การประเมินประชากร และรูปแบบการเคลื่อนย้ายของปูม้า *Portunus pelagicus* (Linnaeus, 1758) เพื่อการจัดการที่ยั่งยืน กรณีศึกษาอ่าวคุ้งกระเบน จังหวัดจันทบุรี

นางสาวชุตาภา คุณสุข

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
สาขาวิชาวิทยาศาสตร์ชีวภาพ
คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2554

ASSESSMENT OF STOCK AND MOVEMENT PATTERN FOR SUSTAINABLE MANAGEMENT OF BLUE SWIMMING CRAB *Portunus pelagicus* (Linnaeus, 1758): CASE STUDY IN KUNG KRABAEN BAY, CHANTHABURI PROVINCE, THAILAND

Ms. Chutapa Kunsook

A Dissertation Submitted in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy Program in Biological Sciences
Faculty of Science Chulalongkorn University
Academic Year 2011

Thesis Title	ASSESSMENT OF STOCK AND MOVEMENT PATTERN FOR SUSTAINABLE MANAGEMENT OF BLUE SWIMMING CRAB *Portunus pelagicus* (Linnaeus, 1758): CASE STUDY IN KUNG KRABAEN BAY, CHANTHABURI PROVINCE, THAILAND
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ชุดาภา คุณสุข: การประเมินประชากร และรูปแบบการเคลื่อนย้ายของปูม้า *Portunus pelagicus* (Linnaeus, 1758) เพื่อการจัดการที่ยั่งยืน กรณีศึกษาอ่าวคุ้งกระเบน จังหวัดจันทบุรี (ASSESSMENT OF STOCK AND MOVEMENT PATTERN FOR SUSTAINABLE MANAGEMENT OF BLUE SWIMMING CRAB *Portunus pelagicus* (Linnaeus, 1758): CASE STUDY IN KUNG KRABAEN BAY, CHANTHABURI PROVINCE, THAILAND) อ. ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. ดร. นันทนา คชเสนี, อ. ที่ปรึกษาวิทยานิพนธ์ร่วม: รศ. ณิฏฐารัตน์ ปภาวสิทธิ์, 166 หน้า.

การประเมินประชากร และรูปแบบการเคลื่อนย้ายของปูม้า *Portunus pelagicus* (Linnaeus, 1758) ในบริเวณอ่าวคุ้งกระเบน จังหวัดจันทบุรี ได้ดำเนินการตั้งแต่เดือนตุลาคม 2551 - เดือนตุลาคม 2552 โดยแบ่งการศึกษาออกเป็น 4 ส่วน ได้แก่ 1) การประเมินประชากรปูม้าว่าอยู่ในสภาวะวิกฤติหรือไม่ 2) การพิสูจน์สมมติฐานว่าประชากรปูม้าในอ่าวและนอกอ่าวเป็นประชากรกลุ่มเดียวกัน 3) การประเมินปัญหาและประสิทธิภาพในการจัดการทรัพยากรปูม้าในปัจจุบัน และ 4) การนำเสนอแนวทางการจัดการทรัพยากรปูม้าอย่างยั่งยืน โดยใช้ข้อมูลที่ได้จากงานวิจัย

ผลการศึกษาการประเมินประชากรปูม้า ด้วยโปรแกรมสำเร็จรูป FiSAT พบว่าประชากรปูม้าที่อยู่ในบริเวณอ่าวคุ้งกระเบนอยู่ในสภาวะวิกฤติ โดยพิจารณาจากค่าดัชนีชี้วัด ดังนี้ ค่าสัมประสิทธิ์การตายจากการประมงมีค่าเพิ่มขึ้น คือ 4.14 มีการนำแม่ปูไข่นอกกระดองมาใช้ประโยชน์มากขึ้นถึงร้อยละ 45.7% อัตราการใช้ประโยชน์มีค่าเท่ากับ 0.71 ซึ่งสูงกว่าค่าสูงสุดที่ประเมินได้ ค่าความกว้างกระดองเฉลี่ยของปูม้าตัวเต็มวัย มีค่าลดลงเท่ากับ 7.52±1.14 เซนติเมตร และความดกไข่มีค่าเฉลี่ยลดลงเท่ากับ 572,138±261,075.56 ฟอง สำหรับการศึกษารูปแบบการเคลื่อนย้ายประชากรปูม้าโดยการติดเครื่องหมายให้กับปูม้าทั้งหมด 513 ตัว และทำการปล่อยในบริเวณอ่าวคุ้งกระเบน พบว่าหลังปล่อยไปสามารถจับปูม้ากลับคืนมาได้ทั้งหมด 155 ตัว (30.21%) ผลการศึกษาการปล่อยจับปูม้าดังกล่าวสามารถพิสูจน์สมมุติฐานได้ว่ากลุ่มของประชากรปูม้านอกอ่าวและในอ่าวคือกลุ่มเดียวกัน การอพยพเคลื่อนย้ายของปูม้าในแต่ละช่วงอายุเกี่ยวข้องกับชีวประวัติในระยะต่างๆ ของปู โดยพบปูม้าเพศผู้มากถึง 83.1% มีการเคลื่อนย้ายไปมาในอ่าว ส่วนปูม้าเพศผู้วัยอ่อนมีการเคลื่อนที่อยู่ในบริเวณแหล่งหญ้าทะเลชนิด *Enhalus acoroides* ปูม้าเพศเมียที่ไม่ใช่แม่ปูไข่นอกกระดองจำนวน 70.3% มีแนวโน้มที่จะอพยพเคลื่อนย้ายออกนอกอ่าว แม่ปูไข่นอกกระดอง พบว่ามีการหากินทั้งในอ่าวและนอกอ่าว ส่วนการศึกษาระยะทางการเคลื่อนที่นั้น พบว่าปูม้าตัวเต็มวัยมีการเคลื่อนที่ในระยะทางเฉลี่ยที่ไกลกว่าและเคลื่อนที่ในอัตราที่เร็วกว่าปูม้าวัยอ่อน แม่ปูไข่นอกกระดองจะเคลื่อนที่ด้วยอัตราการเคลื่อนที่สูงสุด และเคลื่อนที่เป็นระยะทางเฉลี่ยที่ไกลกว่าปูม้าในวัยอื่น คือ 2.43±1.16 กิโลเมตร จากการศึกษานิเวศวิทยาการกินอาหาร พบข้อสนับสนุนการเคลื่อนที่ของปูม้าในเรื่องของการหาแหล่งอาหาร โดยพบว่าอาหารหลักของปูม้า ได้แก่ ปลากระดูกแข็ง ครัสเตเชียน และอินทรียสาร และพบว่าปูม้าวัยอ่อนและตัวเต็มวัยมีการกินอาหารที่แตกต่างกัน

