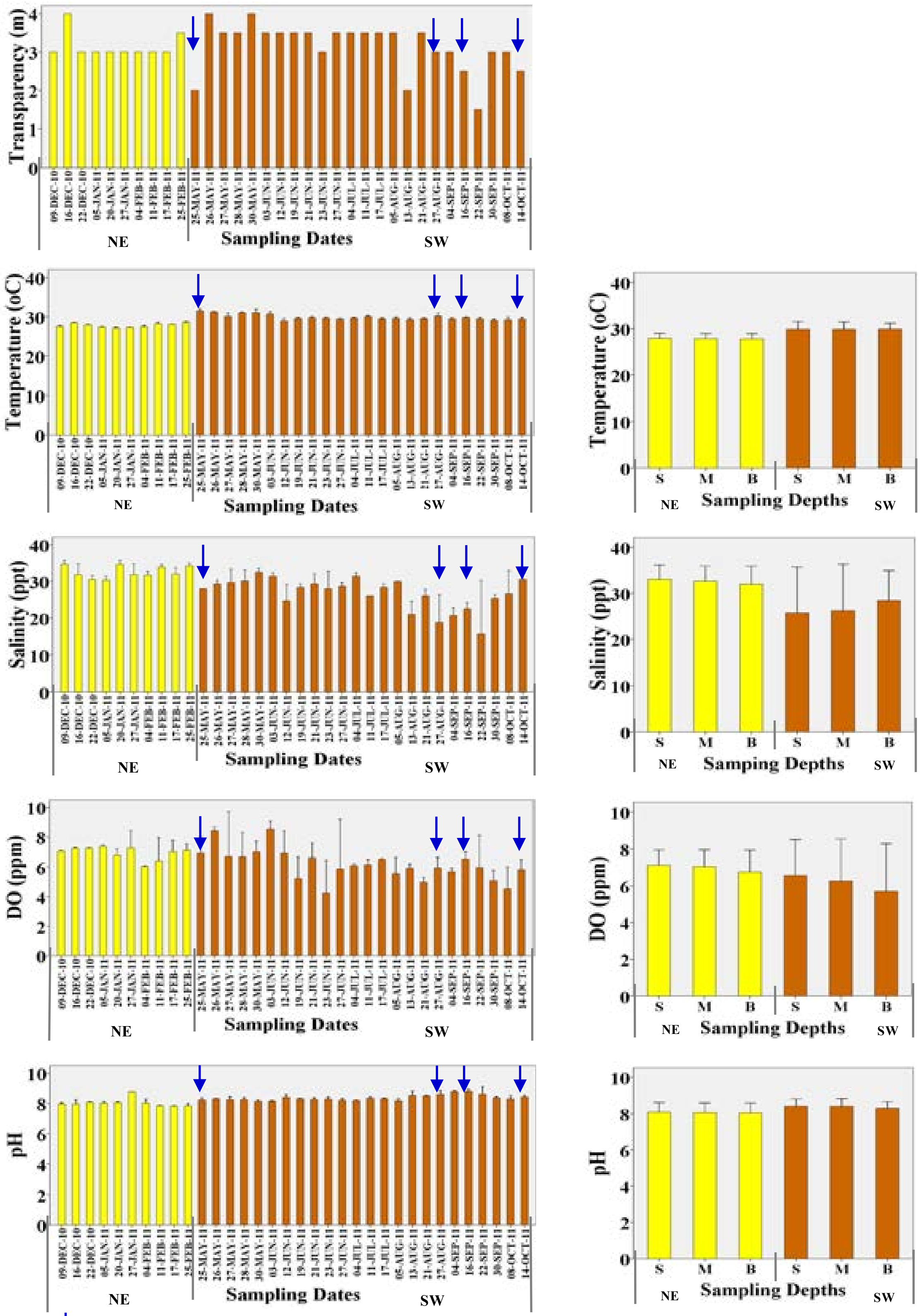
The difference of mean oxygen concentrations at each depth (Figure 4.7) in the NE monsoon was not significant ($p > 0.05$). While in the SW monsoon, significant difference ($p < 0.05$) was found with the higher DO value at surface (6.55 ppm) and the lower DO value at the bottom depth (5.71 ppm). A significant difference ($p < 0.05$) among sampling depths was found between the NE and the SW monsoons.

E) pH

The lowest and the highest pH values in the NE monsoon were 7.77 and 8.78, respectively with a mean value of 8.05 $\pm$ 0.27 (Table 4.1). In the SW monsoon, mean pH was 8.37 $\pm$ 0.20 with the values ranged between 8.07 and 8.90. The significant differences ($p < 0.05$) were found among sampling dates within each monsoon and between different monsoons.

The pH value in the NE monsoon corresponded with Sojisuporn in 2009 (TRF, 2012), he reported that mean pH at Ko Tai KangKao in the NE monsoon was 8.13. However, both pH value in the NE monsoon and the SW monsoon indicated a good condition according to the reported of the Pollution Control Department, PCD (2012). Although the significant differences ($p < 0.05$) were found; but this parameter was not significant to dominant phytoplankton density and diversity.

In the NE monsoon, no significant difference ($p > 0.05$) was found in mean pH values among three depths (Figure 4.7). While in the SW monsoon, means of pH showed a significant difference ($p < 0.05$) with the values around 8.3 (bottom) - 8.4 (surface). However, a significant difference ($p < 0.05$) also was found among sampling depths between different seasons.



Note: ↓ *indicated red tide occurrence.*

Figure 4.7 Temporal variations in means of transparency, temperature, salinity, dissolved oxygen and pH in the coastal area of Ko Si Chang, Chon Buri province in December 2010 to October 2011.

F) Dissolved inorganic nutrients

Ammonia-nitrogen

In the NE monsoon, mean ammonia-nitrogen was 1.76 $\pm$ 0.92 µM (Table 4.1) with the values ranged between 0.33 µM and 3.53 µM. In the SW monsoon, mean ammonia-nitrogen ranged from 0.08 µM to 37.30 µM with a mean of 3.07 $\pm$ 4.63 µM. Significant differences ($p < 0.05$) were observed among sampling dates within each monsoon and between different monsoons.

The result as mentioned showed that the values of ammonia-nitrogen varied very much. The high values were also observed during rainy season as well as Buranapratheprat *et al.*, (2002a) and Junchompoo *et al.*, (2006). Moreover, high concentrations of ammonia always co-occurred with algal blooms, which the maximal mean value of ammonia (16.84 µM) and the highest mean of phytoplankton density (18.86 x 10^5 cell l^{-1}, Figure 4.16) presented at the same time (16^{th} September 2011) in the SW monsoon, agreed well with (Wattayakorn, 2006). This significant relationship also was confirmed by CCA (Figure 4.19).

River discharge also carried runoff from agricultural fertilizers, livestock, domestic wastewater and soil erosion ended up to the sea, which enhanced mineral components in seawater, finally became sources of phytoplankton nutrients. Buranapratheprat *et al.*, (2002b) reported that in the SW monsoon, nutrients from river discharge that driven to the east coast of the UGoT promoted eutrophication for a long time. It is clear that the excess nutrients caused eutrophication and algal bloom.

There were not significant differences ($p > 0.05$) in mean values of ammonia-nitrogen among sampling depths (Figure 4.8) within each monsoon and between different monsoons.

Nitrite-nitrogen

Nitrite-nitrogen concentrations in the NE monsoon ranged from 0.01 µM to 0.14 µM with a mean of 0.05 $\pm$ 0.03 µM (Table 4.1). In the SW monsoon, mean value of nitrite-nitrogen was 0.18 $\pm$ 0.28 µM with the values range from 0.003 µM to 1.76 µM. The differences among sampling dates within each monsoon and between different monsoons were significant ($p < 0.05$).

Means of nitrite-nitrogen among sampling depths (Figure 4.8) in the NE monsoon was not significant ($p > 0.05$). While in the SW monsoon, a significant difference ($p < 0.05$) was found with the highest value of nitrite-nitrogen at surface layer (0.12 µM) and the lowest value at bottom (0.3 µM). A significant difference ($p < 0.05$) among sampling depths between these monsoons also was found.

Nitrate-nitrogen

In the NE monsoon, nitrate-nitrogen had the lowest and the highest values of 0.07 µM and 0.67 µM, respectively with a mean of 0.28 $\pm$ 0.13 µM (Table 4.1). Whereas in the SW monsoon, a mean of nitrate-nitrogen was 1.15 $\pm$ 0.78 µM with the values ranged from 0.14 µM to 3.73 µM. There were significant differences ($p < 0.05$) among sampling dates within each monsoon and between different monsoons.

Mean of nitrate-nitrogen in the SW monsoon which was higher than in the NE monsoon, this result corresponded well with Sriwoon *et al.*, (2008).

The different of means nitrate-nitrogen among sampling depths in the NE monsoon was not significant ($p > 0.05$). While significant difference ($p < 0.05$) was found in the SW monsoon with the lowest value at surface (1.01 µM) and the highest value of nitrate-nitrogen at bottom (1.41 µM) (Figure 4.8). When comparing the difference among sampling depths between different monsoons, found the significance ($p < 0.05$).

Dissolved Inorganic Nitrogen (DIN)

In the NE monsoon, DIN (ammonia-nitrogen plus nitrite-nitrogen and nitrate-nitrogen) had the lowest and the highest values of 0.55 µM and 3.79 µM, respectively with a mean of 2.09 $\pm$ 0.95 µM (Table 4.1). Whereas in the SW monsoon, a mean of DIN was 4.40 $\pm$ 4.58 µM with the values ranged from 0.56 µM to 37.86 µM. There were significant differences ($p < 0.05$) among sampling dates within each monsoon and between different monsoons.

The different of DIN means among sampling depths in the NE and the SW monsoons were not significant ($p > 0.05$). While significant difference ($p < 0.05$) was found among sampling depths between different monsoons (Figure 4.9).

Dissolved Inorganic Phosphate (DIP)

In the NE monsoon, DIP had a mean value of 0.94 $\pm$ 0.64 µM (Table 4.1). The minimum and maximum values were 0.02 µM and 1.93 µM, respectively. In the SW monsoon, mean DIP was 0.21 $\pm$ 0.21 µM with the values ranged from 0.02 µM to 1.62 µM. Significant differences ($p < 0.05$) among sampling dates were found within each monsoon and between different monsoons.

The low concentrations of DIP in the SW monsoon from this result corresponded with Junchompoo *et al.*, (2006). However this result was differed from Buranapratheprat *et al.*, (2002a) and Sriwoon *et al.*, (2008). The reason might be the frequency of red tides in the SW monsoon which DIP was used by the blooming algae for photosynthesis. Lirdwitayaprasit *et al.*, (2006) also found the significant relationship between the concentrations of DIP and the abundance of *Noctiluca scintillans.*

Mean DIP concentrations from different three depths in the NE monsoon were about 0.930 µM to 0.940 µM (Figure 4.9). While in the SW monsoon, DIP values from three depths ranged from 0.190 µM to 0.230 µM. There were not significant differences ($p > 0.05$) from different sampling depths within each monsoon. However, a significant difference ($p < 0.05$) was found between different monsoons.

DIN: DIP ratio

The average DIN: DIP ratio for each sampling date in the NE monsoon ranged from 0.60 to 90.33 with a mean of 14.09 $\pm$ 31.33 (Table 4.1). While in the SW monsoon, mean was 29.60 $\pm$ 32.50 with a range of 8.16 to 133.0. There were significant differences ($p < 0.05$) among sampling dates within each monsoon and between different monsoons. There were not significant differences ($p > 0.05$) among sampling depths within each monsoon. However, a significant difference ($p < 0.05$) was found between different monsoons.

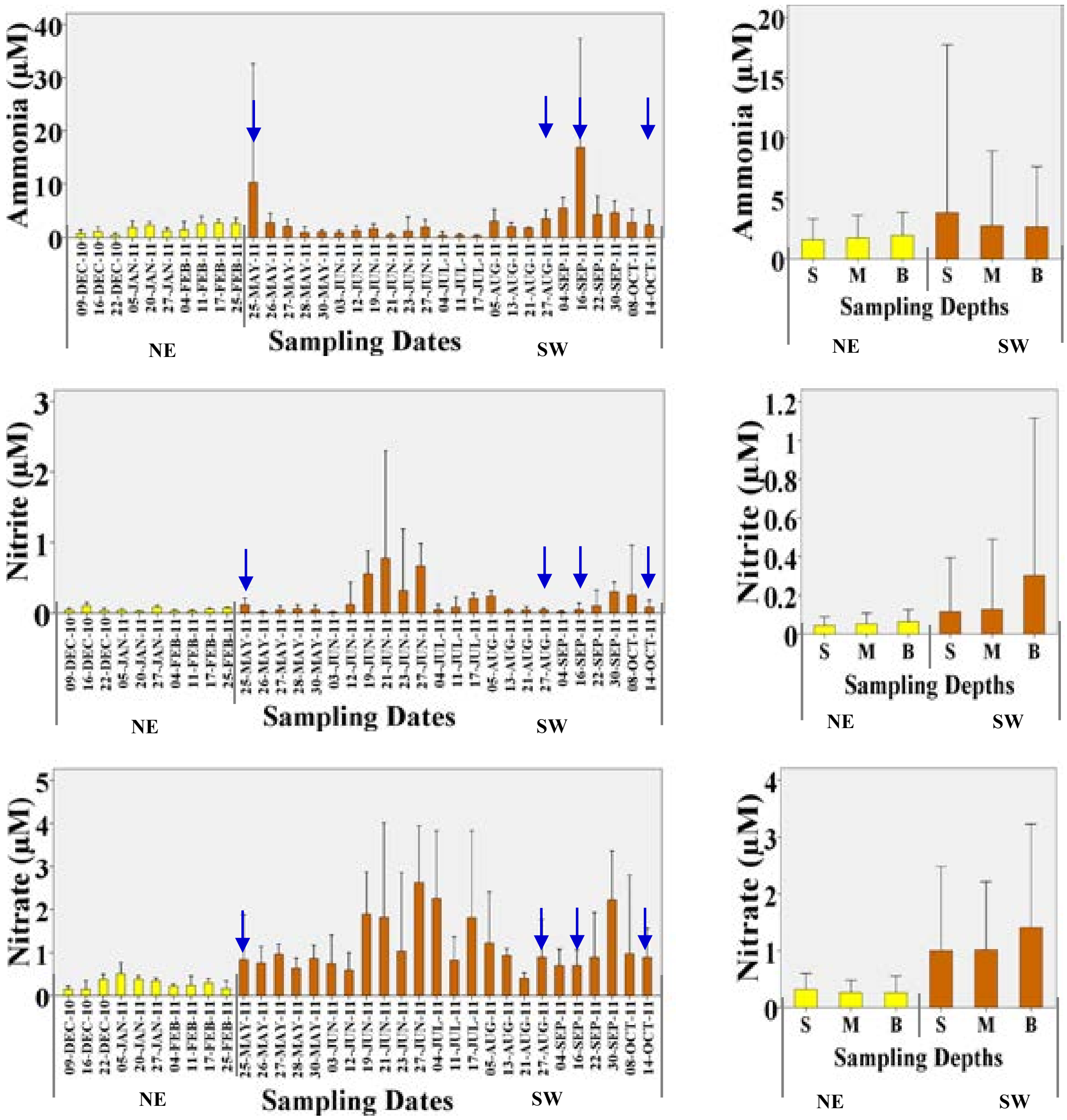
The mean ratio of DIN: DIP in the NE monsoon season of 14.09 indicated the usual condition in nutrient status of the study area with a mean DIN: DIP closed to that of Redfield ratio (N: P = 16). However, there were still fluctuations in DIN: DIP ratio in such that the ratio was low in during the early part of the season and increased toward to end of NE monsoon season (Figure 4.9). Different situation occurred in the SW monsoon season where the unbalanced DIN: DIP ratio; mean value of 29.60 $\pm$ 32.50. DIN: DIP value was about 10 in June 2011 due to an increase in PO_4^{3+}-P. A peak of DIN: DIP ratio occurred in July-August 2011 in corresponded to the high NO_3^--N and lower PO_4^{3+}-P (Figure 4.8-4.9). Junchompoo *et al.*, (2006) also reported that DIN: DIP value in the middle Bang Pakong river during the SW monsoon was higher than 16 and also increased chlorophyll *a* content.

Dissolved Silicate (DSi)

DSi values in the NE monsoon had a mean of 7.31 $\pm$ 3.59 µM (Table 4.1) with the values ranged between 1.69 µM to 12.95 µM. In the SW monsoon, this mean value was 36.38 $\pm$ 21.69 µM with the values ranged from 12.68 µM to 106.38 µM. Significant differences ($p < 0.05$) among sampling dates were found within the NE and the SW monsoons and between these monsoons.

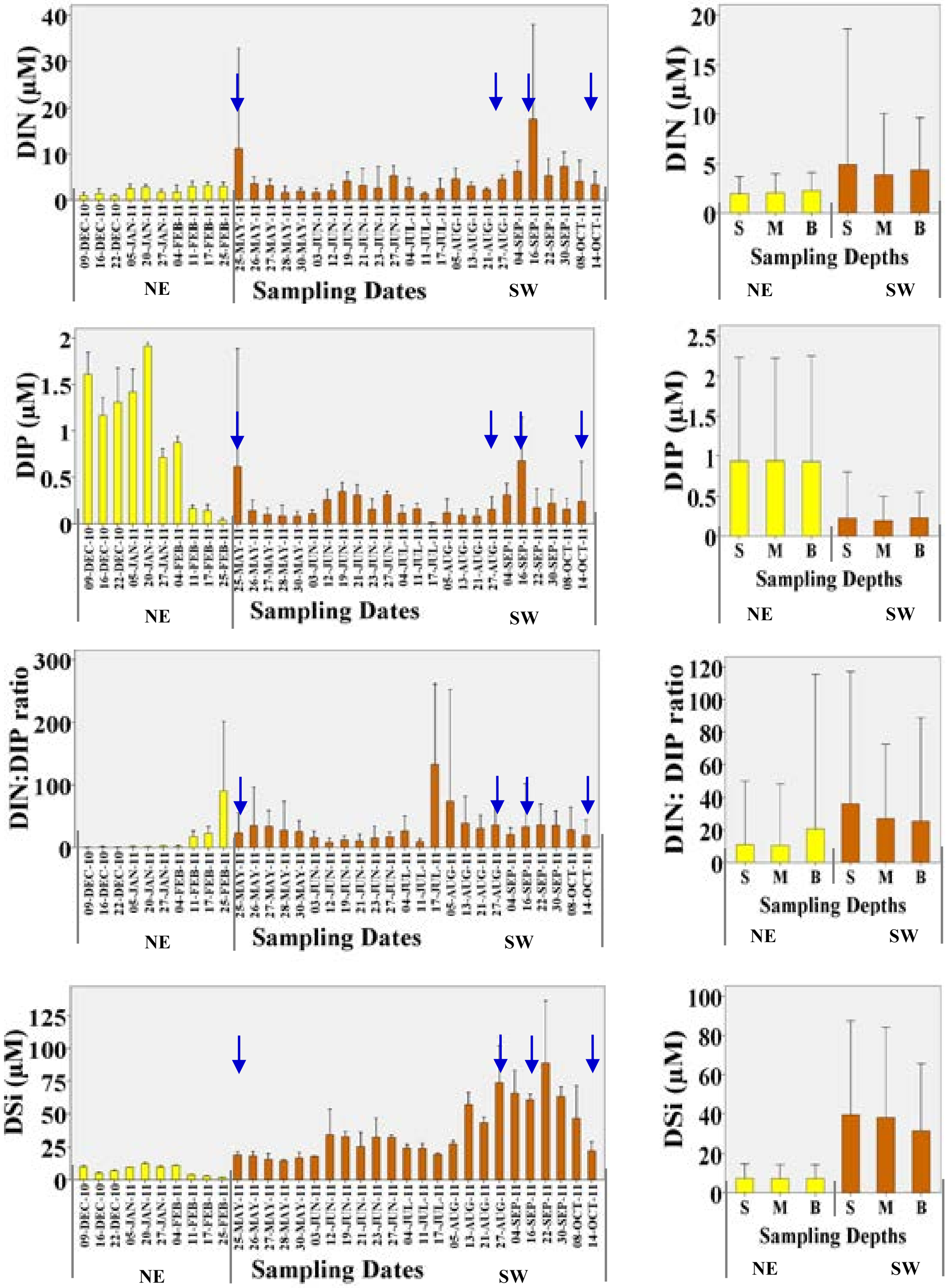
Mean of DSi in the SW monsoon was obviously higher than in the NE monsoon (about 5 times). This corresponded with Buranapratheprat *et al.*, (2002a) and Sriwoon *et al.*, (2008). The reason that high concentrations of DSi were found in this period, because fresh water river discharge had rich DSi, comparing with marine water (Takahashi, 2003). Significant differences ($p < 0.05$) between means of DSi and means of the dominant phytoplankton densities (*Oscillatoria, Noctiluca* and *Ceratium*) in the SW monsoon were also observed. Surprisingly, these correlations presented a positive trend (CCA, Figures 4.19). Generally, a large amount of DSi was absorbed by diatoms for forming their cell walls (Takahashi, 2003), which all of these dominances were not. This large appearance might be DSi was unused and then remained in seawater column (Buranapratheprat *et al.*, 2010).

In the NE monsoon, mean DSi concentrations from the different three depths were around 7.23 µM to 7.36 µM (Figure 4.9). While in the SW monsoon, DSi values were about 31.74 µM to 39.37 µM. No significant differences ($p > 0.05$) were found within each monsoon. However, a significant difference ($p < 0.05$) was observed between different monsoons.



Note: ↓ *indicated red tide occurrence.*

Figure 4.8 Temporal variations in means of ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen in the coastal area of Ko Si Chang, Chon Buri province in December 2010 to October 2011.



Note: ↓ *indicated red tide occurrence.*

Figure 4.9 Temporal variations in means of DIN, DIP, DIN: DIP ratio and DSi in the coastal area of Ko Si Chang, Chon Buri province in December 2010 to October 2011.

G) Chlorophyll *a*

Total chlorophyll *a*

Mean of total chlorophyll *a* in the NE monsoon was 1.51mg m^{-3} (Table 4.2) with the minimum and maximum values of 0.60 mg m^{-3} and 3.02 mg m^{-3}. In the SW monsoon, the values ranged between 0.73 mg m^{-3} and 61.41 mg m^{-3} with a mean of 5.44 $\pm$ 8.30 mg m^{-3}. There were significant differences ($p < 0.05$) among sampling dates within each monsoon and between different monsoons. Due to the blooming of phytoplankton in the SW monsoon, it caused the highest phytoplankton density which related to the total chlorophyll *a* concentration during this period. This result corresponded with Horabun (1997).

Mean values of total chlorophyll *a* from different three depths in the NE monsoon were around 1.39 mg m^{-3} and 1.66 mg m^{-3} (Figure 4.10). While in the SW monsoon, these values ranged from 3.87 mg m^{-3} to 7.04 mg m^{-3}. No significant differences ($p > 0.05$) were found among sampling depths within each monsoon. However, there was a significant difference ($p < 0.05$) between different monsoons.

Microphytoplanktonic fraction of chlorophyll *a*

Microphytoplanktonic fraction of chlorophyll *a* (20-200 µm) in the NE monsoon had a mean value of 0.71 $\pm$ 0.27 mg m^{-3} (Table 4.2) with the values ranged from 0.03 mg m^{-3} to 1.25 mg m^{-3}. In the SW monsoon, mean value of 20-200 µm chlorophyll *a* was 2.58 $\pm$ 5.04 mg m^{-3} with the lowest and the highest values of 0.01 mg m^{-3} and 28.82 mg m^{-3}, respectively. There were significant differences ($p < 0.05$) from different sampling dates within each monsoon and between different monsoons.

In the NE monsoon, 20-200 µm chlorophyll *a* had mean values around 0.62 to 0.79 mg m^{-3} (Figure 4.10). In the SW monsoon, these values ranged from 1.86 mg m^{-3} to 3.29 mg m^{-3}. There were not significant differences ($p > 0.05$) among sampling depths within each monsoon. However, a significant difference ($p < 0.05$) was found between different monsoons.

Nano-and Picophytoplanktonic fractions of chlorophyll *a*

Mean value of nano- and picophytoplanktonic fractions of chlorophyll *a* (< 20 µm) in the NE monsoon was 0.83 $\pm$ 0.33 mg m^{-3} (Table 4.2) with the values ranged between 0.39 mg m^{-3} and 1.97 mg m^{-3} with no significant difference ($p > 0.05$). However, a significant difference ($p < 0.05$) was found in the SW monsoon, which a mean value was 2.96 $\pm$ 4.32 mg m^{-3} and the values ranged between 0.13 mg m^{-3} and 37.38 mg m^{-3}. When comparing between different monsoons, a difference among sampling dates was significant ($p < 0.05$).

In the NE monsoon, < 20 µm chlorophyll *a* values from different three depths were around 0.78 mg m^{-3} to 0.88 mg m^{-3} (Figure 4.10) with no significant difference ($p > 0.05$). However, a significant difference ($p < 0.05$) was found in the SW monsoon, with the lowest value at bottom (2.00 mg m^{-3}) and the highest value at surface (3.95 mg m^{-3}). A significant difference ($p < 0.05$) among sampling depths also was found between different monsoons.

H) Chlorophyll *b*

Total chlorophyll *b*

In the NE monsoon, mean of total chlorophyll *b* concentration was 0.34 $\pm$ 0.17 mg m^{-3}) (Table 4.2) and the values ranged from 0.02 mg m^{-3} to 0.77 mg m^{-3} with no significant difference ($p > 0.05$). While in the SW monsoon, had a mean value of 0.83 $\pm$ 2.33 mg m^{-3} with the lowest and the highest values of 0.02 mg m^{-3} and 22.44 mg m^{-3}, respectively. Significant differences ($p < 0.05$) among sampling dates were found within the SW monsoon and between the NE and the SW monsoons.

Mean of total chlorophyll *b* concentrations among three depths in the NE monsoon were about 0.31 mg m^{-3} to 0.37 mg m^{-3} (Figure 4.11). While these values in the SW monsoon ranged between 0.56 mg m^{-3} and 1.28 $\pm$ 0.62 mg m^{-3}, respectively. No significant differences ($p > 0.05$) were observed within each monsoon. However, a significant difference ($p < 0.05$) among sampling depths between different monsoons was found.

Microphytoplanktonic fraction of chlorophyll *b*

Microphytoplanktonic fraction of chlorophyll *b* (20-200 µm) in the NE monsoon had a mean value of 0.24 $\pm$ 0.15 mg m^{-3} (Table 4.2) with the minimum and the maximum values of 0.02 mg m^{-3} and 0.57 mg m^{-3}, respectively. In the SW monsoon, a mean value was 0.19 $\pm$ 0.15 mg m^{-3} with the values ranged from 0.001 mg m^{-3} to 0.66 mg m^{-3}. There were not significant differences ($p > 0.05$) among sampling dates within each monsoon and between different monsoons.

Mean of 20-200 µm chlorophyll *b* concentrations among three depths in the NE monsoon ranged between 0.19 mg m^{-3} and 0.28 mg m^{-3} (Figure 4.11). While these values in the SW monsoon were around 0.15 mg m^{-3} and 0.22 mg m^{-3}. No significant differences ($p > 0.05$) were found within each monsoon and between different monsoons.

Nano- and picophytoplanktonic fractions of chlorophyll *b*

The lowest and the highest concentrations of nano- and picophytoplanktonic fractions of chlorophyll *b* (< 20 µm) in the NE monsoon were 0.01 mg m^{-3} and 0.77 mg m-3, respectively with a mean value of 0.17 $\pm$ 0.16 mg m^{-3} (Table 4.2), no significant difference ($p > 0.05$) was found from this period. While a significant difference ($p > 0.05$) was found in the SW monsoon, mean value of < 20 µm chlorophyll *b* was 0.74 $\pm$ 2.30 mg m^{-3} with the values ranged between 0.02 mg m^{-3} and 22.44 mg $m^{-3.}$ When comparing the difference among sampling dates between different monsoons, the significance ($p < 0.05$) was found.

In the NE monsoon, mean values of < 20 µm chlorophyll *b* among three depths were around 0.09 mg m^{-3} and 0.18 mg m^{-3} (Figure 4.11). While these values in the SW monsoon ranged between 0.44 mg m^{-3} and 1.74 mg m^{-3}. No significant differences ($p > 0.05$) were found within each monsoon. However, a significant difference ($p < 0.05$) was found among sampling depths between different monsoons.

I) Chlorophyll *c*

Total chlorophyll *c*

The lowest and the highest concentrations of total chlorophyll *c* in the NE monsoon were 0.14 mg m^{-3} and 5.76 mg m^{-3}, respectively with a mean value of 1.69 $\pm$ 1.06 mg m^{-3} (Table 4.2). No significant difference ($p > 0.05$) was found in the NE monsoon. In the SW monsoon, total chlorophyll *c* concentrations had a mean value of = 3.82 $\pm$ 5.23 mg m^{-3} with the values ranged between 0.05 mg m^{-3} and 39.67 mg m^{-3}. There were significant differences ($p < 0.05$) among sampling dates within the SW monsoon and between the NE and the SW monsoons.

In the NE monsoon, mean values of total chlorophyll *c* among three depths were around 1.63 mg m^{-3} and 1.74 mg m^{-3} (Figure 4.12). While in the SW monsoon, these values were around 3.33 mg m^{-3} and 4.52 mg m^{-3}. There were not significant differences ($p > 0.05$) among sampling depths within each monsoon. However, a significant difference ($p < 0.05$) was found between different monsoons.

Microphytoplanktonic fraction of chlorophyll *c*

Mean value of microphytoplanktonic fraction of chlorophyll *c* (20-200 µm) in the NE monsoon was 0.76 $\pm$ 0.74 mg m^{-3} (Table 4.2), with the values ranged from 0.03 mg m^{-3} to 3.66 mg m^{-3} with no significant difference ($p > 0.05$). In the SW monsoon, 20-200 µm chlorophyll *c* had a mean value of 3.67 $\pm$ 5.25 mg m^{-3} with the minimum and the maximum values of 0.05 mg m^{-3} and 31.43 mg m^{-3}, respectively. Significant differences ($p < 0.05$) among sampling dates were found within the SW monsoon and between the NE and the SW monsoons.

In the NE monsoon, mean values of 20-200 µm chlorophyll *c* among sampling depths ranged from 0.58 mg $m^{-3}$and 0.98 mg m^{-3} (Figure 4.12). In the SW monsoon, these values were around 2.76 mg m^{-3} and 4.49 mg m^{-3}. There were not significant differences ($p > 0.05$) within each monsoon. However, a significant difference ($p < 0.05$) among sampling depths was found between different monsoons.

Nano- and picophytoplanktonic fractions of chlorophyll *c*

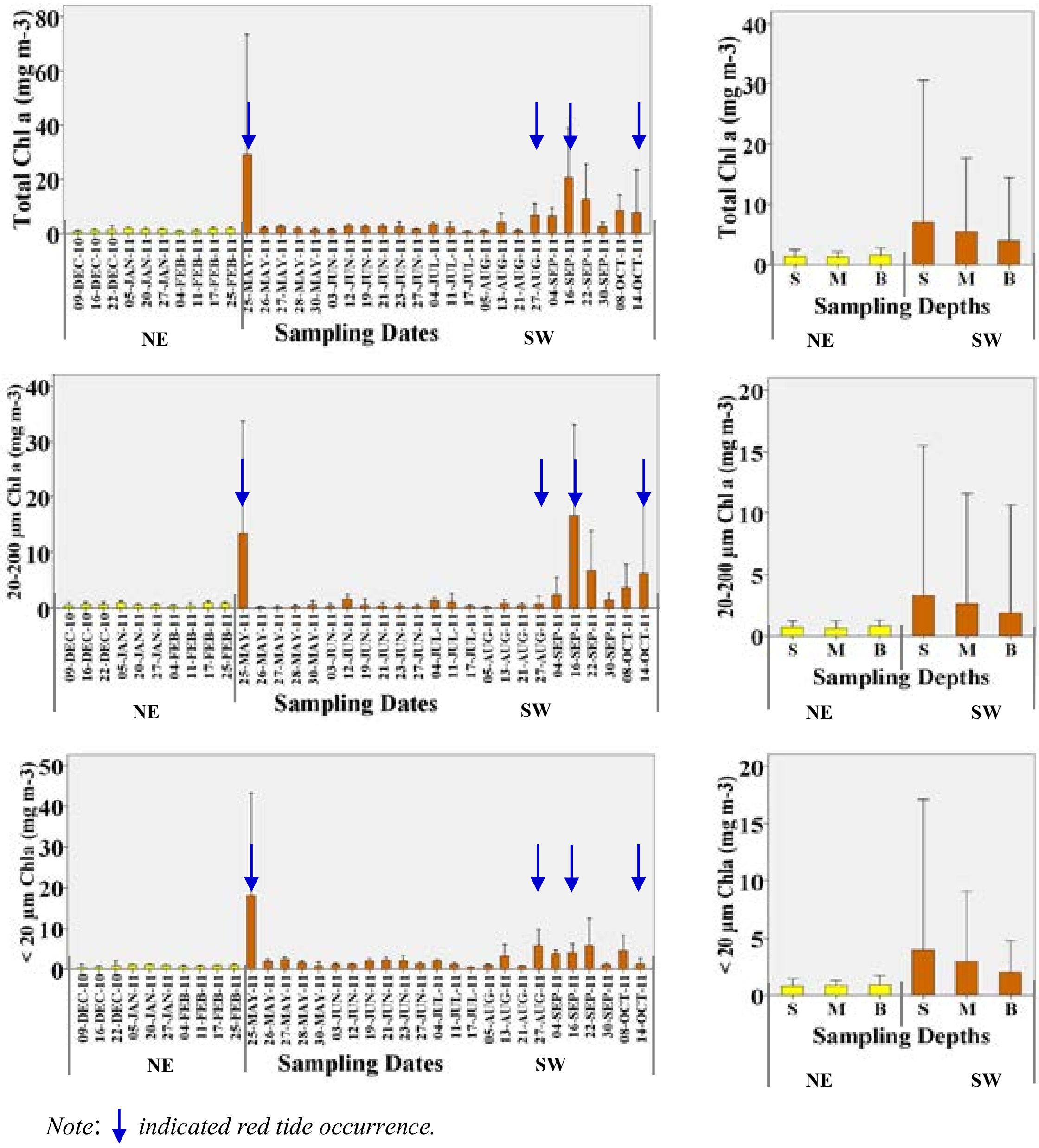
Mean value of nano- and picophytoplanktonic fractions of chlorophyll *c* (< 20 µm) in the NE monsoon was 1.12 ± 1.02 mg m^{-3} with the values ranged from 0.34 mg m^{-3} to 5.76 mg m^{-3} (Table 4.2). In the SW monsoon, < 20 µm chlorophyll *c* concentrations had a mean value of 1.62 ± 1.69 mg m^{-3} with the values ranged between 0.02 mg m^{-3} and 8.28 mg m^{-3}. Significant differences ($p < 0.05$) were found among sampling dates within each monsoon and between different monsoons.

In the NE monsoon, mean values of < 20 µm chlorophyll *c* concentrations among three depths were around 0.95 mg m^{-3} and 1.30 mg m^{-3} (Figure 4.12). In the SW monsoon, these values were around 1mg m^{-3} and 1.47 mg m^{-3}. No significant differences ($p > 0.05$) were found within each monsoon. However, a significant different ($p < 0.05$) was found among sampling depths between different monsoons.

Due to the increasing of dissolved inorganic nutrients especially DIN: DIP ratio, it resulted in the increasing of phytoplankton biomass (Junchompoo *et al.*, 2006) in forms of total-, micro-, nano- and picophytoplanktonic fractions of chlorophyll *a*, *b* and *c* concentrations. Which the result could be seen obviously in the SW monsoon.

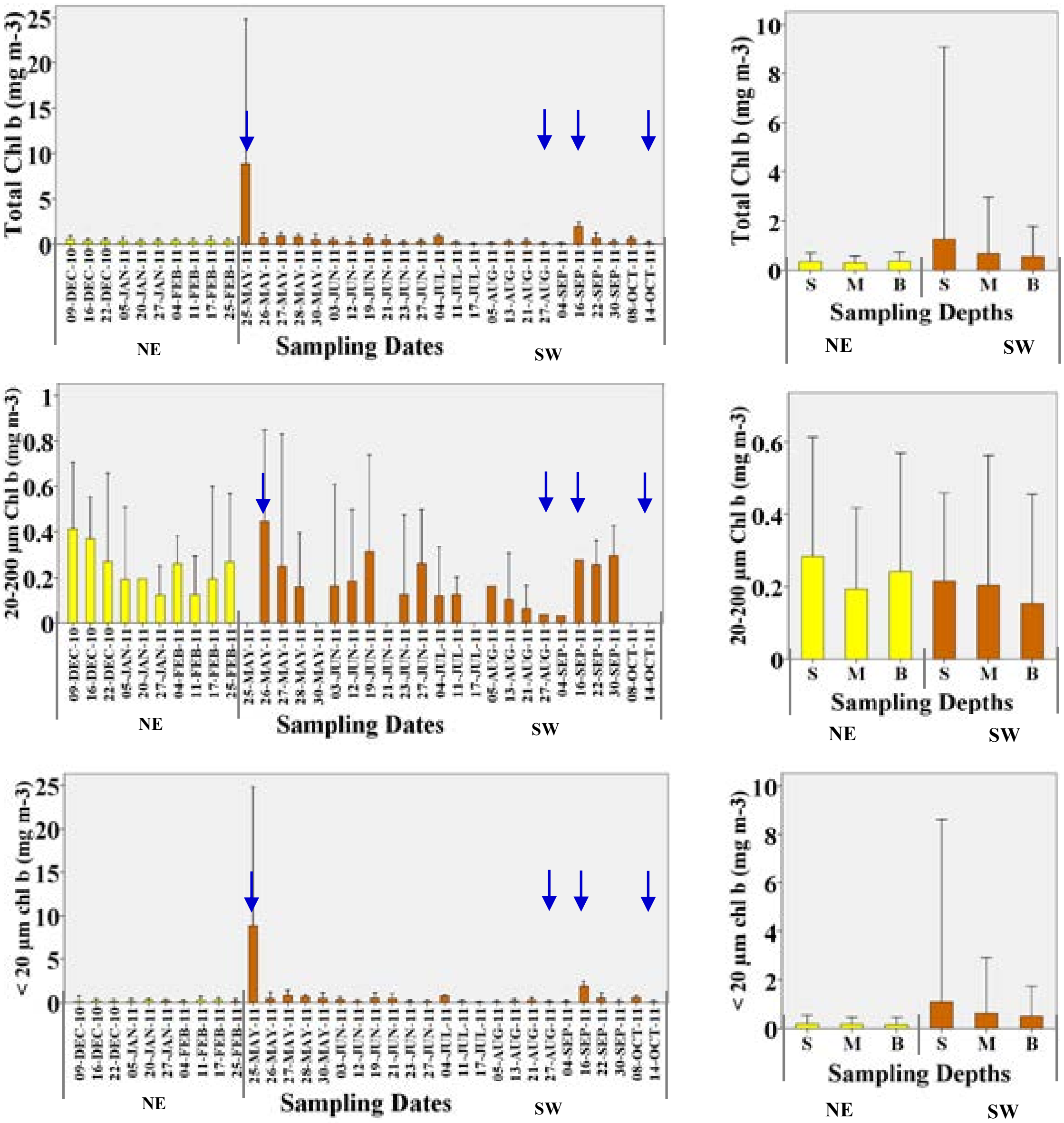
Table 4.2 Means of chlorophyll *a, b* and *c* in the coastal area of Ko Si Chang, Chon Buri province.