แนวทางการจัดการทรัพยากรปูม้าอย่างยั่งยืนในบริเวณอ่าวคุ้งกระเบน ได้มีการประเมินปัญหา และประสิทธิภาพของการจัดการทรัพยากรทรัพยากรปูม้าในปัจจุบัน ดังนั้นจึงมีการเสนอบนพื้นฐานข้อมูลที่ได้จากงานวิจัยนี้ ได้แก่ 1) การปิดอ่าวในช่วงฤดูวางไข่ ได้แก่ เดือนธันวาคม มีนาคม และสิงหาคม 2) การอนุรักษ์แหล่งอนุบาลปูม้าวัยอ่อนในธรรมชาติ ได้แก่ แหล่งหญ้าทะเล และแหล่งวางไข่ 3) การฟื้นฟูและการปลูกหญ้าทะเล เพื่อเป็นแหล่งอนุบาล และแหล่งอาหารให้กับปูม้าวัยอ่อน 4) กำหนดขนาดตาลอบให้มีขนาดไม่น้อยกว่า 2.5 นิ้ว 5) การทำธนาคารปูม้า เพื่อให้แม่ปูไข่ได้มีโอกาสปล่อยไข่สู่ท้องทะเล 6) การเพาะเลี้ยงปูม้าวัยอ่อนให้พัฒนาถึงระยะปูม้าวัยรุ่น แล้วปล่อยในแหล่งธรรมชาติ เพื่อลดอัตราการตาย 7) การให้ความรู้เกี่ยวกับการทำธนาคารปู และการเพาะเลี้ยง 8) สร้างความร่วมมือกับผู้ที่มีส่วนเกี่ยวข้องทุกระดับให้มีความเข้าใจเกี่ยวกับนิเวศวิทยาของปูม้ามากขึ้น ซึ่งจะช่วยทำให้การจัดการประมงปูม้าในบริเวณอ่าวคุ้งกระเบนมีประสิทธิภาพและยั่งยืน

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

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

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

##5073819123 : MAJOR BIOLOGICAL SCIENCES

KEY WORDS: BLUE SWIMMING CRAB/ MOVEMENT PATTERN/KUNG KRABAEN BAY

CHUTAPA KUNSOOK: ASSESSMENT OF STOCK AND MOVEMENT PATTERN FOR SUSTAINABLE MANAGEMENT OF BLUE SWIMMING CRAB *Portunus pelagicus* (Linnaeus, 1758): CASE STUDY IN KUNG KRABAEN BAY, CHANTHABURI PROVINCE, THAILAND. ADVISOR: ASSOC. PROF. NANTANA GAJASENI, Ph.D., CO-ADVISOR: ASSOC. PROF. NITTHARATANA PAPHAVASIT. 166 pp.

Assessment of stock and movement pattern in blue swimming crab *Portunus pelagicus* Linnaeus, 1758 at Kung Krabaen Bay was conducted from October 2008 to September 2009. This study was divided into 4 parts; 1) assessment whether the blue swimming crab population in crisis 2) populations both inside and outside the bay are the same group 3) assessment of the present blue swimming crab management in Kung Krabaen Bay and finally 4) the sustainable management of blue swimming crab was proposed based on scientific findings.

Stock assessment was analysed by FiSAT program. The result indicated that the status of blue swimming crab populations in Kung Krabaen Bay was in crisis. Several key indicators have confirmed this. The fishing mortality was increasing to 4.14. The exploitation rate was 0.71 which was higher than the optimal value. Size of mature female also decreased to 7.52±1.14 cm. Low average fecudity was observed of 572,138±261,075.56 eggs. Movement pattern of blue swimming crab was carried out by tagging technique which was conducted inside the bay. In the first recaptured stage only 155 from 513 tagged crabs (30.21%) were recaptured. The result revealed that crabs living inside and outside the bay were related of the same stock. The result also showed most of the male crabs, 83.1%, traveled inside the bay especially the juveniles moved within the seagrass bed, *Enhalus acoroides*. Most of the non-ovigerous females of 70.3% migrated from inside to outside the bay. Moreover, ovigerous females were found both inside and outside the bay with the same proportion, 54.2% and 45.8%, respectively. Adult crabs can migrate in greater distance and in faster speed than juvenile crabs. The average migration distance of ovigerous females was highest of 2.43±1.16 km. The highest average speed of movement was also found in ovigerous females of 0.71±0.68 km/day. Movement pattern of blue swimming crab was supported by the feeding ecology study. This study showed strongly indicated migration has often been associated with an ontogenetic niche shift in habitat use**.** Major food items of crab were teleost fish, crustacean and organic matter.

Based on the assessment of present crab management and scientific problems in Kung Krabaen Bay and scientific findings from this study, the sustainable management of blue swimming crab was proposed as followed 1) Closing season in the bay during spawning season in December, March and August 2) Conservation area proposed at seagrass beds and spawning site outside the bay 3) Restoration of seagrass bed *Enhalus acoroides* 4) Limited mesh size of fishing gear no less than 2.5 inch 5) Intoducing a crab bank in the mouth of the bay 6) Culturing and restocking of crab larvae in the field 7) Increase awareness on crab banks and restocking to stakeholder and 8) Networking with all stakeholders for better understanding on the ecology of blue swimming crab for sustanable fishery management in Kung Krabaen Bay.

Field of Study……**Biological Sciences**……..Student's Signature……………..............

Academic Year…………**2011**……………...Advisor's Signature……………………..

Co-advisor's signature…………………..

ACKNOWLEDGEMENTS

I am indebt to many people who have assisted and supported me throughout my research works and the preparation of this thesis. I wish to express my sincere gratitude to my advisor, Assoc. Prof. Dr. Nantana Gajaseni for her contributions and dedication to make my Ph.D. experience productive and successful.

To my co-advisor, Assoc. Prof. Nittharatana Paphavasit, Department of Marine Science, I am grateful for her contribution in the data analysis.

I gratefully acknowledge the contributions of the thesis committee for their constructive comments on my reaserch works: Assoc. Prof. Dr. Kumthorn Thirakhupt, Assist. Prof. Dr. Art-Ong Pradatsundarasar, Assoc. Prof. Dr. Charoen Nitithamyong and Assoc. Prof. Dr. Thanitha Thapanand Chaidee.

I am deeply grateful to my collegues in Tropical Ecology Laboratory in particular Dr. Pongchai Dumrongrojwatthana and Mr. Kusol Raungpratuangsuk for their physical and spiritual support in field studies.

I would like to thank the local communities especially at Klong Klud village and Taclang village that support the field experiments and participated in the participatory workshop. This dissertation is dedicated to them.

This project was supported by the Thai government budget 2009, under the research program on Conservation and Utilization of Biodiversity and the Center of Excellent in Biodiversity, Faculty of Science, Chulalongkorn University (CEB_D_17_2009), the TRF/BIOTEC Special Program for Biodiversity Research and Training Grant BRT T352002 and Chulalongkorn University. Graduate School Thesis Grant (F-31-GS-ES13_No. 146) and additional funding from the Prachathipok and Rambhai Barni Grant from the Royal Thai Parliament in 2009.

Finally, I would like to express my deepest gratitude and appreciation to my family and Mr. Sampan Panthasa for their love, caring, support and endless encouragement throughout the research study.

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CHAPTER I
INTRODUCTION

1.1. OVERVIEW

Global crab fisheries have continuously declined over the last decade (FAO, 2009). This affected the world fisheries and economy because crabs have provided a source of income for local fishermen in coastal community. Moreover, it plays an important ecological role as predator and prey in the coastal ecosystem.

In Thailand, crab production has shown the decreasing trend from 2000 to 2008, especially the blue swimming crab *Portunus pelagicus* (Linnaeus, 1758) which is important to local economy and food security of Thai people. The combination of fishing pressure and the degradation of coastal nursery habitats has driven the crab population in Thailand to crisis situation (Tiansongrassamee, 2002). The data from the Department of Fishery (2011) showed that the production of blue swimming crab was drastically declined from 43,871 tonnes/year in 2000 to 23,573 tonnes/year in 2008. However the market price of this crab is higher than in the past. The revenue from the crab fishery declined only 9% in 2008 compare to those in 2000 due to the high market demand. This situation creates more pressure on the crab fishery. In order to capture more crabs, fishermen have adapted their harvesting methods or seek for new techniques with fishing efficiency, e.g. the use of gill net with smaller mesh size and high efficiency machines. As a result, the crab production is furtherd driven to crisis. Therefore, an effective management plan is urgently needed.

Unfortunately, there are limited scientific studies on population ecology of this crab, especially nursery ground, habitat of juvenile and adult crab population, and the migration movement between inshore and offshore during its life cycle. Moreover, the study on crab stock density is also limited. These scientific data are important for effective management. The appropriate marking method is also needed to monitor the population dynamics for this species (Kumar, 1997). Therefore, this study aimed to study on the biology and ecology of the blue swimming crab in relation to the movement pattern, migratory route, spawning and feeding habitats in order to propose a sustainable management action plan.

Kung Krabaen Bay of Chantaburi Province (Figure 1.1) is one of the fishing grounds for the blue swimming crab in the Gulf of Thailand. Fishermen in the Bay are divided according to two different types of fishing gears, the collapsible traps and gill nets. In practice, the collapsible trap is used inside the bay, while the gill net is used outside the bay. Due to problems of crab populations and size reduction, this lead to serious conflict on crab harvesting between the two groups of fishermen. Each group suspected that the another group was the major cause of the crab decline in stock due to overharvesting. This misunderstanding is due to the lack of support from relevant crab biological data. Moreover, some of them do not understand about the migration movement of crabs. This enable them to think that the crab in- and outside the bay are of totally different stocks with no relationship between the two populations. The socio-economic problem resulting from declining crab stocks should be taken into account before setting up a management plan.