Environmental parameters	December 2010-October 2011		Monsoons		Depths		
			Northeast	Southwest	Surface	Middle	Bottom
	Mean ± SD	Range	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Total Chl *a* (mg m^{-3})	4.28 ± 7.19	0.60-61.4	1.51 ± 0.48	5.44 ± 8.30	5.40 ± 10.2	4.22 ± 5.50	3.22 ± 4.55
20-200µm Chl *a* (mg m^{-3})	2.03 ± 4.31	0.01-28.8	0.71 ± 0.27	2.58 ± 5.04	2.50 ± 5.21	2.06 ± 3.89	1.55 ± 3.70
< 20 µm Chl *a* (mg m^{-3})	2.33 ± 3.76	0.13-37.4	0.83 ± 0.33	2.96 ± 4.32	3.02 ± 5.71	2.31 ± 2.77	1.67 ± 1.29
Total Chl *b* (mg m^{-3})	0.68 ± 1.97	0.02-22.4	0.34 ± 0.17	0.83 ± 2.33	0.99 ± 3.25	0.57 ± 0.98	0.51 ± 0.54
20-200 µm Chl *b* (mg m^{-3})	0.21 ± 0.15	0.01-0.66	0.24 ± 0.15	0.19 ± 0.15	0.24 ± 0.14	0.20 ± 0.15	0.20 ± 0.16
< 20 µm Chl *b* (mg m^{-3})	0.57 ± 1.95	0.01-22.4	0.17 ± 0.16	0.74 ± 2.30	0.82 ± 3.18	0.48 ± 0.1	0.40 ± 0.55
Total Chl *c* (mg m^{-3})	3.17 ± 4.51	0.05-39.7	1.69 ± 1.06	3.82 ± 5.23	3.51 ± 4.76	3.21 ± 3.94	2.83 ± 4.82
20-200 µm Chl *c* (mg m^{-3})	2.63 ± 4.45	0.03-31.4	0.76 ± 0.74	3.67 ± 5.25	3.16 ± 4.52	2.88 ± 4.10	1.98 ± 4.69
< 20 µm Chl *c* (mg m^{-3})	1.47 ± 1.54	0.02-8.28	1.12 ± 1.02	1.62 ± 1.69	1.53 ± 1.63	1.36 ± 1.37	1.52 ± 1.63



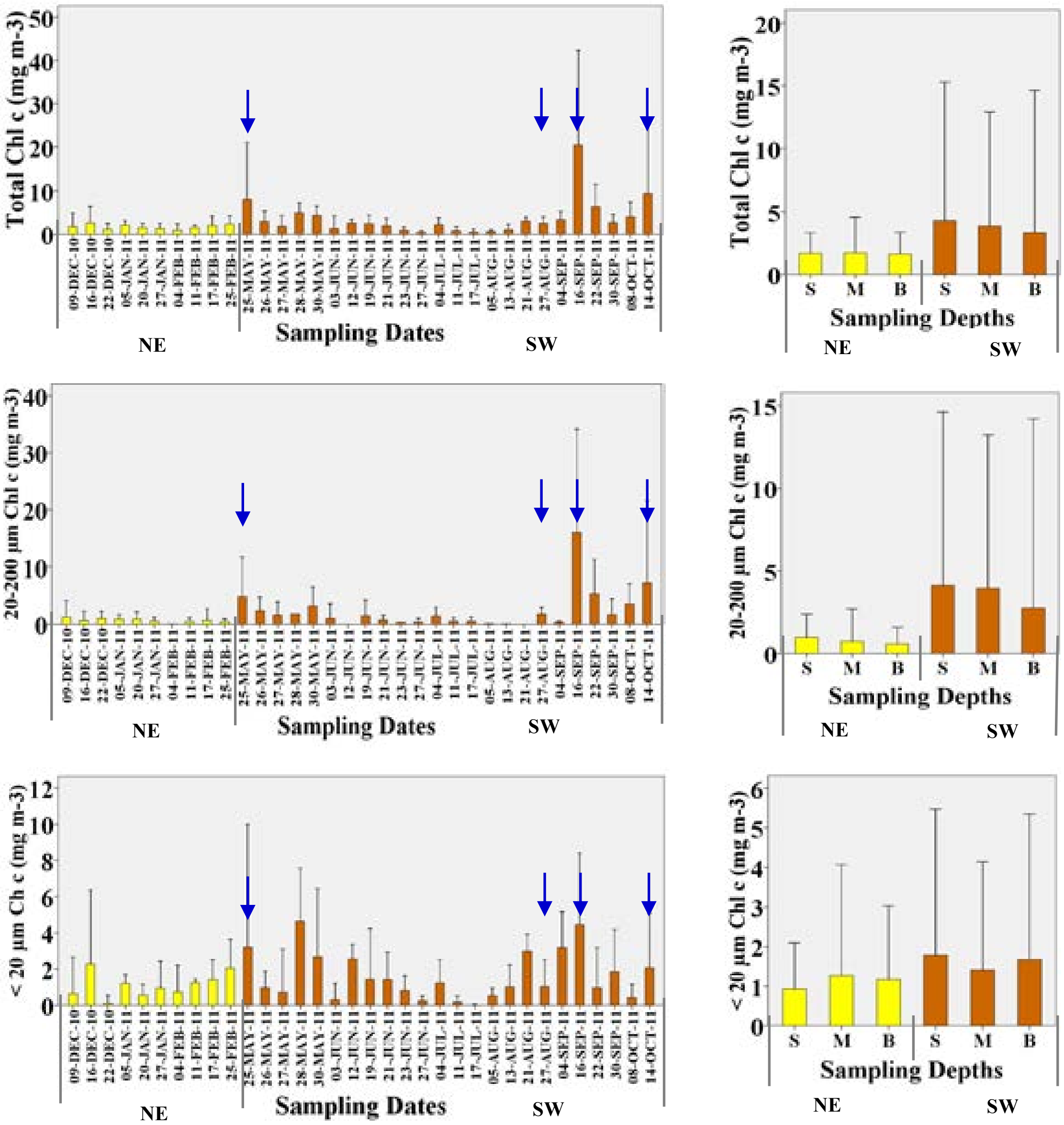
Note: ↓ *indicated red tide occurrence.*

Figure 4.10 Temporal variations in means of total-, 20-200 µm-, < 20 µm chlorophyll *a* in the coastal area of Ko Si Chang, Chon Buri province in December 2010 to October 2011.



Note: ↓ *indicated red tide occurrence.*

Figure 4.11 Temporal variations in means of total-, 20-200 µm-, < 20 µm chlorophyll *b* in the coastal area of Ko Si Chang, Chon Buri province in December 2010 to October 2011.



Note: ↓ *indicated red tide occurrence.*

Figure 4.12 Temporal variations in means of total-, 20-200 µm-, < 20 µm chlorophyll *c* in the coastal area of Ko Si Chang, Chon Buri province in December 2010 to October 2011.

4.3.2 Phytoplankton

A) Phytoplankton communities

From December 2010 to October 2011, phytoplankton samples were classified to 64 genera (the NE monsoon = 53 genera and the SW monsoon = 60 genera) (Table 4.3).

Most of the genera in the NE monsoon belonged to diatoms (37 genera, 65.52%), followed by cyanobacteria (2 genera, 34.15%), dinoflagellates (13 genera, 0.26%) and silicoflagellate (1 genus, 0.06%) (Figure 4.13). In the NE monsoon, the most dominated genus was *Oscillatoria* (27.29%) which had the highest density on 25th February 2011. Other dominant genera were *Thalassionema* (16.45%), *Chaetoceros* (14.75%) and *Bacteriastrum* (13.70%) (Table 4.3 and Figure 4.14). Boonyaphiwat *et al*., (1998) also recorded that dominant phytoplankton in the GoT in the NE monsoon were *Oscillatoria*, *Chaetoceros*, *Coscinodiscus*, *Proboscia* and *Thalassionema*. Saosee (2004) also found that *Oscillatoria* and *Chaetoceros* were in high abundance at Bang Pra coastal area, Chon Buri province. Moreover, Khwaiphan (2005) reported that the dominant phytoplankton genus at Bang Pakong river mouth in dry and wet season was *Oscillatoria.*

In wet season, the most group were cyanobacteria (2 genera, 59.34%), dinoflagellates (17 genera, 24.56%), diatoms (40 genera, 16.10%) and silicoflagellate (1 genus, 0.01%) (Figure 4.13). The most dominated genus in the SW monsoon was *Oscillatoria* (59.17%) as same as Boonyaphiwat (1997) and Khwaiphan (2005). Which the highest value was observed on 16th September 2011. The other dominant genera were *Ceratium* (23.17%), *Skeletonema* (9.02%), and *Noctiluca* (0.74%; very low density but high in cell volume; 200 to 2,000 μm in diameter, formed bloom) (Table 4.3 and Figure 4.15).

In the SW monsoon, red tides were found many times which occurred from *Noctiluca scintillans* (25th, 26th, 27th and 28th May 2011), *Skeletonema costatum* (27th August 2011) and *Ceratium furca* (16th September 2011and 14th October 2011). This study corresponded with Saosee (2004) reported that there were 12 times of red tides during the SW monsoon in the coastal area of Bang Pra, Chon Buri province, which came from the blooming of *Noctiluca scintillans*, *Ceratium furca* and diatoms.

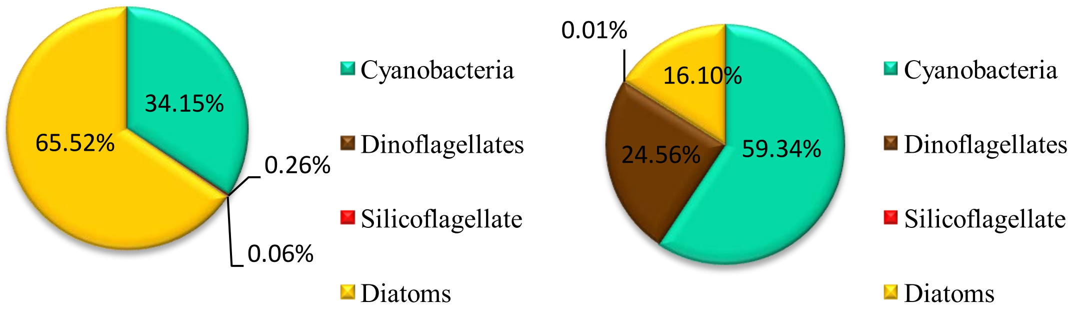
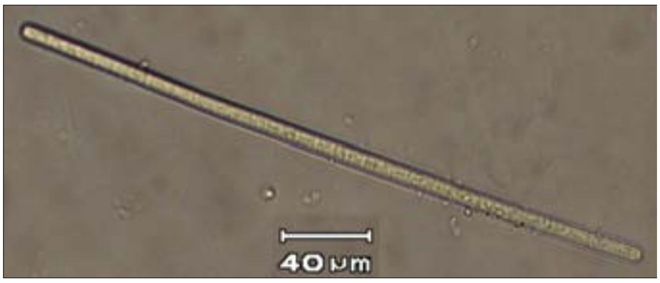
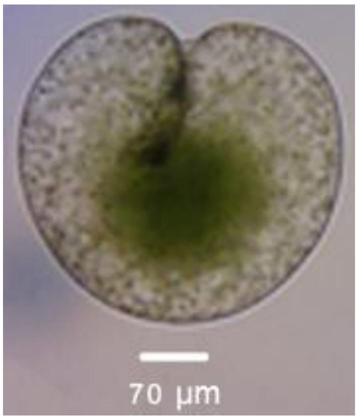


Figure 4.13 Phytoplankton genera recorded in the NE (left) and the SW (right) monsoons in the coastal area of Ko Si Chang, Chon Buri province.

Figure 4.14 Dominant phytoplankton in the NE monsoon in the coastal area of Ko Si Chang, Chon Buri province

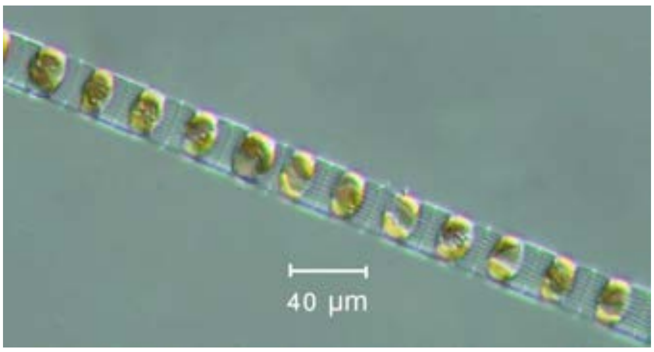


Oscillatoria sp.



Noctiluca scintillans

Ceratium furca



Skeletonema costatum

Figure 4.15 Dominant phytoplankton in the SW monsoonin the coastal area of Ko Si Chang, Chon Buri province.

Table 4.3 Phytoplankton genera recorded in the coastal area of Ko Si Chang, Chon Buri province in December 2010 to October 2011 showing relative contribution (%) to the total count by Monsoons and depths and diversity values.

Phytoplankton genera			Monsoons		Depths		
	Mean of cell density (10^3cell/l)	%	Northeast %	Southwest %	Surface %	Middle %	Bottom %
Oscillatoria	**124.9**	**55.5**	**27.3**	**59.2**	**54.9**	**56.6**	**54.9**
Pseudanabaena	2.112	0.94	6.87	0.16	0.73	0.92	1.34
Prorocentrum	0.554	0.25	0.09	0.27	0.20	0.25	0.34
Dinophysis	0.172	0.08	0.00	0.09	0.05	0.08	0.12
Ornithocercus	0.000	0.00	0.00	0.00	0.00	0.00	0.00
Phalacroma	0.021	0.01	0.00	0.01	0.01	0.01	0.01
Gymnodinium	0.001	0.00	0.00	0.00	0.00	0.00	0.00
Gyrodinium	0.006	0.00	0.00	0.00	0.00	0.00	0.01
Noctiluca scintillans	**1.472**	**0.65**	**0.00**	**0.74**	**1.06**	**0.34**	**0.42**
Ceratium	**46.14**	**20.5**	**0.09**	**23.2**	**18.2**	**21.1**	**23.8**
Cladopyxis	0.000	0.00	0.00	0.00	0.00	0.00	0.00
Alexandrium	0.000	0.00	0.00	0.00	0.00	0.00	0.00
Gonyaulax	0.007	0.00	0.00	0.00	0.00	0.00	0.00
Oxytoxum	0.000	0.00	0.00	0.00	0.00	0.00	0.00
Pyrocystis	0.001	0.00	0.00	0.00	0.00	0.00	0.00
Pyrophacus	0.012	0.01	0.01	0.01	0.00	0.01	0.00
Scrippsiella	0.010	0.00	0.01	0.00	0.00	0.00	0.01
Diplopsalis	0.001	0.00	0.00	0.00	0.00	0.00	0.00
Podolampas	0.000	0.00	0.00	0.00	0.00	0.00	0.00
Protoperidinum	0.539	0.24	0.07	0.26	0.16	0.27	0.34
Dictyocha	0.036	0.02	0.06	0.01	0.01	0.02	0.02
Cyclotella	0.100	0.04	0.10	0.04	0.07	0.02	0.04
Detonula	0.049	0.02	0.12	0.01	0.04	0.01	0.01

Phytoplankton genera	Mean of cell density		Monsoons		Depths		
			Northeast	Southwest	Surface	Middle	Bottom
	(10^3cell/l)	%	%	%	%	%	%
Lauderia	0.647	0.29	1.31	0.15	0.34	0.24	0.26
Planktoniella	0.000	0.00	0.00	0.00	0.00	0.00	0.00
Skeletonema	**17.98**	**7.99**	**0.13**	**9.02**	**7.75**	**10.6**	**4.37**
Thalassiosira	2.270	1.01	1.27	0.98	0.87	1.01	1.27
Melosira	0.002	0.00	0.00	0.00	0.00	0.00	0.00
Palaria	0.038	0.02	0.08	0.01	0.01	0.01	0.04
Corethron	0.010	0.00	0.03	0.00	0.00	0.00	0.01
Coscinodiscus	0.077	0.03	0.06	0.03	0.03	0.03	0.05
Asteromphalus	0.000	0.00	0.00	0.00	0.00	0.00	0.00
Rhizosolenia	0.691	0.31	0.52	0.28	0.39	0.20	0.33
Guinardia	0.378	0.17	1.41	0.01	0.16	0.15	0.22
Ceratualina	0.003	0.00	0.00	0.00	0.00	0.00	0.01
Climacodium	0.000	0.00	0.00	0.00	0.00	0.00	0.00
Eucampia	0.017	0.01	0.06	0.00	0.01	0.01	0.01
Hemiaulus	0.233	0.10	0.64	0.03	0.11	0.08	0.13
Bacteriastrum	**4.791**	**2.13**	**13.7**	**0.62**	**2.27**	**1.67**	**2.59**
Chaetoceros	**11.59**	**5.15**	**14.7**	**3.90**	**8.99**	**2.41**	**2.45**
Bellerochea	0.000	0.00	0.00	0.00	0.00	0.00	0.00
Ditylum	0.006	0.00	0.01	0.00	0.00	0.00	0.00
Helicotheca	0.002	0.00	0.00	0.00	0.00	0.00	0.00
Odontella	0.048	0.02	0.10	0.01	0.02	0.02	0.03
Asterionellopsis	0.000	0.00	0.00	0.00	0.00	0.00	0.00
Thalassionema	**4.943**	**2.20**	**16.4**	**0.33**	**1.71**	**1.97**	**3.43**
Thalassiotrix	0.060	0.03	0.18	0.01	0.02	0.02	0.04
Meuniera	0.087	0.04	0.00	0.04	0.05	0.03	0.03

Phytoplankton genera			Monsoons		Depths		
	Mean of cell density		Northeast	Southwest	Surface	Middle	Bottom
	(10^3cell/l)	%	%	%	%	%	%
Navicula	0.088	0.04	0.28	0.01	0.03	0.03	0.06
Bacillaria	0.863	0.38	3.09	0.03	0.27	0.32	0.68
Cylindrotheca	0.159	0.07	0.40	0.03	0.05	0.05	0.13
Fragilariopsis	0.040	0.02	0.15	0.00	0.01	0.02	0.04
Pseudo-nitzschia	2.416	1.07	5.56	0.49	1.08	0.91	1.32
Triceratium	0.001	0.00	0.00	0.00	0.00	0.00	0.00
Biddulphia	0.001	0.00	0.00	0.00	0.00	0.00	0.00
Trigonium	0.000	0.00	0.00	0.00	0.00	0.00	0.00
Licmophora	0.020	0.01	0.00	0.01	0.01	0.01	0.01
Diploneis	0.004	0.00	0.01	0.00	0.00	0.00	0.00
Gyrosigma/Pleurosigma	1.186	0.53	4.17	0.05	0.37	0.46	0.91
Amphora	0.026	0.01	0.08	0.00	0.01	0.01	0.02
Nitzschia	0.118	0.05	0.42	0.00	0.04	0.04	0.08
Entomoneis	0.054	0.02	0.20	0.00	0.02	0.02	0.04
Surirella	0.075	0.03	0.25	0.01	0.02	0.02	0.07
Campylodiscus	0.000	0.00	0.00	0.00	0.00	0.00	0.00
Total phytoplankton density (10^3 cell/l)	91808		10612	81196	38108	32687	21013
Number of genera	64		53	60	55	58	60
Mean cell density (10^3 cell/l)	225		88.4	283	280	240	155
Standard deviation ($\pm$) of mean	384		51.8	444	418	413	303
Shannon-Wiener diversity index (*H′*)	1.66		2.89	1.14	1.56	1.58	1.82
Standard deviation ($\pm$) of *H′*	1.02		0.34	0.73	1.03	1.01	1.02
Pielou evenness index (*J′*)	0.37		0.59	0.28	0.35	0.36	0.41
Standard deviation ($\pm$) of *J′*	0.20		0.07	0.16	0.20	0.19	0.20

Note: the red letters indicated the dominant phytoplankton.