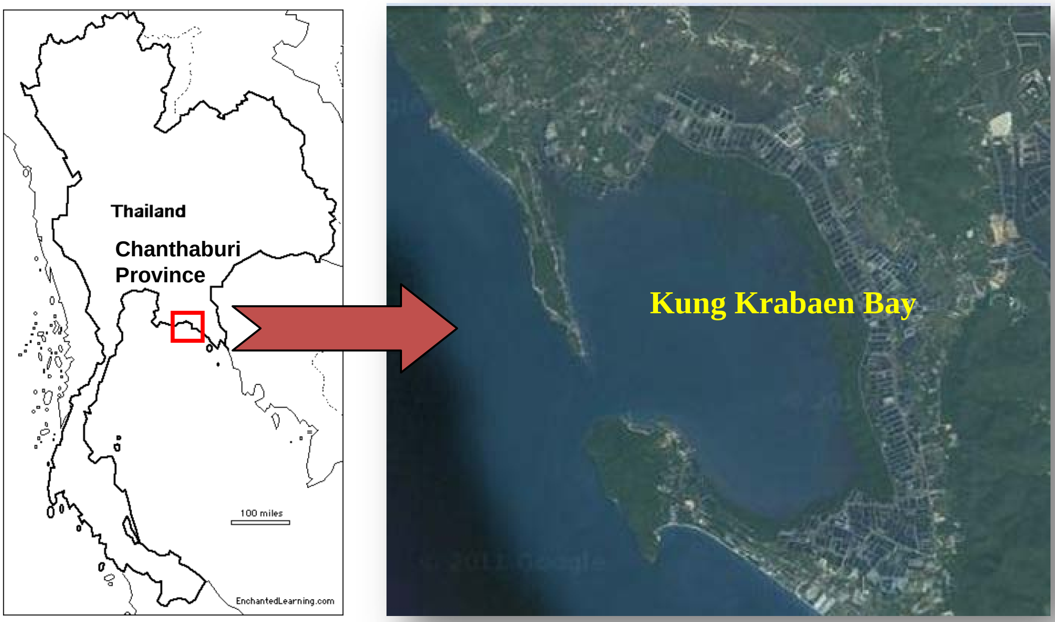


Figure 1.1. Kung Krabaen Bay, Chanthaburi Province, Thailand; study site of assessment of stock and movement pattern for sustainable management of blue swimming crab *Portunus pelagicus* (Linnaeus, 1758)

Source: http://www.maps.google.co.th/maps?hl=th&tab=wl

Due to the local government policy on the above problem, many projects have been promoted, for examples, the establishment of the protected zone during spawning season. However, they are ineffective due to the lack of appropriate communication and interrelationship between local government and local fishermen.

Based on the above information, this research aims to conduct stock assessment and movement pattern of swimming crab based on biological and ecological studies at Kung Krabaen Bay. These scientific findings were integrated with the current socio-economics of the crab fishery in order to draw up the sustainable management plan among stakeholders. To do so, the objectives were set up as specified below.

1.2. OBJECTIVES

1. To assess stock and population structure of the blue swimming crab in Kung Krabaen Bay, Chanthaburi Province,

2. To investigate the movement patterns and migration routes in relation to spawning, nursery and feeding grounds of the blue swimming crab, and

3. To propose sustainable management plan of blue swimming crab in Kung Krabaen Bay based on scientific findings

1.3. HYPOTHESIS

1. Stocks of the blue swimming crab living inside and outside the bay are the same group of population.

2. Juvenile crabs limit their distribution only inside the bay while adult crab can distribute both in- and outside the bay due to migration patterns related to spawning, nursery and feeding grounds.

1.4. SCOPE OF THE STUDY

Stock of the crab was assessed by the FiSAT II (FAO-ICLARM Stock Assessment Tools) Program produced by FAO (Sparre and Venema, 1992). Movement patterns were also studied by capture-recapture method in order to determine the spawning and feeding grounds of blue swimming crabs. Comparisons of natural diets of crabs in various stages were carried out to determine the feeding grounds. The assessment of present management plan based on socio-economic data was carried out based on participatory workshop among stakeholders. The sustainable management plan based on scientific findings was proposed.

1.5. CONCEPTUAL FRAMEWORK

1.5.1 Stock assessment and population structure based on biological and ecological data were carried out in order to assess the present crab production to determine whether there was the risk to overexploitation or in crisis. Moreover, the crab production is depended on the reproductive biology and also the recruitment of larvae.

1.5.2 Movement pattern was studied by capture-recapture method based on the migration of adults to determine the spawning and feeding grounds of blue swimming crabs in Kung Krabaen Bay. Route of migration and distance from releasing point to capture point were created and calculated by ArcView GIS program. These data would support the hypothesis that stocks of the blue swimming crab living inside and outside the bay are the same group. Comparison of natural diets between inside and outside the bay was carried out in order to determine the feeding ground for various stages of crabs. Natural diets are important to crab development in each stage and lead to determine the relationships between diet type and its habitat.

1.5.3 The assessment of present management plan based on socio-economic data was carried out participatory workshop among stakeholders in order to evaluate the efficiency of the present management plan.

1.5.4 The sustainable management plan based on the scientific findings was proposed

Conceptual framework of this study is presented in Figure 1.2

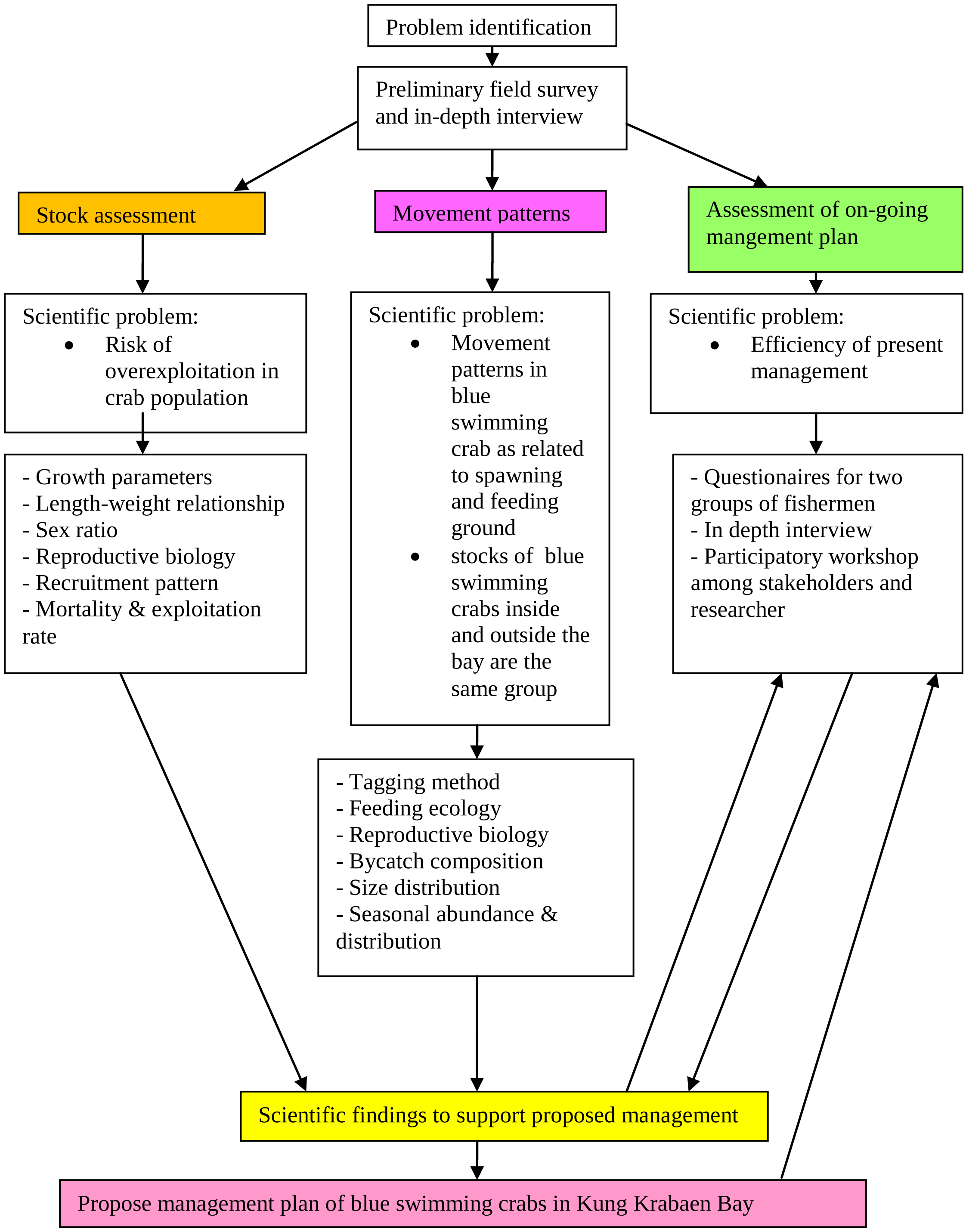


Figure 1.2. Conceptual framework of assessment of stock and movement pattern for sustainable management of blue swimming crabs *Portunus pelagicus* (Linnaeus, 1758): Case study in Kung Krabaen Bay, Chanthaburi Province, Thailand

CHAPTER II
LITERATURE REVIEW

Blue swimming crab *Portunus pelagicus* (Linnaeus, 1758) is a true brachyuran crab belonging to family Portunidae like the other commercial mud crab *Scylla serrata* and *Portunus sanguinolenthus*. Morphologically, they have five pairs of legs which the first pair are chelae, the following three pair are walking legs and the last pair of legs are modified as paddle-shaped swimming legs (Svane and Hooper, 2004). Male crabs are blue, whereas female crabs are brown color (Figure 2.1)

Male Female

Figure 2.1. Male and female blue swimming crab**s**

Current knowledge of the biology of this species has been summarized by Smith (1982) and Potter et al. (1983). Blue swimming crabs inhabit in a wide range of habitat type throughout their life cycle. Juvenile crabs inhabit in shallow seagrass meadows, sand and mudflat and around estuaries. Adults generally inhabit in deeper waters and shallow sandbanks areas within bays and estuaries, however they are also commonly found in offshore waters (Sumpton and Williams, 2002).

2.1. BLUE SWIMMING CRAB FISHERY IN THAILAND

Blue swimming crab *Portunus pelagicus* (Linnaeus, 1758) has a wide geographical distribution throughout Indo-Pacific region (Figure 2.2) (Kaiola et al., 1993). They are usually found in large numbers in shallow bay with sandy bottom (Williams, 1981). This crab is very important commercial species in many countries such as Australia, Japan, India and Southeast Asia countries particularly Thailand. These crabs are distributed throughout coastal area in the Andaman sea and the Gulf of Thailand in the total of 21 provinces (Figure 2.2). The production of this crab in Thailand's commercial fishery currently totalled more than 23,000 tonnes per year (Department of Fishery, 2011). Moreover, the total production of blue swimming crabs were greatly declined from 2000 to 2008 in the coastal areas of Thailand (Table 2.1). Major factors contributing to the reduction in crab productions are overexploitation, loss of the ovigerous female crab in spawning season due to harvesting, inappropriated fishing gears and natural habitat degradation. Types of fishing gears used also have the pronounced impacts on the crab stocks. Two fishing methods are used to harvest blue swimming crab in Thailand including collapsible crab trap and crab gill net. The mesh size of crab gill net is approximately 8-12 cm. depend on the fishing ground while the mesh size of crab trap is approximately 1.7-2.5 cm. These gears are efficient in harvesting the majority of blue swimming crab, representing more than 90% of the total yield in Thailand (Department of Fishery, 2007).