B) Phytoplankton density, diversity index and evenness index.

Phytoplankton density

Phytoplankton density (Table 4.3 and Figure 4.16) in the NE monsoon (mean = 0.89 $\pm$ 0.52 x 10^5 cell l^{-1}) ranged between 0.37 x 10^5 cell l^{-1} and 2.49 x 10^5 cell l^{-1}. In the SW monsoon, this value ranged from 0.12 x 10^5 cell l^{-1} to 25.46 x 10^5 cell l^{-1} with a mean of 2.82 $\pm$ 4.44 x 10^5 cell l^{-1}. There were significant differences ($p < 0.05$) within each monsoon and between different monsoons.

At S, M and B levels, phytoplankton densities in the NE monsoon were 1.00 $\pm$ 0.63 x 10^5 cell l^{-1}, 0.88 $\pm$ 0.51 x 10^5 cell l^{-1} and 0.78 $\pm$ 0.38 x 10^5 cell l^{-1}, respectively (Figure 4.16) with no significant difference ($p > 0.05$). While these values in the SW monsoon were 3.55 $\pm$ 4.77 x 10^5 cell l^{-1}, 3.04 $\pm$ 4.77 x 10^5 cell l^{-1} and 1.86 $\pm$ 3.55 x 10^5 cell l^{-1}, respectively. Significant differences ($p < 0.05$) were found within the SW monsoon and between the NE and the SW monsoons.

Because of the frequency of red tides in the SW monsoon, high densities of phytoplankton were found in this period especially on seawater surface. Takahashi (2003) suggested that many algal growths depend on photosynthesis so phytoplankton must increase rate of light absorption as much as possible by distributed on surface layer.

Phytoplankton diversity index

Phytoplankton diversity index or Shannon–Wiener diversity index (Table 4.3 and Figure 4.16) during the NE monsoon (mean = 2.89 $\pm$ 0.34) had the lowest and the highest values of 1.92 and 3.47, respectively. While this index in the SW monsoon (mean = 1.14 $\pm$ 0.73) ranged from 0.08 to 3.81. Significant differences ($P < 0.05$) were found within each monsoon and between different monsoons.

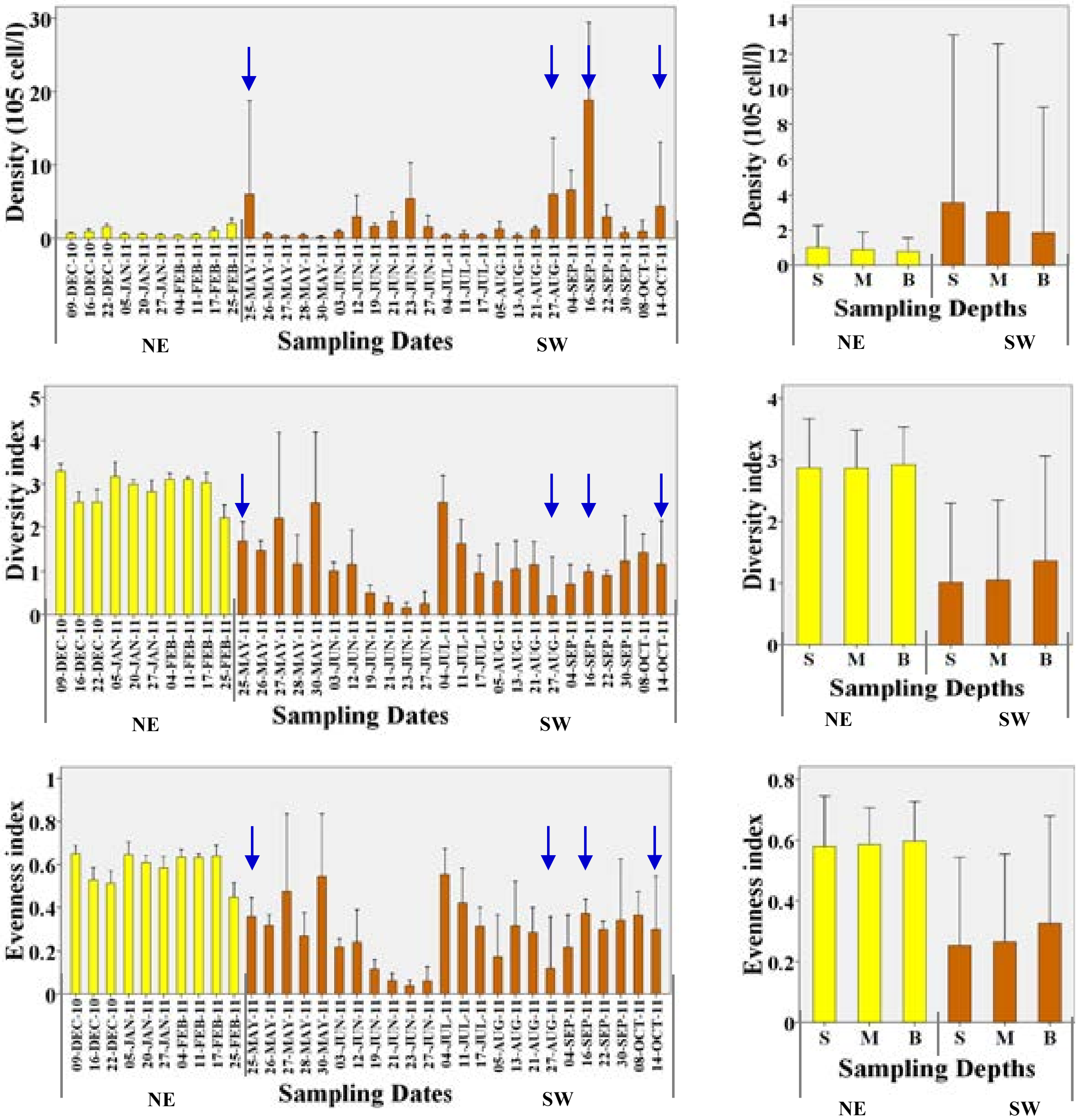
In the NE monsoon, phytoplankton diversity indices at S, M and B levels were 2.87 $\pm$ 0.40, 2.87 $\pm$ 0.31 and 2.92 $\pm$ 0.31, respectively (Figure 4.16) with no significant difference ($P > 0.05$). In the SW monsoon, these indices were 1.01 $\pm$ 0.64, 1.05 $\pm$ 0.65 and 1.36 $\pm$ 0.85, respectively. There were significant differences ($P < 0.05$) within the SW monsoon and between the NE and the SW monsoons.

Phytoplankton evenness index

Phytoplankton evenness index or Pielou evenness index (Table 4.3 and Figure 4.16) in the NE monsoon had the minimum and the maximum values of 0.37 and 0.68, respectively with a mean of 0.59 $\pm$ 0.07. This index in the SW monsoon (mean = 0.28 $\pm$ 0.16) ranged from 0.02 to 0.77. Significant differences ($P < 0.05$) within each monsoon and between different monsoons were observed.

At S, M and B levels, Phytoplankton evenness indices in the NE monsoon were 0.58 $\pm$ 0.08, 0.59 $\pm$ 0.06 and 0.60 $\pm$ 0.07, respectively (Figure 4.16) with no significant difference ($P > 0.05$) . These indices in the SW monsoon were 0.25 $\pm$ 0.15, 0.26 $\pm$ 0.14 and 0.33 $\pm$ 0.18, respectively. The differences within the SW monsoon and between the NE and the SW monsoons were significantly ($P < 0.05$).

Red tides also influenced on diversity index and evenness index, due to these values were calculated from the count number of each genus and total count number of all genera in the communities. High values from both indices represent more diverse communities and more distribution. In the SW monsoon, the count number of each genus had wide range especially from the blooming genera in red tides. So diversity index and evenness index were lower than in the NE monsoon.



Note: ↓ *indicated red tide occurrence.*

Figure 4.16 Temporal variations in means of phytoplankton density, diversity index and evenness index in the coastal area of Ko Si Chang, Chon Buri province in December 2010 to October 2011.

C) Succession pattern of phytoplankton communities

During the NE monsoon

During the NE monsoon (December 2010 to February 2011), phytoplankton succession pattern was divided into three phases with the changes of *Bacteriastrum, Thalassionema and Oscillatoria*.

The first phase

During the early NE monsoon period (9^{th} to 22^{nd} December 2010), the dominant phytoplankton genera were represented by *Bacteriastrum* at a concentration of 0.37 x 10^5 cell l^{-1}, representing 35.36% dominance of total cell density, *Chaetoceros* (0.26 x 10^5 cell l^{-1}, 24.16%) and *Oscillatoria* (0.14 x 10^5 cell l^{-1}, 13.41%) (Figure 4.17).

During this period, seawater was characterized by the high values of transparency (3.33 m), salinity (32.33 ppt), DO (7.18 ppm), DIP (1.36 µM) with low value of DIN: DIP ratio (0.84) (Appendix 4.1). These environmental parameters were the optimal seawater conditions for promoting the growth of *Bacteriastrum* and *Chaetoceros*. Which the correlations between these dominant phytoplankton and these environmental factors were confirmed by Canonical Correspondence Analysis (CCA, Figure 4.19). Inversely, when comparing with *Oscillatoria*, CCA showed the opposite correlations. When investigating the relationships between these three dominant phytoplankton by Pearson's correlation (Table 4.4). The result showed that *Bacteriastrum* had the positive relationship with *Chaetoceros* (0.407, $p < 0.05$), then these two dominances could co-occur at the same time with the same density. While *Bacteriastrum* had the negative relationship with *Oscillatoria* (-0.11), it resulted in the lower density of *Oscillatoria.*

The second phase

During the second phase (5^{th} January to 17^{th} February 2011), the dominant phytoplankton were replaced by *Thalassionema* (0.17 x 10^5 cell l^{-1}, 32.28%) and *Oscillatoria* (0.10 x 10^5 cell l^{-1}, 19.17%) with the decreasing of total phytoplankton densities (Figure 4.17). During this period, seawater had the increasing values of pH

(8.10), DIN (2.44 μM) and DIN: DIP ratio (8.01) (Appendix 4.1). The relationship between *Thalassionema* and *Oscillatoria* presented the negative value (-0.254) (Table 4.4).

The third phase

Finally, the third phase (25th February 2011), *Oscillatoria* (0.74×10^5 cell l^{-1}, 48.93%) succeeded by reaching to the peak in late NE monsoon period. The sub-dominances were *Thalassionema* (0.20×10^5 cell l^{-1}, 13.31%) and *Chaetoceros* (0.18×10^5 cell l^{-1}, 11.84%) (Figure 4.17).

During this period, seawater had the increasing value of DIN (2.93 μM) with the decreasing value of DIP (0.04 μM), then it caused the increasing of unbalanced DIN: DIP ratio (90.33) (Appendix 4.1). The highest value of DIN and DIN: DIP ratio during this phase caused the peak of *Oscillatoria*. The relationships between *Oscillatoria* and the environmental factors were also supported by CCA (Figure 4.18). Pearson's correlation (Table 4.4) showed the positive relationship between *Oscillatoria* and *Chaetoceros* (0.082), and also the relationship between *Thalassionema* and *Chaetoceros* (0.029).

This result indicated that the occurrence of *Oscillatoria* related to the unbalanced DIN: DIP ratio.

During the SW monsoon

During the SW monsoon (May to October 2011), five phases of phytoplankton succession pattern consisted of the blooming of *Noctiluca scintillans*, *Skeletonema costatum* and *Ceratium furca* with the co-occurrence of *Oscillatoria*.

The first phase

The first phase (25th May 2011), seawater color was green because of red tide occurrence from the blooming of *Noctiluca scintillans* at a concentration of 0.43×10^5 cell l^{-1}, representing 7.05% dominance of total cell density. The other dominances were *Oscillatoria* (2.80×10^5 cell l^{-1}, 46.22%) and *Chaetoceros* (2.27×10^5 cell l^{-1}, 37.47%) (Figure 4.18).

During this time, seawater condition was characterized by high values of pH (8.23), DIN (11.18 µM), DIP (0.61 µM) and unbalanced DIN: DIP (23.5) (Appendix 4.1). Due to the heavy rainfall on 23rd and 24th May, a large nutrient from freshwater river discharge was enhanced to the UGoT. Moreover, there was strong sunshine during this time. These suitable environmental conditions promoted the blooming of *Noctiluca scintillans* and *Oscillatoria*. The correlations between these dominant genera and the environmental factors were confirmed by CCA (Figure 4.19). Pearson's correlation (Table 4.4) showed the positive relationships between *Noctiluca scintillans* and *Oscillatoria* (0.118), and *Noctiluca scintillans* with *Chaetoceros* (0.971, $p < 0.01$). Then these three dominances could co-exist in the same time with the same densities.

The second phase

The second phase (3rd June to 4th July 2011), the dominant phytoplankton represented by the fluctuation of *Oscillatoria* with the peak of 5.35 x 10^5 cell l^{-1} or 98.61% on 23rd June 2011 (Figure 4.18). At this time, seawater condition had the values of DIN (2.58 µM), DIP (0.16 µM) and DIN: DIP (15.12) (Appendix 4.1).

The third phase

The third phase (27th August 2011), *Skeletonema costatum* was successfully with the highest density during this period of 5.87 x 10^5 cell l^{-1} or 97.10% (Figure 4.18). Due to the heavy rainfall occurred many times, which resulted in the dilution of salinity (18.83 ppt). Moreover, seawater condition had high values of pH (8.61), DIN (4.51 µM), unbalanced DIN: DIP (35.98) and silicate (73.67 µM) with low value of DIP (0.15) (Appendix 4.1). High values of inorganic nutrients and also the dilution of salinity supported the blooming of this species. Liu *et.al,* (2005) suggested that *Skeletonema costatum* can adapt in lower salinity better than other diatoms.

The fourth phase

The fourth phase (16th September 2011), seawater color was red brown due to the red tide occurrence from the blooming of *Ceratium furca* (7.14 x 10^5 cell l^{-1}, 37.84%). Another co-occurrence was *Oscillatoria* (11.15 x 10^5 cell l^{-1}, 61.39%), presented the highest density in the SW monsoon period (Figure 4.18). Because of the frequency of heavy rainfall during this time, it resulted in the high amount of freshwater river discharge inputted to the UGoT. During this time, seawater was characterized by the decreasing of salinity (22.50 ppt) with the increasing values pH (8.82), DIN (17.59 µM), DIP (0.67 µM), unbalanced DIN: DIP (33.1) and silicate (60.7 µM) (Appendix 4.1).

The fifth phase

The last phase (14^{th} October 2011), red tide from *Ceratium furca* also occurred, but in the lower density (3.50 x 10^5 cell l^{-1}, 79.55%) than the fourth phase. Another co-existing genus still was *Oscillatoria* (0.73 x 10^5 cell l^{-1}, 16.51%) (Figure 4.18). Due to the early October, there was Nal-Gae storm. Then the seawater was characterized by the high values of DIN (3.41 µM) and DIN: DIP (19.81) with the low value of DIP (0.20 µM) (Appendix 4.1).

This result indicated that the blooming of *Noctiluca scintillans*, *Skeletonema costatum* and *Ceratium furca* and also the co-occurrence of *Oscillatoria* related to the values of DIN and DIP especially to the unbalanced DIN: DIP ratio.

In the SW monsoon, red tides from the blooming of *Noctiluca scintillans*, *Ceratium furca* and *Skeletonema costatum*, was same result with Lirdwitayaprasit *et al*., (2006); reported that red tides in the UGot from June 2003 to November 2004 occurred from *Noctiluca scintillans* (9 times), *Ceratium furca* (7 times) and diatoms (4 times). Sriwoon *et al*., (2008) also found *Noctiluca* bloomed in the SW monsoon (2002 and 2003) and had low density in the NE monsoon. Normally, *Noctiluca* blooms in the tropical region appeared from green *Noctiluca*, caused brilliant greenish color on seawater surface (Sweeny, 1976).

This result indicated that *Noctiluca scintillans* dominated in the range of salinity (28 to 33 ppt). While optimal salt concentrations of *Ceratium furca* ranged between 10 and 32 ppt. Lirdwitayaprasit *et al.*, (2006) also reported that in the UGoT, red tides from *Noctiluca scintillans* always occurred in higher salinity values than red tides from *Ceratium furca*. Granéli *et al* (2008) suggested that When pH value in the coastal area increased from 8 to 9, followed by the increased of non-motile cells of dinoflagellate more than 2 times.

In different monsoons, physico-chemical parameters had different effects on diversity and density of phytoplankton (Aubry, 2004). Phytoplankton occurred under suitable environmental conditions, till the optimum changes, cell division turn to resting stage (Takahashi, 2003).