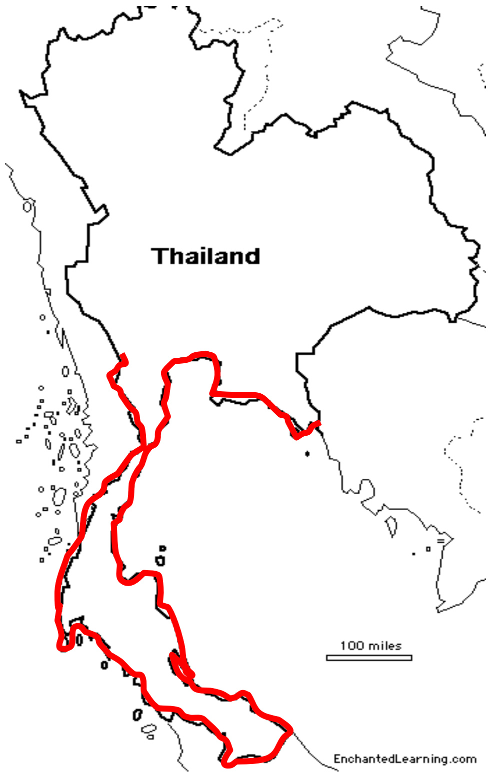


Figure 2.2. Distribution of the blue swimming crabs in Thailand

Table 2.1. Production of blue swimming crabs in Thailand
(Department of Fishery, 2011)

Year	Production of blue swimming crab (Tonne)
2000	43,871
2001	36,805
2002	28,874
2003	32,374
2004	29,524
2005	27,871
2006	31,832
2007	24,221
2008	23,573

2.2. BLUE SWIMMING CRAB FISHERY IN KUNG KRABAEN BAY

Crab traps are usually set twice a day in the shallow water zone of the bay. The fishermen harvest them according to high and low tides either in the morning or during the night. Normally, crabs caught by the crab traps are boiled and the meat taken separately from different parts for sale. The crab gill nets are set offshore for 3 days prior to harvest. Crabs are taken out from nets and sold as fresh crabs of approximately 120 - 250 Baht/kilogram (Figure 2.3 and 2.4). However, many blue swimming crab fishermen are not only harvested blue swimming crabs but also non-target species. These non-target species are known as “bycatch” with limited data. Therefore, this study also aimed to identify bycatch in lowest category. In general, crab fishermen have two major areas for harvesting blue swimming crabs. Crab gill nets are used in the deeper layer or offshore while crab traps are used in shallow water or inside the bay (Figure 2.5) (Kunsook, 2006; Petchgumnerd et al., 2004). However, the present scenario changed with the gill nets fishermen harvesting the crabs inside the bay whereas collapsible crab traps fishermen harvesting the crabs outside the bay. There were the conflicts of interest in crab fishing gears in the Kung Krabaen Bay.

Figure 2.3. Blue swimming crab trap fishery at Kung Krabaen Bay

A; Collapsible crab trap fishermen

B; Mesh size of crab trap = 2 cm.

C; Fresh crabs

D; Crab meat

A B

Figure 2.4. Blue swimming crabs gill net fishery at Kung Krabaen Bay

A; Crab gill net fishermen

B; Mesh size of crab gillnet = 10 cm

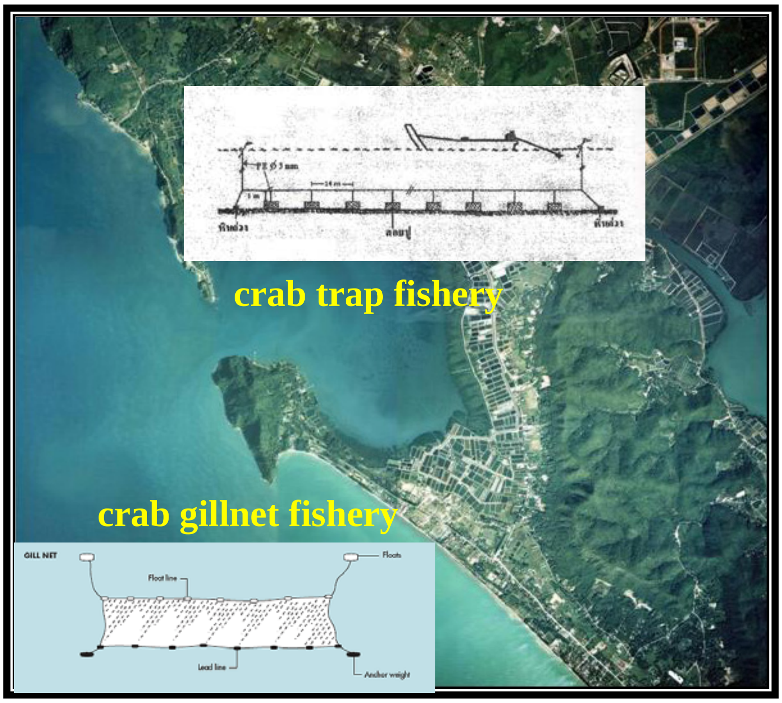


Figure 2.5. Blue swimming crabs fishery area at Kung Krabaen Bay in the past with separate fishing grounds of different gears.