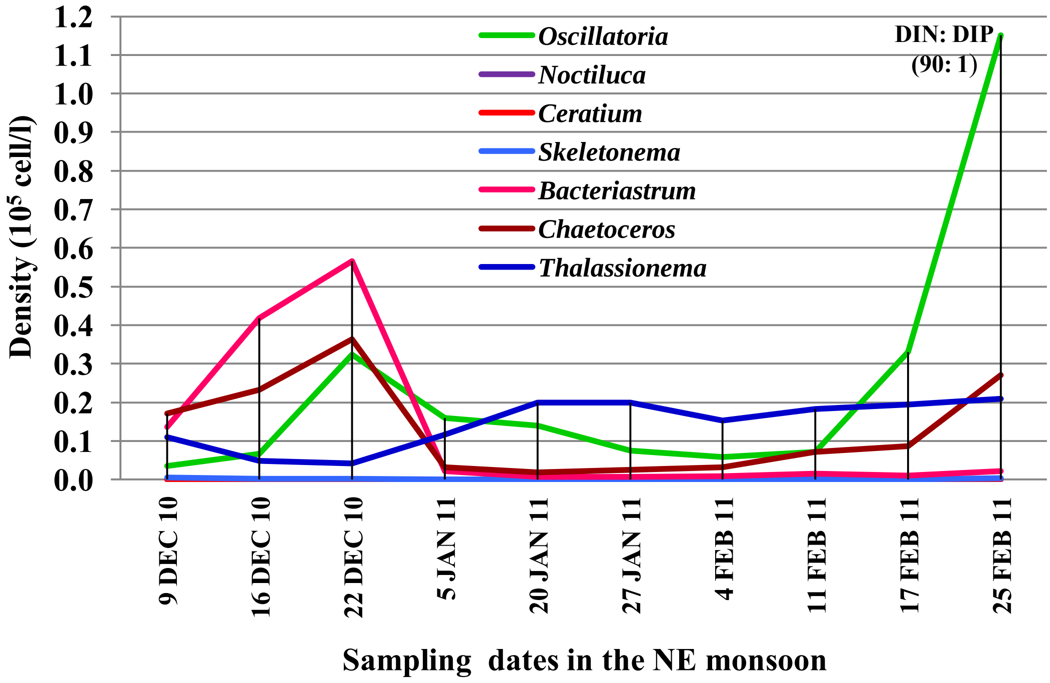
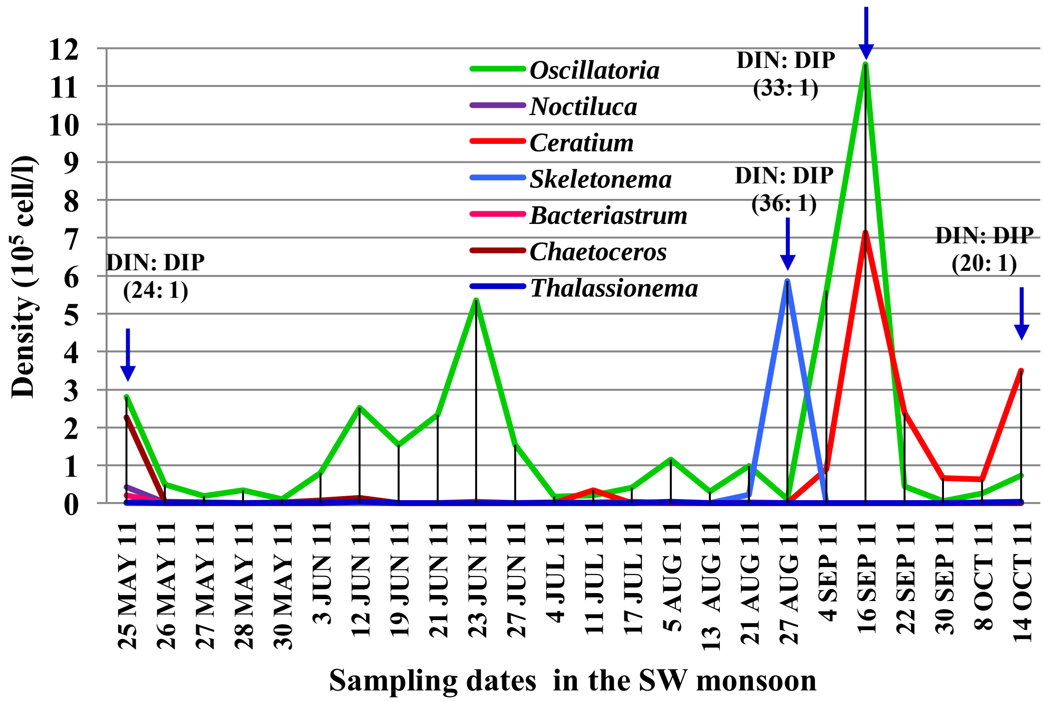


Figure 4.17 Variations in dominant phytoplankton density in the NE monsoon in the coastal area of Ko Si Chang, Chon Buri province.



Note: ↓ *indicated red tide occurrence.*

Figure 4.18 Variations in phytoplankton density in the SW monsoon in the coastal area of Ko Si Chang, Chon Buri province.

D) The relationships between dominant phytoplankton density and environmental parameters

The relationship between dominant phytoplankton density and the values of environmental parameters were test by Canonical Correspondence Analysis (CCA, Figure 4.19).

The influence of environmental parameters on the abundance of dominant phytoplankton indicates that, in the NE monsoon (December 2010 to February 2011), high density of *Chaetoceros*, *Bacteriastrum* and *Thalassionema* corresponded with high concentrations of transparency, salinity, dissolved oxygen, and DIP.

While in the SW monsoon (May to October 2011), the density of *Oscillatoria, Noctiluca*, *Ceratium* and also the concentrations of total- chlorophyll *a,* chlorophyll b and chlorophyll *c* increased in response to high values of temperature, DIN and DIN: DIP.

This relationships displayed in the diagram were supported by a statistical test by CCA which found the significance (P < 0.05) in transparency, temperature, salinity, DO, DIN, DIP, DIN: DIP and DSi.

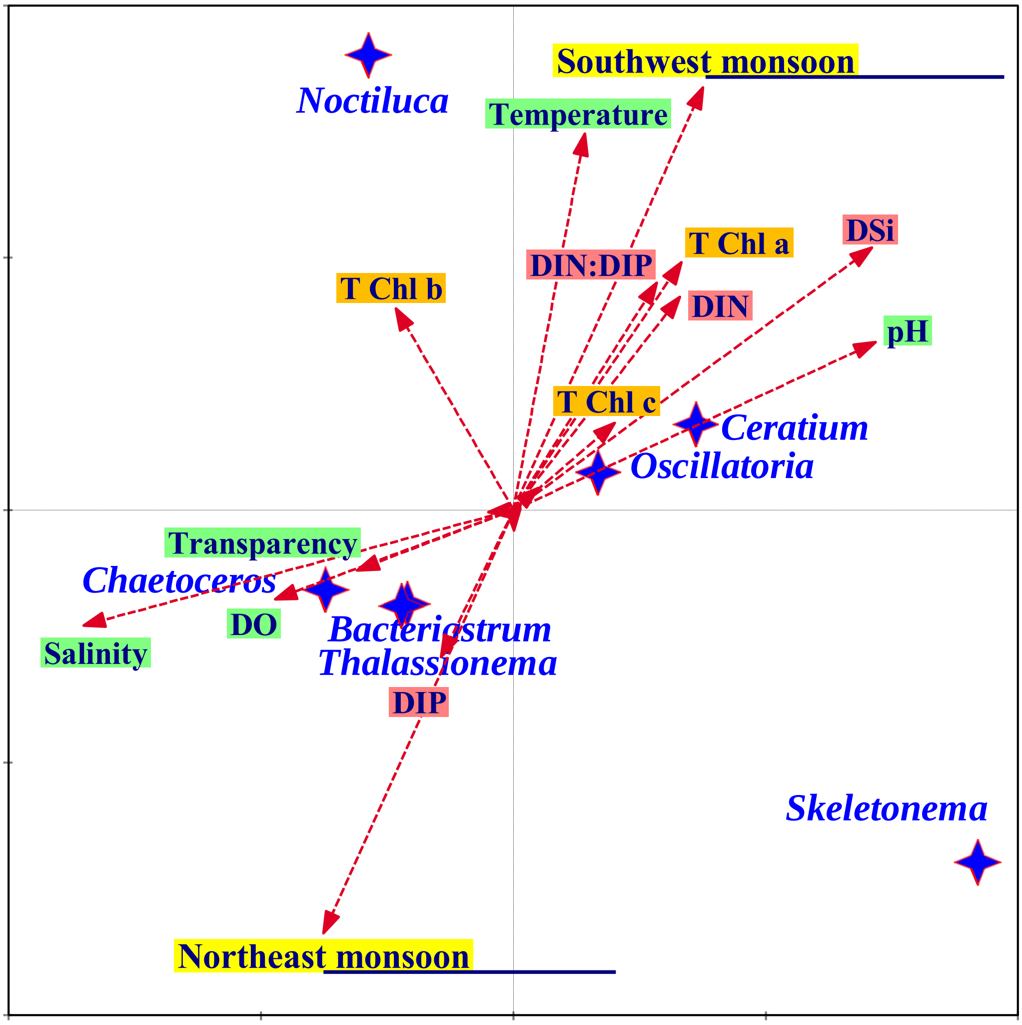


Figure 4.19 Ordination diagram displaying the first two axes of a redundancy analysis for the effect of environmental parameters on dominant phytoplankton density in the coastal area of Ko Si Chang, Chon Buri province in December 2010 to October 2011.

E) The relationships among the dominant phytoplankton abundance

The result showed the different dominant genera in the different monsoons. *Bacteriastrum*, *Chaetoceros* and *Thalassionema* were dominant phytoplankton in the northeast (NE) monsoon from December 2010 to February 2011. While *Oscillatoria*, *Noctiluca*, *Ceratium* and *Skeletonema* dominated during the SW monsoon.

When investigated the relationships among these dominant phytoplankton densities by Pearson's correlation (Table 4.4). The results showed that *Oscillatoria* had positive trends with *Noctiluca* (.118), *Ceratium* (.693; with significant difference (p < 0.01)) and *Chaetoceros* (.082). However, this genus presented negative trends with *Skeletonema* (-.089), *Bacteriastrum* (-.110) and *Thalassionema* (-.254).

Noctiluca had positive relationships with *Bacteriastrum* (.229) and *Chaetoceros* (.971; with significant difference (p < 0.01)). But it showed negative relationships with *Ceratium* (-.068), *Skeletonema* (-.037) and *Thalassionema* (-.070).

The correlations of *Ceratium* with *Skeletonema* (-.061), *Bacteriastrum* (-.128), *Chaetoceros* (-.099) and *Thalassionema* (-.181) indicated the inhibitive effects.

The negative correlations also were found from *Skeletonema* with *Bacteriastrum* (-.070), *Chaetoceros* (-.054) and *Thalassionema* (-.121).

Inversely, *Bacteriastrum* showed the promotable correlations with *Chaetoceros* (.407; with significant difference (p < 0.05)) and *Thalassionema* (.010).

Finally, *Chaetoceros* had a good relationship with *Thalassionema* (.029).

Table 4.4 Pearson's correlation matrix between the dominant phytoplankton densities in the coastal area of Ko Si Chang in December 2010 to October 2011.

Dominant phytoplankton	*Oscillatoria*	*Noctiluca*	***Ceratium***	*Skeletonema*	*Bacteriastrum*	*Chaetoceros*	*Thalassionema*
Oscillatoria	1						
Noctiluca	.118	1					
Ceratium	.693**	-.068	1				
Skeletonema	-.089	-.037	-.061	1			
Bacteriastrum	-.110	.229	-.128	-.070	1		
Chaetoceros	.082	.971**	**-.099**	-.054	.407*	1	
Thalassionema	-.254	-.070	-.181	-.121	.010	.029	1

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

4.4 Conclusions

Significant temporal variations in the environmental parameters during the study period were influenced by seasonal variations and Bang Pakong freshwater river discharge. The dilution of salt concentrations and nutrients-enriched in terms of DIN, DIN: DIP and DSi were found in the SW monsoon.

The different optimal environmental conditions promoted different groups of phytoplankton in different periods (Iizuka, 2003). In the NE monsoon, the dominant groups of phytoplankton were diatoms (*Thalassionema*, *Chaetoceros* and *Bacteriastrum*) with lower mean of cell density than in the SW monsoon whereas diversity index and evenness index were higher.

In the SW monsoon, high trophic conditions enhanced rapid growth of *Oscillatoria*, finally cyanobacteria became a major group during this period. Furthermore, *Noctiluca scintillans*, *Ceratium furca* and *Skeletonema costatum* also were supported and then caused red tides.

The final replacement of *Oscillatoria* in the NE monsoon, the red tides of *Noctiluca scintillans*, *Ceratium furca*, *Skeletonema costatum* and also the co-occurrence of *Oscillatoria* in the SW monsoon, it indicated that phytoplankton succession related to the fluctuation of DIN and DIP especially in the unbalanced DIN: DIP ratio.

The significant relationships between dominant phytoplankton and environmental parameters was tested by CCA, it indicated that successions of phytoplankton were affected by suitable environmental conditions.

The relationships between the dominant phytoplankton which were investigated by Pearson's correlation in this chapter, was tested for the allelopathic relationship between the dominant phytoplankton by algal culturing in the laboratory. Which the result was shown in Chapter V.

This result was clearly that due to the eutrophication in the SW monsoon, then it followed by the blooming of phytoplankton. For solve this problem, the proper management of wastewater such as livestock, agriculture, industry and household is required.

CHAPTER V
ALLEOPATHIC RELATIONSHIP BETWEEN TWO DOMINANT PHYTOPLANKTON: DINOFLAGELLATE (*Ceratium furca*) AND DIATOM (*Chaetoceros curvisetus*) IN THE COASTAL AREA OF KO SI CHANG, CHON BURI PROVINCE

Abstract

This study aims to study the allelopathic effect between two dominant phytoplankton *Ceratium furca* and *Chaetoceros curvisetus* which were the most common and bloom-forming species in the coastal area of Ko Si Chang, Chon Buri province. *C. curvisetus* was grown cultured in f/2+Si medium with the addition of 0%, 0.1%, 1%, 10% and 100% filtrate from *C. furca*. In control unit (without *C. furca* filtrate or 0% filtrate), *C. curvisetus* exhibited the longest exponential phase of 12 days and other 12 days in stationary phase in comparison to other treatments. The significant highest mean cell density in exponential phase of 1.13 $\pm$ 1.20 x 10^5 cell ml^{-1} and maximum cell density was recorded from the control treatment of *C. curvisetus*. The additions of dinoflagellate filtrate in small amounts; 0.1%, 1% and 10% filtrate; prolonged stationary growth of *C. curvisetus* up to 30 days of the experiment in the 10% filtrate addition. Whereas the inhibition of diatom growth was noticed in *C. curvisetus* grew in 100% filtrate since the culture collapsed from the beginning of the experiment. The result from 0.1% filtrate presented the highest for growth promotion to *C. curvisetus* by stimulating cell division.

5.1 Introduction

When external nutrients input to seawater were unbalanced at ratios N: P = 16 (Redfield ratio), eutrophication occurred and followed by the limiting of phytoplankton growth. Under the condition of growth-limiting nutrients, certain algal species present allelopathy, "the ability of certain harmful algal species which can produce and release allelochemicals to inhibit the growth of co-occurring phytoplankton species" (Granéli *et al*., 2008). Finally they have the potential to become dominant and form blooming. Marine phytoplankton that can produce allelochemicals such as cyanobacteria, dinoflagellates, flagellates, diatoms and green algae (Graneli and Hansen, 2006; Graneli and Pavia, 2006).

The knowledge about allelochemicals of phytoplankton in aquatic systems were largely unknown (Legrand *et al*., 2003). Although some researchers, Myklestad (1995) reported that most of organic substance released from phytoplankton were polysaccharides, types and concentrations varied in different species. But the chemical substances have not yet been isolated and structurally characterized. The present study of allelopathy reported only the effect of allelochemicals on other phytoplankton (Granéli *et al*., 2008). Which growth results showed both stimulation and inhibition (Kubanek *et al*., 2005; Tameishi *et al*., 2009; Wang and Tang, 2008; Wang *et al*., 2006).

Currently, there was no standard method to study allelopathy (Legrand *et al*., 2003). However, Granéli and Hansen (2006) suggested that filtrates are particularly useful in studies of potentially toxic effects on natural planktonic communities, the filtrates or cross-culturing method by adding cell-free filtrate from donor alga to culture of target species Legrand *et al*. (2003) also recommended.

The study of succession of phytoplankton in the coastal area of Ko Si Chang from Chapter IV showed that the environmental factors significantly influenced the distribution and abundance of phytoplankton or caused the succession of phytoplankton. Moreover, the allelopathic relationships between phytoplankton are also involved in this process (Granéli *et al*., 2008).

The relationships among dominant phytoplankton by Pearson's correlation from Chapter IV showed that the abundance of *Oscillatoria* exhibited positive trends with *Noctiluca*, *Ceratium* and *Chaetoceros* and negative trends with *Skeletonema*, *Bacteriastrum* and *Thalassionema*. While *Noctiluca* presented positive relationships with *Bacteriastrum* and *Chaetoceros* and negative relationships with *Ceratium*, *Skeletonema* and *Thalassionema*. The correlations of *Ceratium* with *Skeletonema*, *Bacteriastrum*, *Chaetoceros* and *Thalassionema* indicated the inhibitive effects, as same as the correlations of *Skeletonema* with *Bacteriastrum*, *Chaetoceros* and *Thalassionema*. Inversely, *Bacteriastrum* showed the promotable correlations with *Chaetoceros* and *Thalassionema*, same result as *Chaetoceros* and *Thalassionema*.

To determine the allelopathic relationship from the results in the previous chapter, *Ceratium* and *Chaetoceros* were chosen as tested species for this purpose. These two phytoplankton dominated phytoplankton communities in different monsoons, for *Chaetoceros* was the common species in the NE monsoon while *Ceratium* bloom was detected in the SW monsoon (September to October 2011). Their densities showed negative relationship with Pearson's correlation coefficient of -.099. Beside, *Chaetoceros* is important food for aquatic animal larvae (Fishery, 2012), so it was interesting to know how *Ceratium* can affect other marine producer.

Ceratium furca, a large species dinoflagellate with two unequal, parallel or slightly divergent hypothecal horns, distributes worldwide (Steidinger and Tangen, 1996). It causes harmless red tide where it stayed on the surface water during daytime and moves down at night (Fukuyo, *et al.*, 2003). Most of red tide from *Ceratium furca* in Japan was associated with anoxic waters, and sometimes followed by mortality of pearl oysters (Okaichi, 2003).

Chaetoceros curvisetus, a centric diatom with adjacent cells in chains connected by drawn up poles of the concave valves, all setae directed toward the outside of the chain spiral, cosmopolitan (Hasle and Syvertsen, 1996).

This study aims to confirm the allelopathic relationship between *Ceratium furca* and *Chaetoceros curvisetus*, therefore this research was designed to study the effects of different concentrations of *Ceratium furca* filtrates on growth of *Chaetoceros curvisetus*.

5.2 Methodology

5.2.1 Study area and study period

Field samples were collected from the coastal area of Ko Si Chang, located on the west coast of Chon Buri Province, the Upper Gulf of Thailand. Sampling area was located at latitude 13^{o} 9' 32.6" N and longitude 100^{o} 49' 05.2" E (Figure 5.1). Phytoplankton samples were collected during the NE monsoon and species isolation and culture were maintained. Seawater samples were sampled in the SW monsoon (May to October 2011). Laboratory experiment was set up at Si Chang Marine

Science Research Center and Training Station (SMARTS) for 1 month from 23rd October to 24th November 2011.

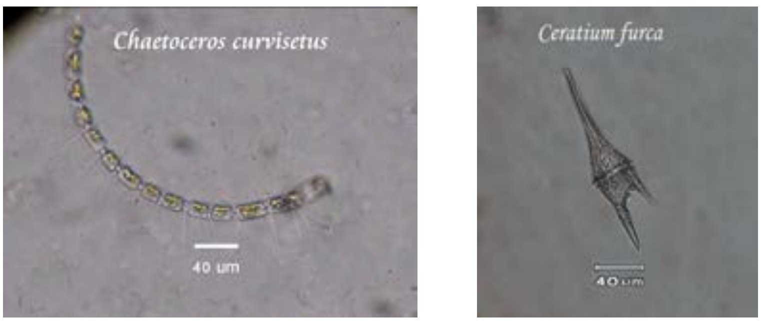
Source: Google earth [22 4 2012].

Source: [http://www.nations online.org/](http://www.nationsonline.org/)

Figure 5.1 Sampling site in the coastal area of Ko Si Chang, Chon Buri Province.

5.2.2 Phytoplankton sampling methodology for inoculum of *Chaetoceros curvisetus*

Ten liters of seawater samples were collected by using 1 l of Van Dorn bottle. The samples were filtered through 20 µm phytoplankton net. The cells retained on this net were used for isolation of phytoplankton. A single cell of *Chaetoceros curvisetus* (Figure 5.2 A) was isolated by micropipette washing technique (Wongrat, 1998). After cell washing, it was inoculated into in an f/2-enriched seawater medium (Guillard and Ryther, 1962). Then clonal culture was prepared for stock culture by grown in f/2 medium and kept for testing with *Ceratium furca* (Figure 5.2 B).



A B

Figure 5.2 A; *Chaetoceros curvisetus*, B; *Ceratium furca*.

5.2.3 Sampling methodology for cell-freed filtrates of *Ceratium furca*

During red tide of *Ceratium furca* in September to October, 2011 in the SW monsoon, an aliquot of 10 l of seawater samples were collected using a Van Dorn bottle. Seawater samples were divided into 2 fractions, one was preserved with 2% neutralized formalin and counted for *C. furca* density. Another one was filtered through GF/C filters. This filtrate from natural population of *C. furca* was then passed through a 0.2 µm syringe filters in order to remove suspended particles such as cell *C. furca* and bacteria etc. then kept frozen until tested with culture of *Chaetoceros curvisetus*.

5.2.4 Laboratory experiments

A 100% filtrate was extracted from *Ceratium furca* of 1.24 x 10^4 cell ml^{-1} in density. To compare the effects of different concentrations of *C. furca* filtrates on the growth of *Chaetoceros curvisetus*, the experiment was designed into five treatments. Each treatment had the same density of *Chaetoceros curvisetus* inoculums and f/2 nutrients but different amount of *C. furca* filtrates and seawater volumes (Table 5.1).

Table 5.1 Experimental design for the study of the effects of different concentrations of *Ceratium furca* filtrates on the growth of *Chaetoceros curvisetus*.

Treatments	*C. furca* filtrates (%)	*C. furca* filtrates (ml)	Seawater (ml)
T1	0 (control)	-	200
T2	0.1	0.2	199.8
T3	1	2	198
T4	10	20	180
T5	100	200	-

Note: seawater had the values of salinity = 30 ppt and pH =8.2.

Each treatment was cultured in triplicate in 250 ml Erlenmeyer flasks (Figure 5.3). All treatments were incubated under the same conditions of 12:12 hours light:dark cycle. The artificial lighting (40 W) type cool daylight fluorescent lamps were used to give daytime light intensity about 118 lux m^{-1}. The experimental temperature was kept constant at 26 $\pm$ 1°C by placing all flasks in a glass tank (with the water level about one-fifth of the tank). Each flask was shaken by hand every 12 hours during the experimental period of 1 month.

The initial cell density of *Chaetoceros curvisetus* from stock culture was approx. 1.00 x 10^4 cells ml^{-1}. Growth in diatom from each culture flask was monitored every 2 days by sterile sampling technique. Cells were counted under a compound microscope with an improved Neubauer haemacytometer and calculated for cell densities in the unit of cells ml^{-1} (Lobban *et al*., 1988).

Figure 5.3. Cultures of *Chaetoceros curvisetus* in f/2 medium with the addition of different concentrations of *Ceratium furca* filtrates.

5.2.5 Growth rate of *Chaetoceros curvisetus*

To determine growth of *Chaetoceros curvisetus*, the number of cell density in each treatment were determined every other day. Cell counts after LN (natural logarithm) transformation, were plotted against time of experiment to create a growth curve. Specific growth rate (μ) was calculated for each treatment using the following equation (Lobban *et al*., 1988):

$$\mu = \ln X_2 - \ln X_1 / t_2 - t_1$$

where X_2 and X_1 were cell densities at two times t_2 and t_1

5.2.6 Data analysis

The values of mean cell densities, maximal cell densities and specific growth rates (μ) from each treatment were tested for the differences by using one way ANOVA, T-test and one way ANOVA, respectively.

5.3 Results and Discussions

Means cell density and specific growth rate (μ) of *Chaetoceros curvisetus* cultured in f/2 media with various concentrations of *Ceratium furca* filtrates are illustrated in Figure 5.4 and summarized in Table 5.2 (Appendix 5.4 and Appendix 5.5).

Cell density of *Chaetoceros curvisetus* in f/2 medium without filtrate from *Ceratium furca* (T1 treatment) increased exponentially for the first 12 days of the experiment. After that cell densities reached a stationary phase for another 12 days, then the cells began to decline toward the end of the experiment (Figure 5.4). *Chaetoceros curvisetus* grew in the f/2 medium with the additions of various concentrations (T2, T3 and T4) of filtrates from *Ceratium furca* expressed slower growth at the beginning of the experiment but started to grow faster after the 4th day and reached the stationary phase on the 12th day. These cultures can maintain longer in stationary phase than the culture without filtrate addition. The addition of 10% filtrate seemed to sustained growth of the diatom than other treatments since high cell densities were observed for 30 days. The treatment with 100% filtrate addition was, however, was lethal to *Chaetoceros curvisetus* growth since cell densities in all replicates decreased gradually from the beginning of the experiment and the culture was obstructed within 4 days.

The means of cell density in exponential phase from each treatment (Table 5.2) were significant differences ($P < 0.05$). As control experiment had the highest value (1.13 $\pm$ 1.20 x 10^5 cell ml^{-1}), followed by T4 (1.03 $\pm$ 0.1 x 10^5 cell ml^{-1}), T3 (1.01 $\pm$ 0.99 x 10^5 cell ml^{-1}) and T2 (0.8 $\pm$ 0.85 x 10^5 cell ml^{-1}).

The maximal cell densities in stationary phase (Table 5.2) also showed the significant differences ($P < 0.05$) among five treatments. The highest value was found from T1 (4.3 $\pm$ 0.17 x 10^5 cell ml^{-1}), followed by T3 (3.9 $\pm$ 0.29 x 10^5 cell ml^{-1}), T4

(3.75 $\pm$ 0.75 x 10^5 cell ml^{-1}), T2 (3.74 $\pm$ 0.84 x 10^5 cell ml^{-1}) and T5 (0.08 $\pm$ 0.02 x 10^5 cell ml^{-1}), respectively.

There were no significant differences in specific growth rate (μ) from all treatments (Table 5.2). T2 presented the best condition for growth of *Chaetoceros curvisetus* at the exponential phase with the value of 0.36 $\pm$ 0.11 day^{-1}.

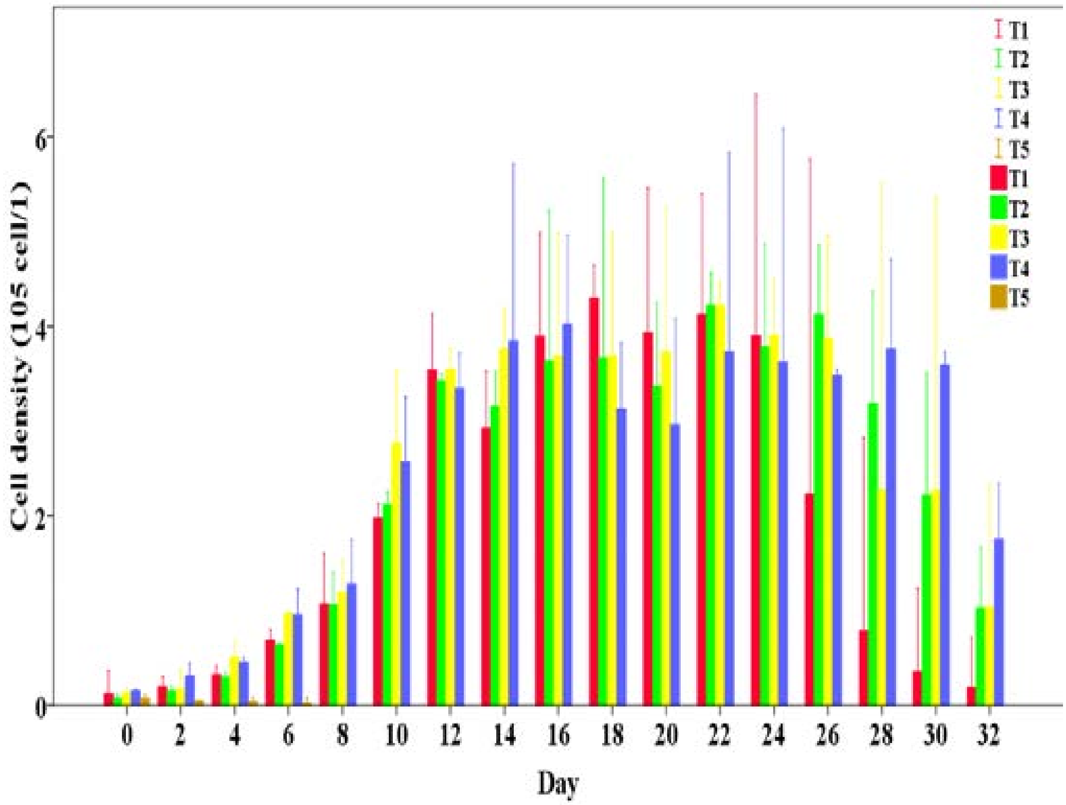


Figure 5.4 Means of cell density (10^5 cell l^{-1}) with standard deviation of means of *Chaetoceros curvisetus* in f/2 media with different concentrations of *Ceratium furca* filtrates.

Table 5.2 Means of cell density (10^5 cell l^{-1}), maximal cell density (10^5 cell l^{-1}) and means of specific growth rate (μ, day^{-1}) of *Chaetoceros curvisetus* grown in f/2 media with varied concentrations of *Ceratium furca* filtrates.

Growth parameter	T1	T2	T3	T4	T5
Mean cell density	**1.13 ± 1.20^{d}**	0.8 ± 0.85^{a}	1.01 ± 0.99^{b}	1.03 ± 0.1^{c}	-
Maximal cell density	**4.3 ± 0.17^{e}**	3.74 ± 0.84^{b}	3.9 ± 0.29^{d}	3.75 ± 0.75^{c}	0.08 ± 0.02^{a}
Specific growth *rate (μ)*	0.30 ± 0.17^{a}	**0.36 ± 0.11^{a}**	0.33 ± 0.29^{a}	0.30 ± 0.11^{a}	-

Note: same letters indicated no significant differences, $a<b<c<d<e$.

This result indicated that *Ceratium furca* filtrate on the lower concentrations can promote growth of a diatom *Chaetoceros curvisetus*. This growth promotion effect was similar to Tameishi *et al.* (2009) who reported that low concentration of dinoflagellate *Prorocentrum minimum* filtrates significantly promoted growth of a diatom *Skeletonema costatum*. Wang *et al*. (2006) found that lower density of dinoflagellate *Prorocentrum donghaiense* filtrate stimulated growth of the co-cultured dinoflagellate *Alexandrium tamarense* whereas higher concentration could depress *Alexandrium* growth. Wang and Tang (2008) also reported that the lower and higher density of dinoflagellate *Prorocentrum donghaiense* filtrates had different effects on growth of dinoflagellate *Scrippsiella trochoidea*; promotion and depression, respectively.

The growth inhibition effect found in culture of *Chaetoceros curvisetus* with high concentration of filtrate from *Ceratium furca* was corresponding with the report of Granéli and Hansen (2006); they suggested that the unknown allelopathic substance from *Ceratium* could present growth inhibition to other algae. The examples of inhibition were photosynthesis inhibition, reduction of growth rate (Granéli *et al*., 2008). Kubanek *et al.* (2005) also reported that at bloom concentrations of a dinoflagellate *Karenia brevis* suppressed growth of 9 co-occurring phytoplankton species from 12 species tested and *K. brevis* filtrates also inhibited 6 of these 9 species. Granéli *et al*. (2008) suggested that the level of allelochemical effect on other species depended on cell densities of allelopathic donor and target species.

5.4 Conclusions

The study showed that the different concentrations of *Ceratium furca* filtrates gave the different effects on growth of *Chaetoceros curvisetus*. It clearly explained that the lowest concentration presented growth stimulation on *Chaetoceros curvisetus.* Whereas the highest concentration of *Ceratium furca* filtrates showed the inhibitive ability. These research results supported the allelopathic relationship between *Ceratium furca* and *Chaetoceros curvisetus*.

The study in Chapter IV showed that *Ceratium* significantly increased in certain environmental conditions: high temperature, pH, DIN and DIN: DIP concentrations. Then it was followed by the decreasing of *Chaetoceros*'s density. By co-considering with this study result, it indicated that both environmental factors and allelopathic relationship between phytoplankton had the influence on diversity and abundance of phytoplankton.

The interesting points from this study were the allelochemicals which showed both promotable and inhibitive abilities from the donor algae. Due to the lowest concentration of *Ceratium furca* filtrate resulted in the highest specific growth rate of *Chaetoceros curvisetus*. Therefore, the promotable ability maybe applied for stimulating rapid yield of *Chaetoceros curvisetus* using for feeding in aquatic animal larvae such as in shrimp farm. For the benefit of inhibitive ability, the allelochemicals maybe applied for the biocontrol. For examples, in Australia, allelochemical was applied for agricultural bio-control (Legrand *et al*., 2003). Sharifah and Eguchi (2012) reported that live *Chlorella vulgaris* could exhibit biocontrol to fish pathogen *Vibrio anguillarum*.

CHAPTER VI
CONCLUSIONS AND RECCOMMENDATIONS

The study on diversity and abundance of phytoplankton communities in relations to the environmental factors in the coastal area of Si Racha and Ko Si Chang, Chonburi province had been conducted in 2008-2009. The first part was the field observation from 4 different seasons; the SW-to-NE inter-monsoon (October 2008), the NE monsoon (December 2008), the NE-to-SW inter-monsoon (March 2009) and the SW monsoon (May 2009). The result indicated significant seasonal variations in the environmental parameters due to freshwater runoff. The high temperature, dissolved inorganic phosphate (DIP) and dissolved inorganic silicate-silicon (DSi) were recorded at the same period of low salinity in the NE-to-SW inter-monsoon and the SW monsoon. High concentrations of dissolved inorganic nitrogen (DIN), DIP and Dsi always found at the stations located in the northeastern part of Ko Si Chang closed to Bang Pakong river mouth. Phytoplankton communities in the inter-monsoon seasons; the SW-to-NE and the NE-to-SW, dominated by species of diatoms. Whereas cyanobacteria dominated during the NE and the SW monsoons. A cyanobacterium *Oscillatoria* reached the highest density of 84% of total phytoplankton density in the SW monsoon where the unbalanced DIN: DIP ratios of 33: 1 (March) and 2: 1 (May) were recorded. Thus, the presence of a cyanobacterium *Oscillatoria* was significant related to the fluctuations of DIN and DIP concentrations, particularly the unbalanced DIN: DIP ratio.

Succession in phytoplankton communities in the NE and the SW monsoons of 2010-2011 also related to the environmental factors. The result indicated that significantly high values of DIN, DIN: DIP ratio and DSi reflected the low salinity period of SW monsoon in comparison to the high salinity period of the NE monsoon. These variations in environmental factors resulted in significant variations in the diversity and density of phytoplankton. In the NE monsoon, the dominant phytoplankton were diatoms (66%) and cyanobacteria (34%) while in the SW monsoon, the dominated phytoplankton were cyanobacteria (59%), dinoflagellates (25%) and diatoms (16%). Succession pattern of phytoplankton changed from

Bacteriastrum and *Chaetoceros* dominated in the early NE monsoon with high values of salinity, DO and DIP to *Oscillatoria* in late NE monsoon in corresponding to the decreases in pH, DIP and DSi. In the early SW monsoon (May), succession pattern changed from *Oscillatoria* and *Chaetoceros* with a bloom of *Noctiluca scintillans* to the bloom of *Ceratium furca* in June, *Skeletonema costatum* in August and *Oscillatoria* - *Ceratium furca* in late SW monsoon. The succession of phytotoplankton in this SW monsoon was related to the variation in DIN and DIP especially the unbalanced DIN: DIP ratio.

The study on allelopathic relationships between two different dominant phytoplankton *Ceratium furca* and *Chaetoceros curvisetus* presented the influencing of dinoflagellates on other co-occurring phytoplankton in two aspects; promotion and inhibition. As control experiment (0%; without *Ceratium furca* filtrate) had the significant highest cell density. The small addition of filtrate (0.1%) presented the highest promotable for growing of *Chaetoceros curvisetus* by stimulating cell division and specific growth rate (μ) of *Chaetoceroos curvisetus*. Whereas 100% filtrate presented the inhibitive effect on growth of *Chaetoceros curvisetus*, cell reached to death phase since the beginning of the experiment.

This study indicated that factors affecting biodiversity and succession of phytoplankton in the coastal area of Si Racha coastal area and Ko Si Chang were dissolved inorganic nutrients especially DIN: DIP ratio and the allelopathic relationships between phytoplankton.

This knowledge of phytoplankton diversity and abundance can be used as baseline information on marine biodiversity in the coastal area of Si Racha-Si Chang. The knowledge of factors affecting phytoplankton succession can be used as guideline for proper management of the coastal zone such as wastewater control from agriculture, livestock, industry and household as well as the guideline for the monitoring of coastal ecosystems as well as the application of bio-indicator to the monitoring scheme.

The result from the allelopathic relationships between different phytoplankton could be applied for the stimulating rapid growth and hence increase yield of phytoplankton such as *Chaetoceros curvisetus* for feeding marine animal larvae in aquaculture. The inhibitive relationships between phytoplankton could be developed for algal bloom control (bio-control). For examples, in Australia, allelochemical was applied for agricultural bio-control (Legrand *et al*., 2003). Sharifah and Eguchi (2012) reported that live *Chlorella vulgaris* could exhibit biocontrol to fish pathogen *Vibrio anguillarum*.

However, the knowledge of allelopathic relationships between phytoplankton is still need for further study. The correlation analyses presented that there might be interspecific relationships among phytoplankton species, the allelopathic relationships in particular and this still waiting for further investigation.

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APPENDICES

Appendix 4.1. Means of environment parameters between different sampling dates in different monsoons and depths in the coastal area of Sichang Island, Chonburi province in December 2010 to October 2011.