2.3. STOCK ASSESSMENT AND POPULATION STRUCTURE OF BLUE SWIMMING CRAB

Growth and total mortality parameter, recruitment pattern and exploitation rate were calculated by FiSAT II program package (Gayanilo et al., 1994) based on the carapace width (CW) frequency of monthly data caught by fishing gear. This program was the resulted following the merging of its two prodecessors, the Compleat ELEFAN (Electronic Length Frequency Analysis) package and LFSA (Length-based Fish Stock Assessment) (Gayanilo et al., 1994). This program was developed mainly for the detailed analysis of length frequency data, but also enables related analyses, size at age, catch at age, selection and other data typically collected for tropical fish stock assessment. The Electronic Length-Frequency Analysis "ELEFAN I" was used to identify the Von Bertalanffy Growth Function (VBGF) for best fits size frequencies:

$$CW_1 = CW\infty\ (1\text{-exp-}K(t\text{-}t_0))$$

Where

$CW\infty$	=	the asymptotic size
CW_t	=	the size at time
K	=	the growth coefficient
t_0	=	the theoretical age at length 0

A value of t_0 = -0.014 year was used, based on the results of laboratory studies (Jiempreecha and Duang-ongen, 2000).

Probability of capture; Cause of bias in length frequency data is the selectivity of the gears used to obtain the samples. This bias can be in part overcome by correcting size frequency samples with the probabilities of captured. The method was solved the bias of gear selectivity in process below;

1. Estimated $L\infty$ by using Powell & Wetherall method
2. Adapted length of captured for selectivity by use K = 1.0 and $L\infty$ from (1)
3. Using Bhattacharya method to analyse normal distribution of population

4. Estimated average length in Modal progression analysis
5. Estimated total mortality (Z) from selection ogive

Total mortality (Z) of crabs was estimated by the length-converted catch curve method (Pauly, 1983) as contain in FiSAT II program (Sparre and Venema, 1998). The calculations were between collapsible crab trap and crab gill net catches. Natural mortality (M) was estimated with the empirical formula of Rikhter and Efanov (1976). Fisheries mortality (F) was calculated by this below equation:

$$F = Z - M$$

The exploitation rate (E) was calculated as:

$$E = F/Z$$

Beverton and Holt (1957) proposed "relative yield per recruit model" (Y/R) that can be applied to identify the exploitation rate (E). In this model computation of (Y'/R) is the function of the growth and mortality parameters of the stock (CW_∞, K, M, F, E) and the size at which 50% of individuals within that size class are captured (CW_c), which was assessed as the "probability of capture".

The carapace width and weight relationship for both sexes were described by the allometric relationship $Y=aX^b$ which was a log transformed for covariance analysis of the CW/W regression. Sex ratio was calculated by χ^2 –test.

However, in length-based models, many assumptions are based on the growth pattern of the stock, so the errors or biases in the growth model may cause the inaccuracies in the recommended levels of exploitation (Miller and Smith, 2003).

2.3.1. Stock assessment of blue swimming crabs in Thailand

The stock structure of blue swimming crab populations in Thailand is not well understood. There were several studies on stock assessment and management of blue swimming crab in the Upper Gulf of Thailand. The production of blue swimming crabs in the upper Gulf of Thailand from Chonburi Province to Prachuapkhirikhan Province during 1984 to 1998, 87% of the catches were from small scale fisheries sector in this area. Growth parameter had been estimated from length frequency distribution: K = 1.64 per year and $L\infty$ = 18.48 cm. collected from main fishing gears: trawlers, push nets and crab gill nets (Cheunpan and Vibhasiri, 2005). Stock size and exploitation level had been estimated by the cohort analysis. The study also showed that the maximum sustainable yield of blue swimming crabs in this area totalled to 11,000 tons. The measures on 10% reduction of current fishing efforts by the totally banned push net and reducing fishing effort of trawler were advisable for long term management (Cheunpan and Vibhasiri, 2002). Recently, there were some studies on the stock assessment of blue swimming crabs such as case study in Trang Province by Sawusdee and Songrak (2010) found that $L\infty$ = 17.3 and K= 1.5 per year. The total mortality was 8.96 per year, natural mortality was 1.61 per year and fishing mortality was 7.35 per year. The exploitation rate was 0.82. The stock assessment also showed that the maximum sustainable yield was 364.33 tonne. The maximum economic yield was estimated 25.29 million Baht with the total biomass of 139.83 tonne.

2.3.2. Stock assessment of blue swimming crab in Kung Krabaen Bay

During the last decade, the production of blue swimming crabs in Kung Krabaen Bay drastically declined. The comparison of the blue swimming crab productions in 2002 (120 tonne) to the production in 2004 (80 tonne), clearly demonstrated the decreased production of 33.4% (Kunsook, 2006). In addition, the size of crabs was reduced dramatically. However, the blue swimming crabs fishing still play the important role in terms of ecological and socio-economic aspect in Kung Krabaen Bay. It is the source of local income and jobs opportunities to villagers. It is also play the important role in term of ecology for its relationship to different trophic level in the food webs. The crab fishery also associated with the production of fish and other aquatic resources in Kung Krabaen Bay ecosystem. If the crab fishery process as usual without the implementations of appropriated management, the risk of possible collapse in crab fishery may exist in the near future. This will have tremendous impacts on food security not only at the local level but also the national level.