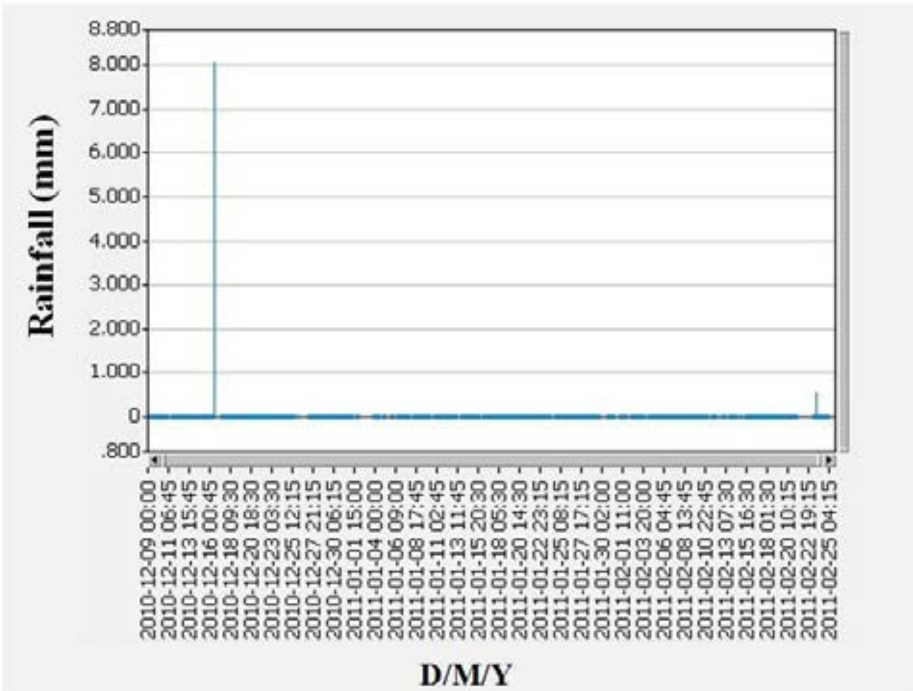
Monsoon	Sampling date	Transparency (m)	Tem °C	Salinity ppt	DO ppm	pH	NH_4^+ µM	NO_2^- µM	NO_3^- µM	PO_4^- µM	N:P ratio µM	SiO_3^- µM	Chlorophyll *a* Total mg m^{-3}	Chlorophyll *a* 20-200 µm mg m^{-3}	Chlorophyll *a* < 20 µm mg m^{-3}	Chlorophyll *b* Total mg m^{-3}	Chlorophyll *b* 20-200 µm mg m^{-3}	Chlorophyll *b* < 20 µm mg m^{-3}	Chlorophyll *c* Total mg m^{-3}	Chlorophyll *c* 20-200 µm mg m^{-3}	Chlorophyll *c* < 20 µm mg m^{-3}
NE	**9 Dec 2010**	3	27.57 ± 0.08	34.67 ± 0.52	7.05 ± 0.02	7.97 ± 0.05	0.79 ± 0.35	0.04 ± 0.01	0.15 ± 0.04	1.61 ± 0.12	0.6 ± 0.20	10.05 ± 0.31	0.90 ± 0.19	0.54 ± 0.28	0.46 ± 0.42	0.50 ± 0.22	0.41 ± 0.15	0.13 ± 0.31	1.68 ± 1.57	1.25 ± 1.46	0.64 ± 1.01
	16 Dec 2010	4	28.52 ± 0.08	31.83 ± 1.47	7.25 ± 0.03	7.97 ± 0.14	1.15 ± 0.45	0.10 ± 0.02	0.15 ± 0.10	1.17 ± 0.10	1.2 ± 0.44	5.07 ± 0.19	1.28 ± 0.24	0.77 ± 0.20	0.52 ± 0.13	0.34 ± 0.12	0.37 ± 0.09	0.16 ± 0.13	2.58 ± 1.90	0.60 ± 0.84	2.28 ± 2.03
	22 Dec 2010	3	27.93 ± 0.12	30.50 ± 0.55	7.25 ± 0.01	8.09 ± 0.02	0.51 ± 0.19	0.03 ± 0.02	0.38 ± 0.06	1.31 ± 0.18	0.72 ± 0.16	6.88 ± 0.29	1.47 ± 0.83	0.68 ± 0.24	0.79 ± 0.66	0.35 ± 0.14	0.27 ± 0.20	0.13 ± 0.14	1.08 ± 0.68	0.99 ± 0.63	0.09 ± 0.22
	5 Jan 2011	3	27.42 ± 0.08	30.33 ± 0.52	7.38 ± 0.05	8.03 ± 0.05	1.92 ± 0.61	0.04 ± 0.01	0.51 ± 0.13	1.42 ± 0.12	1.75 ± 0.41	9.65 ± 0.07	2.04 ± 0.14	0.97 ± 0.18	1.07 ± 0.06	0.32 ± 0.23	0.19 ± 0.16	0.13 ± 0.15	2.06 ± 0.55	0.85 ± 0.41	1.21 ± 0.23
	20 Jan 2011	3	27.15 ± 0.08	34.67 ± 0.52	6.78 ± 0.22	8.08 ± 0.02	2.35 ± 0.34	0.03 ± 0.00	0.38 ± 0.04	1.91 ± 0.02	1.44 ± 0.18	12.18 ± 0.52	1.62 ± 0.27	0.61 ± 0.14	1.11 ± 0.07	0.27 ± 0.13	0.20	0.23 ± 0.10	1.42 ± 0.50	0.85 ± 0.64	0.56 ± 0.29
	27 Jan 2011	3	27.28 ± 0.04	31.83 ± 1.47	7.27 ± 0.58	8.78 ± 0.01	1.26 ± 0.31	0.09 ± 0.02	0.34 ± 0.04	0.71 ± 0.05	2.36 ± 0.35	9.96 ± 0.22	1.63 ± 0.16	0.67 ± 0.10	0.97 ± 0.09	0.30 ± 0.13	0.12 ± 0.06	0.20 ± 0.10	1.27 ± 0.63	0.51 ± 0.35	0.93 ± 0.75
	4 Feb 2011	3	27.50 ± 0.11	31.67 ± 0.52	6.05 ± 0.02	8.04 ± 0.12	1.47 ± 0.79	0.03 ± 0.01	0.22 ± 0.03	0.87 ± 0.03	1.98 ± 0.90	10.97 ± 0.16	1.06 ± 0.09	0.40 ± 0.15	0.66 ± 0.16	0.37 ± 0.11	0.26 ± 0.06	0.11 ± 0.09	0.89 ± 0.71	0.04	0.74 ± 0.74
	11 Feb 2011	3	28.22 ± 0.21	33.83 ± 0.41	6.42 ± 0.78	7.86 ± 0.01	2.64 ± 0.69	0.03 ± 0.01	0.24 ± 0.11	0.17 ± 0.02	17.77 ± 4.50	3.75 ± 0.12	1.23 ± 0.22	0.48 ± 0.30	0.75 ± 0.10	0.28 ± 0.19	0.13 ± 0.08	0.25 ± 0.22	1.48 ± 0.29	0.45 ± 0.34	1.25 ± 0.10
	17 Feb 2011	3	28.10 ± 0.00	32.00 ± 0.89	7.00 ± 0.39	7.84 ± 0.01	2.77 ± 0.38	0.06 ± 0.01	0.29 ± 0.05	0.14 ± 0.03	22.73 ± 5.18	2.80 ± 0.09	1.91 ± 0.19	0.99 ± 0.16	0.92 ± 0.07	0.38 ± 0.23	0.20 ± 0.20	0.22 ± 0.16	1.95 ± 1.08	0.64 ± 1.02	1.42 ± 0.565
	25 Feb 2011	3.5	28.68 ± 0.08	34.17 ± 0.41	7.10 ± 0.22	7.86 ± 0.09	2.68 ± 0.52	0.08 ± 0.00	0.17 ± 0.09	0.04 ± 0.01	90.33 ± 55.70	1.76 ± 0.07	1.96 ± 0.18	0.92 ± 0.11	1.04 ± 0.09	0.34 ± 0.16	0.27 ± 0.15	0.12 ± 0.15	2.33 ± 0.90	0.42 ± 0.26	2.05 ± 0.79
	Depth level																				
	Surface		27.89 ± 0.52	33.00 ± 1.59	7.10 ± 0.42	8.07 ± 0.27	1.60 ± 0.86	0.04 ± 0.02	0.32 ± 0.14	0.94 ± 0.65	11.06 ± 19.36	7.36 ± 3.75	1.48 ± 0.48	0.71 ± 0.25	0.78 ± 0.32	0.35 ± 0.18	0.28 ± 0.17	0.18 ± 0.18	1.69 ± 0.83	0.98 ± 0.70	0.92 ± 0.58
	Middle		27.84 ± 0.52	32.65 ± 1.63	7.03 ± 0.46	8.05 ± 0.27	1.73 ± 0.94	0.05 ± 0.03	0.26 ± 0.11	0.94 ± 0.64	10.51 ± 18.78	7.23 ± 3.64	1.39 ± 0.41	0.62 ± 0.30	0.83 ± 0.22	0.31 ± 0.14	0.19 ± 0.11	0.17 ± 0.15	1.74 ± 1.42	0.73 ± 0.99	1.26 ± 1.40
	Bottom		27.79 ± 0.54	32.00 ± 1.95	6.74 ± 0.60	8.03 ± 0.28	1.94 ± 0.96	0.06 ± 0.03	0.26 ± 0.15	0.93 ± 0.66	20.69 ± 47.45	7.34 ± 3.56	1.66 ± 0.52	0.79 ± 0.24	0.88 ± 0.42	0.37 ± 0.18	0.24 ± 0.16	0.15 ± 0.16	1.63 ± 0.87	0.58 ± 0.50	1.17 ± 0.93
	Means	3.15 ± 0.34	27.84 ± 0.52	32.55 ± 1.75	6.96 ± 0.52	8.05 ± 0.27	1.76 ± 0.92	0.05 ± 0.03	0.28 ± 0.13	0.94 ± 0.64	14.09 ± 31.33	7.31 ± 3.59	1.51 ± 0.48	0.71 ± 0.27	0.83 ± 0.33	0.34 ± 0.17	0.24 ± 0.15	0.17 ± 0.16	1.69 ± 1.06	0.76 ± 0.74	1.12 ± 1.02

Monsoon	Sampling date	Transparency (m)	Tem °C	Salinity ppt	DO ppm	pH	NH_4^+ µM	NO_2^- µM	NO_3^- µM	PO_4^- µM	N:P ratio µM	SiO_3^- µM	Chlorophyll *a*			Chlorophyll *b*			Chlorophyll *c*		
													Total mg m^{-3}	20-200 µm mg m^{-3}	< 20 µm mg m^{-3}	Total mg m^{-3}	20-200 µm mg m^{-3}	< 20 µm mg m^{-3}	Total mg m^{-3}	20-200 µm mg m^{-3}	< 20 µm mg m^{-3}
SW	**25 May 2011**	2	31.5 ± 0.24	28 ± 0.00	6.91 ± 0.55	8.23 ± 0.06	10.22 ± 11.2	0.12 ± 0.05	0.84 ± 0.52	0.61 ± 0.64	23.5 ± 16.1	19.08 ± 1.12	29.23 ± 22.15	13.47 ± 10.06	18.0 ± 12.64	8.85 ± 7.98	ND	8.85 ± 7.98	8.02 ± 6.45	4.81 ± 3.42	3.21 ± 3.99
	26 May 2011	4	31.23 ± 0.05	29.33 ± 0.52	8.44 ± 0.13	8.31 ± 0.01	2.82 ± 0.89	0.02 ± 0.01	0.76 ± 0.19	0.14 ± 0.06	35.0 ± 30.9	18.42 ± 1.61	2.14 ± 0.25	0.21 ± 0.09	1.97 ± 0.31	0.68 ± 0.29	0.45 ± 0.20	0.46 ± 0.38	2.91 ± 1.22	2.33 ± 1.20	0.97 ± 0.45
	27 May 2011	3.5	30.13 ± 0.39	29.67 ± 1.86	6.7 ± 1.51	8.26 ± 0.10	2.15 ± 0.70	0.05 ± 0.03	0.97 ± 0.11	0.1 ± 0.03	33.6 ± 12.8	15.48 ± 2.33	2.58 ± 0.32	0.18 ± 0.17	2.46 ± 0.29	0.88 ± 0.21	0.25 ± 0.29	0.80 ± 0.32	1.78 ± 1.25	1.59 ± 1.17	0.72 ± 1.19
	28 May 2011	3.5	31.02 ± 0.12	30.17 ± 1.47	6.69 ± 0.81	8.25 ± 0.07	0.97 ± 0.59	0.06 ± 0.03	0.64 ± 0.11	0.09 ± 0.06	27.6 ± 23.3	14.47 ± 0.41	1.94 ± 0.29	0.34 ± 0.16	1.59 ± 0.21	0.76 ± 0.20	0.16 ± 0.12	0.68 ± 0.11	4.95 ± 1.13	1.81	4.65 ± 1.46
	30 May 2011	4	31.1 ± 0.41	32.5 ± 0.55	7 ± 0.36	8.16 ± 0.05	1.07 ± 0.20	0.05 ± 0.03	0.86 ± 0.15	0.08 ± 0.03	25.4 ± 8.90	16.84 ± 2.04	1.40 ± 0.34	0.64 ± 0.39	0.76 ± 0.51	0.47 ± 0.33	ND	0.47 ± 0.33	4.28 ± 1.09	3.2 ± 1.67	2.68 ± 1.88
	3 June 2011	3.5	30.7 ± 0.27	31.33 ± 0.52	8.55 ± 0.28	8.16 ± 0.02	0.91 ± 0.25	0.02 ± 0.01	0.74 ± 0.33	0.11 ± 0.02	15.7 ± 5.29	17.94 ± 0.16	1.53 ± 0.15	0.40 ± 0.23	1.13 ± 0.18	0.39 ± 0.17	0.16 ± 0.22	0.33 ± 0.15	1.24 ± 1.45	0.98 ± 1.32	0.30 ± 0.46
	12 June 2011	3.5	28.95 ± 0.30	24.67 ± 2.25	6.91 ± 0.76	8.41 ± 0.10	1.33 ± 0.45	0.12 ± 0.16	0.59 ± 0.21	0.26 ± 0.06	8.16 ± 3.39	33.91 ± 9.79	2.94 ± 0.39	1.71 ± 0.41	1.24 ± 0.07	0.27 ± 0.23	0.19 ± 0.16	0.12 ± 0.11	2.56 ± 0.41	ND	2.56 ± 0.40
	19 June 2011	3.5	29.57 ± 0.12	28.33 ± 0.52	5.25 ± 0.72	8.31 ± 0.01	1.68 ± 0.48	0.56 ± 0.16	1.89 ± 0.49	0.35 ± 0.05	12.1 ± 3.31	32.3 ± 1.95	2.64 ± 0.32	0.56 ± 0.58	2.07 ± 0.32	0.64 ± 0.25	0.31 ± 0.21	0.53 ± 0.30	2.4 ± 1.00	1.46 ± 1.39	1.43 ± 1.40
	21 June 2011	3.5	29.75 ± 0.14	29.33 ± 1.37	6.61 ± 0.50	8.27 ± 0.05	0.61 ± 0.15	0.78 ± 0.76	1.82 ± 1.10	0.31 ± 0.06	10.4 ± 5.65	25.55 ± 5.08	2.77 ± 0.48	0.46 ± 0.30	2.31 ± 0.40	0.45 ± 0.29	ND	0.45 ± 0.29	1.90 ± 0.86	0.72 ± 0.44	1.42 ± 0.76
	23 June 2011	3	29.65 ± 0.12	28 ± 2.37	4.26 ± 1.10	8.29 ± 0.07	1.22 ± 1.34	0.32 ± 0.44	1.04 ± 0.91	0.16 ± 0.06	15.1 ± 9.51	31.87 ± 7.33	2.61 ± 0.92	0.50 ± 0.25	2.11 ± 0.67	0.18 ± 0.10	0.13 ± 0.17	0.12 ± 0.09	0.87 ± 0.38	0.32	0.81 ± 0.41
	27 June 2011	3.5	29.38 ± 0.1	28.67 ± 0.52	5.87 ± 1.67	8.21 ± 0.05	2.01 ± 0.69	0.67 ± 0.16	2.63 ± 0.65	0.31 ± 0.02	17.0 ± 3.80	31.7 ± 1.07	1.75 ± 0.13	0.39 ± 0.20	1.36 ± 0.17	0.29 ± 0.11	0.26 ± 0.12	0.12 ± 0.08	0.36 ± 0.21	0.34 ± 0.35	0.25 ± 0.13
	4 July 2011	3.5	29.7 ± 0.06	31.33 ± 0.52	6.11 ± 0.06	8.2 ± 0.01	0.47 ± 0.33	0.05 ± 0.04	2.25 ± 0.79	0.12 ± 0.04	26.6 ± 11.8	24.38 ± 1.36	3.53 ± 0.39	1.42 ± 0.31	2.11 ± 0.17	0.82 ± 0.16	0.12 ± 0.11	0.74 ± 0.08	2.19 ± 0.78	1.42 ± 0.78	1.24 ± 0.65
	11 July 2011	3.5	30.1 ± 0.11	26 ± 0.00	6.17 ± 0.16	8.34 ± 0.06	0.51 ± 0.12	0.09 ± 0.07	0.82 ± 0.27	0.16 ± 0.03	8.95 ± 2.26	24.19 ± 1.63	2.35 ± 0.99	1.12 ± 0.84	1.23 ± 0.19	0.20 ± 0.08	0.13 ± 0.04	0.14 ± 0.09	0.78 ± 0.45	0.51 ± 0.33	0.18 ± 0.17
	17 July 2011	3.5	29.48 ± 0.12	28.33 ± 0.52	6.52 ± 0.03	8.32 ± 0.02	0.39 ± 0.11	0.21 ± 0.04	1.81 ± 1.01	0.02 ± 0.00	133 ± 64.3	19.49 ± 0.41	0.89 ± 0.12	0.42 ± 0.13	0.47 ± 0.05	0.07 ± 0.03	ND	0.07 ± 0.03	0.36 ± 0.38	0.51 ± 0.38	0.01 ± 0.02
	5 Aug 2011	3.5	29.6 ± 0.17	30 ± 0.00	5.57 ± 0.53	8.18 ± 0.08	3.12 ± 1.12	0.24 ± 0.04	1.23 ± 0.59	0.12 ± 0.08	74.2 ± 89.2	27.41 ± 0.94	1.16 ± 0.20	0.17 ± 0.10	0.99 ± 0.12	0.13 ± 0.06	0.16	0.08 ± 0.08	0.55 ± 0.21	0.11	0.53 ± 0.21
	13 Aug 2011	2	29.3 ± 0.17	21 ± 1.79	5.93 ± 0.15	8.54 ± 0.14	2.1 ± 0.38	0.04 ± 0.01	0.94 ± 0.08	0.09 ± 0.03	38.9 ± 1.5	56.92 ± 4.70	4.29 ± 1.58	0.88 ± 0.39	3.41 ± 1.41	0.26 ± 0.11	0.10 ± 0.10	0.18 ± 0.13	1.01 ± 0.60	0.06	1.00 ± 0.61
	21 Aug 2011	3.5	29.53 ± 0.08	26 ± 0.89	4.99 ± 0.17	8.51 ± 0.02	1.82 ± 0.12	0.04 ± 0.03	0.4 ± 0.06	0.09 ± 0.04	30.3 ± 10.5	43.07 ± 2.08	1.11 ± 0.27	0.56 ± 0.21	0.74 ± 0.09	0.28 ± 0.14	0.06 ± 0.05	0.24 ± 0.16	2.98 ± 0.47	ND	2.98 ± 0.47

Monsoon	Sampling date	Transparency (m)	Tem °C	Salinity psu	DO ppm	pH	NH_4^+ µM	NO_2^- µM	NO_3^- µM	PO_4^- µM	N:P ratio µM	SiO_3^- µM	Chlorophyll *a* Total mg m^{-3}	Chlorophyll *a* 20-200 µm mg m^{-3}	Chlorophyll *a* < 20 µm mg m^{-3}	Chlorophyll *b* Total mg m^{-3}	Chlorophyll *b* 20-200 µm mg m^{-3}	Chlorophyll *b* < 20 µm mg m^{-3}	Chlorophyll *c* Total mg m^{-3}	Chlorophyll *c* 20-200 µm mg m^{-3}	Chlorophyll *c* < 20 µm mg m^{-3}
SW	**27 Aug 2011**	3	30.25 ± 0.36	18.83 ± 3.76	5.95 ± 0.34	8.61 ± 0.12	3.57 ± 0.86	0.05 ± 0.01	0.89 ± 0.44	0.15 ± 0.07	36.0 ± 18.3	73.67 ± 14.21	6.75 ± 2.18	0.84 ± 0.70	5.91 ± 1.94	0.12 ± 0.06	0.04	0.12 ± 0.07	2.5 ± 0.72	1.78 ± 0.58	1.02 ± 0.75
	4 Sep 2011	3	29.48 ± 0.15	20.67 ± 1.03	5.69 ± 0.12	8.8 ± 0.03	5.57 ± 1.02	0.02 ± 0.01	0.7 ± 0.19	0.31 ± 0.06	20.8 ± 5.38	65.64 ± 8.80	6.46 ± 1.48	2.52 ± 1.54	3.94 ± 0.44	0.12 ± 0.05	0.03	0.10 ± 0.07	3.29 ± 1.01	0.33 ± 0.10	3.19 ± 0.99
	16 Sep 2011	2.5	29.8 ± 0.09	22.5 ± 0.84	6.54 ± 0.23	8.82 ± 0.08	16.84 ± 10.28	0.05 ± 0.05	0.7 ± 0.18	0.67 ± 0.24	33.1 ± 34.3	60.7 ± 2.10	20.73 ± 9.15	16.62 ± 8.20	4.11 ± 1.13	1.90 ± 0.28	0.27	1.86 ± 0.30	20.42 ± 10.94	15.98 ± 9.08	4.44 ± 1.98
	22 Sep 2011	1.5	29.48 ± 0.16	15.67 ± 7.28	5.98 ± 1.06	8.63 ± 0.25	4.33 ± 1.77	0.11 ± 0.11	0.89 ± 0.52	0.18 ± 0.10	36.1 ± 16.7	88.68 ± 23.88	12.78 ± 6.51	6.82 ± 3.54	5.96 ± 3.26	0.63 ± 0.30	0.25 ± 0.05	0.51 ± 0.33	6.3 ± 2.60	5.34 ± 2.95	0.96 ± 1.11
	30 Sep 2011	3	29.1 ± 0.15	25.33 ± 0.52	5.08 ± 0.35	8.36 ± 0.04	4.74 ± 1.12	0.3 ± 0.07	2.22 ± 0.57	0.22 ± 0.08	35.4 ± 11.5	63.05 ± 3.67	2.69 ± 0.79	1.54 ± 0.68	1.15 ± 0.19	0.24 ± 0.12	0.29 ± 0.07	0.09 ± 0.12	2.66 ± 0.96	1.64 ± 1.39	1.84 ± 1.17
	8 Oct 2011	3	29.25 ± 0.36	26.67 ± 3.14	4.55 ± 0.74	8.3 ± 0.12	2.88 ± 1.25	0.26 ± 0.35	0.97 ± 0.91	0.16 ± 0.06	28.3 ± 18.0	46.31 ± 12.54	8.46 ± 2.91	3.77 ± 2.12	4.69 ± 1.84	0.55 ± 0.14	ND	0.55 ± 0.14	3.95 ± 1.71	3.53 ± 1.77	0.42 ± 0.37
	14 Oct 2011	2.5	29.42 ± 0.19	30.5 ± 0.84	5.82 ± 0.34	8.43 ± 0.07	2.44 ± 1.38	0.09 ± 0.05	0.89 ± 0.34	0.24 ± 0.21	19.8 ± 12.1	22.06 ± 3.34	7.75 ± 7.90	6.39 ± 7.24	1.36 ± 0.69	0.12 ± 0.10	ND	0.08 ± 0.10	9.35 ± 8.39	7.28 ± 7.13	2.08 ± 1.51
	Depth level																				
	Surface		29.88 ± 0.81	25.73 ± 4.99	6.55 ± 0.98	8.4 ± 0.20	3.82 ± 6.96	0.12 ± 0.14	1.01 ± 0.74	0.22 ± 0.29	36.3 ± 40.5	39.37 ± 24.05	7.04 ± 11.75	3.29 ± 6.12	3.95 ± 6.59	1.28 ± 3.90	0.22 ± 0.12	1.09 ± 3.76	4.29 ± 5.50	4.49 ± 5.32	1.78 ± 1.85
	Middle		29.88 ± 0.77	26.21 ± 5.07	6.26 ± 1.14	8.4 ± 0.21	2.75 ± 3.10	0.13 ± 0.18	1.02 ± 0.60	0.19 ± 0.15	27.1 ± 22.7	38.03 ± 23.09	5.40 ± 6.18	2.64 ± 4.48	2.93 ± 3.10	0.68 ± 1.15	0.20 ± 0.18	0.61 ± 1.16	3.87 ± 4.52	3.96 ± 4.64	1.41 ± 1.37
	Bottom		29.92 ± 0.60	28.42 ± 3.26	5.71 ± 1.29	8.3 ± 0.18	2.66 ± 2.50	0.3 ± 0.41	1.41 ± 0.91	0.23 ± 0.16	25.5 ± 31.7	31.74 ± 16.89	3.87 ± 5.28	1.86 ± 4.38	2.00 ± 1.38	0.56 ± 0.62	0.15 ± 0.15	0.51 ± 0.62	3.33 ± 5.65	2.76 ± 5.72	1.67 ± 1.84
	Means	3.15 ± 0.63	29.90 ± 0.73	26.78 ± 4.64	6.17 ± 1.19	8.37 ± 0.20	3.07 ± 4.63	0.18 ± 0.28	1.15 ± 0.78	0.21 ± 0.21	29.6 ± 32.5	36.38 ± 21.69	5.44 ± 8.30	2.58 ± 5.04	2.96 ± 4.32	0.83 ± 2.33	0.19 ± 0.15	0.74 ± 2.30	3.82 ± 5.23	3.67 ± 5.25	1.62 ± 1.69
Depth level																					
Surface			29.29 ± 1.17	27.87 ± 5.42	6.71 ± 0.89	8.31 ± 0.27	3.17 ± 5.94	0.09 ± 0.12	0.80 ± 0.70	0.44 ± 0.54	28.77 ± 37.24	29.96 ± 25.01	5.40 ± 10.17	2.50 ± 5.21	3.02 ± 5.71	0.99 ± 3.25	0.24 ± 0.14	0.82 ± 3.18	3.51 ± 4.76	3.16 ± 4.52	1.53 ± 1.63
Middle			29.28 ± 1.17	28.10 ± 5.25	6.48 ± 1.05	8.30 ± 0.28	2.45 ± 2.68	0.10 ± 0.15	0.80 ± 0.61	0.41 ± 0.50	22.21 ± 22.81	28.97 ± 24.04	4.22 ± 5.50	2.06 ± 3.89	2.31 ± 2.77	0.57 ± 0.98	0.20 ± 0.15	0.48 ± 0.1	3.21 ± 3.94	2.88 ± 4.10	1.36 ± 1.37
Bottom			29.30 ± 1.14	29.47 ± 3.35	6.01 ± 1.22	8.22 ± 0.25	2.45 ± 2.18	0.23 ± 0.36	1.07 ± 0.93	0.44 ± 0.50	24.07 ± 36.78	24.56 ± 18.15	3.22 ± 4.55	1.55 ± 3.70	1.67 ± 1.29	0.51 ± 0.54	0.20 ± 0.16	0.40 ± 0.55	2.83 ± 4.82	1.98 ± 4.69	1.52 ± 1.63
Means		3.15 ± 0.56	29.29 ± 1.16	28.48 ± 4.79	6.40 ± 1.10	8.28 ± 0.27	2.69 ± 3.96	0.14 ± 0.25	0.89 ± 0.77	0.43 ± 0.51	25.00 ± 32.87	27.83 ± 22.61	4.28 ± 7.19	2.03 ± 4.31	2.33 ± 3.76	0.68 ± 1.97	0.21 ± 0.15	0.57 ± 1.95	3.17 ± 4.51	2.63 ± 4.45	1.47 ± 1.54

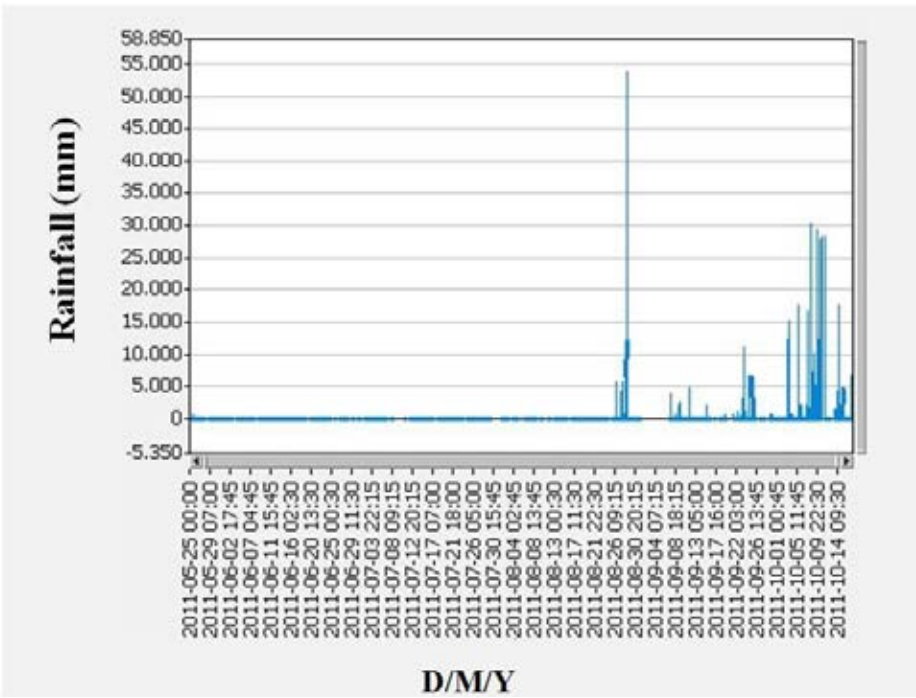
Appendix 4.2. Rainfall at Bang Pakong river mouth during the study period.

a) Rainfall at Bang Pakong river mouth during the NE monsoon.



Source: Adapted from Hydro and Agro Informatics Institute, 2012.

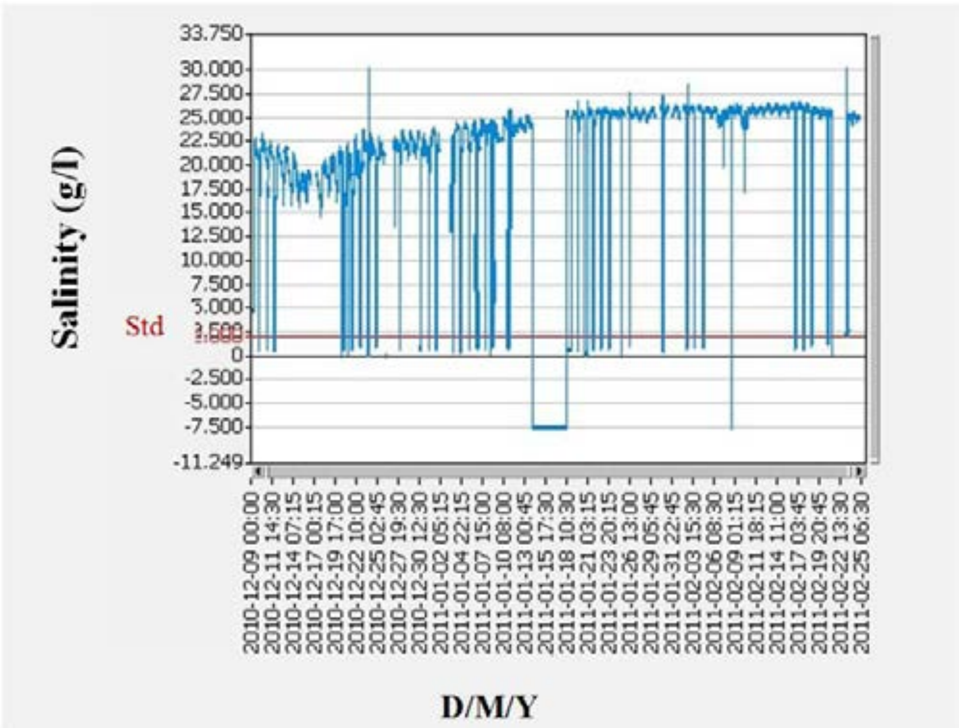
b) Rainfall at Bang Pakong river mouth during the SW monsoon.



Source: Adapted from Hydro and Agro Informatics Institute, 2012.

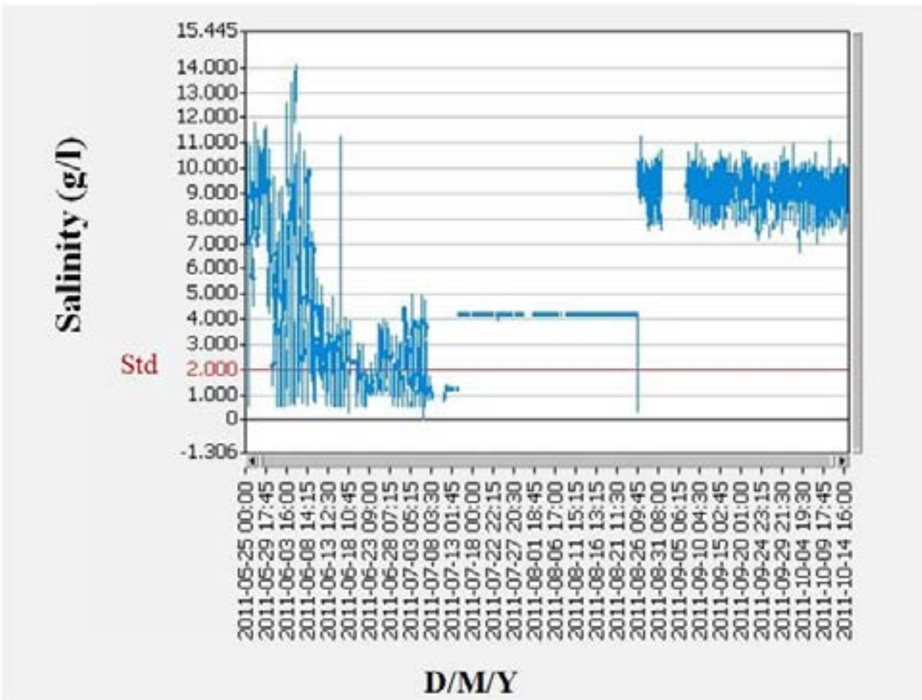
Appendix 4.3. Salinity at Bang Pakong river mouth during the study period.

a) Salinity at Bang Pakong river mouth during the NE monsoon.



Source: Adapted from Hydro and Agro Informatics Institute, 2012.

b) Salinity at Bang Pakong river mouth during the SW monsoon.



Source: Adapted from Hydro and Agro Informatics Institute, 2012.

Appendix 5.4. Means of cell density (10^5 cells ml^{-1}) and standard deviations of means of *Chaetoceros curvisetus* grown in f/2 media with varied concentrations of *Ceratium furca* filtrates.

D/M/Y	Day	T1	T2	T3	T4	T5
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
23/10/2011	0	0.13 ± 0.12	0.07 ± 0.02	0.11 ± 0.05	0.15 ± 0.02	0.08 ± 0.02
25/10/2011	2	0.21 ± 0.05	0.16 ± 0.02	0.24 ± 0.14	0.29 ± 0.06	0.04 ± 0.02
27/10/2011	4	0.33 ± 0.05	0.33 ± 0.06	0.48 ± 0.08	0.46 ± 0.02	0.04 ± 0.02
29/10/2011	6	0.69 ± 0.06	0.66 ± 0.03	1.01 ± 0.07	1.01 ± 0.12	0.01 ± 0.03
31/10/2011	8	1.07 ± 0.27	1.16 ± 0.21	1.3 ± 0.23	1.42 ± 0.29	0.00
2/11/2011	10	1.98 ± 0.08	2.4 ± 0.49	2.92 ± 0.37	2.88 ± 0.58	0.00
4/11/2011	12	3.54 ± 0.30	3.31 ± 0.20	3.23 ± 0.55	3.27 ± 0.19	0.00
6/11/2011	14	2.93 ± 0.30	3.33 ± 0.34	3.9 ± 0.29	3.67 ± 0.73	0.00
8/11/2011	16	3.9 ± 0.54	3.57 ± 0.57	3.42 ± 0.65	3.54 ± 0.90	0.00
10/11/2011	18	4.3 ± 0.17	3.5 ± 0.74	3.42 ± 0.65	3.11 ± 0.25	0.00
12/11/2011	20	3.94 ± 0.76	3.18 ± 0.45	3.12 ± 1.19	2.95 ± 0.40	0.00
14/11/2011	22	4.13 ± 0.64	3.74 ± 0.84	3.64 ± 1.01	3.75 ± 0.75	0.00
16/11/2011	24	3.9 ± 1.27	3.57 ± 0.54	3.52 ± 0.70	3.63 ± 0.87	0.00
18/11/2011	26	2.23 ± 1.77	3.7 ± 0.79	3.65 ± 0.54	2.46 ± 1.77	0.00
20/11/2011	28	0.79 ± 1.02	3.03 ± 0.50	2.67 ± 1.33	2.6 ± 2.03	0.00
22/11/2011	30	0.36 ± 0.44	2.36 ± 0.52	2.58 ± 1.22	2.5 ± 1.90	0.00
24/11/2011	32	0.2 ± 0.26	1.01 ± 0.23	1.19 ± 0.53	1.21 ± 0.97	0.00

Appendix 5.5. Means of cell division (μ) and standard deviations of means of *Chaetoceros curvisetus* grown in f/2 media with varied concentrations of *Ceratium furca* filtrates.

D/M/Y	Day	T1	T2	T3	T4	T5
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
23/10/2011	0	-	-	-	-	-
25/10/2011	2	0.37 ± 0.43	0.42 ± 0.20	0.35 ± 0.58	0.32 ± 0.11	-0.42 + 0.41
27/10/2011	4	0.23 ± 0.05	0.37 ± 0.11	0.42 ± 0.36	0.25 ± 0.13	-0.02 + 0.32
29/10/2011	6	0.38 ± 0.12	0.35 ± 0.06	0.37 ± 0.10	0.39 ± 0.08	0.30
31/10/2011	8	0.21 ± 0.17	0.28 ± 0.07	0.12 ± 0.06	0.17 ± 0.05	-
2/11/2011	10	0.31 ± 0.15	0.36 ± 0.05	0.41 ± 0.03	0.35 ± 0.02	-
4/11/2011	12	0.29 ± 0.06	0.17 ± 0.13	0.05 ± 0.14	0.07 ± 0.11	-
6/11/2011	14	-0.09 + 0.09	0.00 ± 0.08	0.1 ± 0.12	0.05 ± 0.07	-
8/11/2011	16	0.14 ± 0.12	0.03 ± 0.08	-0.07 + 0.13	-0.02 + 0.10	-
10/11/2011	18	0.05 ± 0.05	-0.01 + 0.17	-0.03 + 0.21	-0.05 + 0.12	-
12/11/2011	20	-0.05 + 0.08	-0.04 + 0.14	-0.07 + 0.18	-0.03 + 0.03	-
14/11/2011	22	0.03 ± 0.02	0.07 ± 0.08	0.09 + 0.07	0.12 + 0.04	-
16/11/2011	24	-0.04 + 0.09	-0.02 + 0.09	-0.01 + 0.06	-0.02 + 0.02	-
18/11/2011	26	-0.36 + 0.28	0.01 ± 0.06	0.02 + 0.09	-0.36 + 0.63	-
20/11/2011	28	-0.88 + 1.54	-0.1 + 0.07	-0.21 + 0.31	-0.04 + 0.14	-
22/11/2011	30	-0.27 + 0.19	-0.13 + 0.11	-0.01 + 0.03	0.00 + 0.06	-
24/11/2011	32	-0.61 + 0.47	-0.42 + 0.06	-0.38 + 0.03	-0.4 + 0.08	-

BIOGRAPHY

The author who is responsible for this dissertation is Miss Nittaya Somsap. She was born on 30th October, 1973 at Ratchaburi Province, Thailand. She works as lecturer at Kasetsart University, Bangkok, Thailand since 2000.

She graduated with Bachelor of Education in Science-Biology (1991-1995) from the Faculty of Education, Srinakharinwirot University, Thailand. She completed Master of Science in Biology (1995-2000) from the Department of Zoology, Faculty of Science, Kasetsart University, Thailand.

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