The stock assessment of the blue swimming crabs in Kung Krabaen Bay in relation to seagrass beds inside the bay were investigated by Kunsook (2006); Bhattarasatapornkul et al. (2008) and Raungprataungsuk (2009). The result showed in Table 2.2

Table 2.2. Timeline of stock assessment of blue swimming crabs *P. pelagicus* in Kung Krabaen Bay

	Kunsook (2006) 2005	Bhattarasatapornkul (2008) 2007	Raungprataungsuk (2009) 2008
L∞,	13.23,	13.81	12.23
K	0.87	1.52	0.56
Total mortality	2.96	3.77	1.31
Natural mortality	1.84	2.94	0.82
Fishing mortality	1.12	0.83	0.49
Exploitation rate	0.38	0.25	0.37
Peak of recruitment	February to March 2005 and July toOctober 2005	June to September 2007	June to August 2008 and December 2008 to February 2009
Sex ratio	1:1.19	1:0.93	1:0.5

From the Table 2.2 the parameter of the blue swimming crab stocks were showed during different period in Kung Krabaen Bay since 2005, 2007 and 2008. This table showed in 2009 that L∞, K, and total mortality were lower than the previous study from Kunsook (2006) and Bhattarasatapornkul (2008). However, difference in sample collection should be considered and carefully to compare. In these studies (Kunsook, 2006; Bhattarasatapornkul, 2008) and Rueangpratuangsuk, 2009), the researchers sampled the crab specimen from only one fishing gear. In addition, crab specimens also sampled just only inside the bay so crab specimens would not cover all stages of population. The adult crabs were not pooled in these studies. Moreover, stock assessment knowledge would clarified and proved that crabs live inside and outside the bay were related of the same stock using capture and recapture technique.

2.4. MOVEMENT PATTERN OF BLUE SWIMMING CRABS

2.4.1. Movement patterns in brachyuran crabs

Understanding animal movement patterns in time and space is a fundamental of the study of animal ecology and the design of effective conservation and resource management strategies. Animal movement is an important ecological process that determines the spatial, demographic and genetic structure of population (Hanski and Gilpin, 1997; Wiens, 2000). For several decapod and fish species, movements between habitat types, such as coral reef and the adjacent of seagrasses and mangroves are critical to the maintenance of population in an area. A wide variety of strategies and tactics in decapod crustaceans has evolved, often exhibiting high phenotypic plasticity in response to complex abiotic and biotic environment and processes, including human activity (Rochet, 2000).

The strategies in these decapod crustaceans determined the patterns and purpose of movements in both time and space such as offshore spawning migrations and the subsequent use of inshore nursery areas. Such movements and resource use pattern have been observed and documented for many years and have probably always been an important process for human coastal populations (Pittman and McAlpine, 2003). Shallow water, decapod crustaceans usually have the tri-phasic life cycles involving: 1) movement of planktonic eggs and larvae for settlement in nursing and feeding ground; 2) movement of juvenile to shallow water areas for nursing and feeding ground; and 3) movement of adult to deep water for finding food source and spawning site (Figure 2.6). Tantichaiwanit (2005) studied the distribution and density of brachyuran larvae at Kung Krabaen Bay. The result showed high density of brachyuran in the seageass beds *Enhalus acoroides* during Southeast monsoon and at the mouth of the bay in Northeast monsoon. Raungprataungsuk (2009) found that the megalopa stage of blue swimming crabs settled in the seagrass bed *Enhalus acoroides*. These studies revealed the importance of seagrass beds in Kung Krabaen Bay as nursing grounds for the planktonic larvae of blue swimming crabs. Two patterns of brachyuran were observed as the non-spawning and spawning movement. A non-spawning migration is a highly directional movement to temporary alternative home range. This is usually associated with seasonal changes in environmental factors, such as temperature or salinity and with the locating food sources. Regarding to spawning migration, the females of many decapod crustaceans due to spawning migration undergo long-distance migrations to release eggs and larvae in the favorable and suitable areas for early development. The risk associated with migration can be costly for the individual females, including acquiring and allocating high energy for both migration and oogenesis and increases predatory or mortality risk. However, the strategies used by the female including migratory processes, timing of migration, route of migration often promote the success of completed migration and maximize the survival of offsprings. Understanding the role of migratory movements in determining life history, distribution, and population dynamics is necessary for the effective management of exploited species.

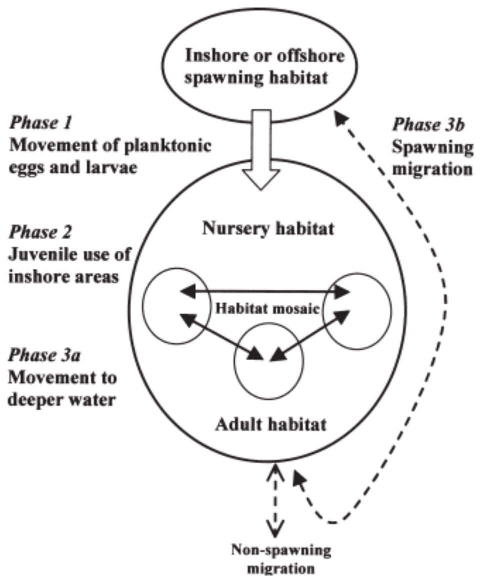


Figure 2.6. Tri-phasic life cycle of decapods crustaceans

Source: Pittman and McAlpine (2001)

The migratory patterns in relation to the life history of aquatic animals in temperate zone are with specific migratory season, but this was not the case in the tropical area. The female crab migration in Thailand is poorly understood. The phases of movement and what happen after the mature females released their eggs in the deeper water outside the bay has not been documented. It is uncertain whether the female move back to the bay or inhabit in deeper water until they die. There is only the assumption on the habitat of juveniles and the possibility of larvae being released in deeper water or outside bay. Water currents and wind in monsoon season bring the planktonic larvae to the bay. The juvenile crabs inhabit in seagrass beds as nursing ground and grow to maturation and mate inside the bay. After that they moved out in deeper water. Almost of adult crabs lived in deeper water did not move in the bay while the immature crabs live in shallow water because they had risk to eaten by predator and affected by physical factors (Tantikul, 1984). However, from this assumption, there are the arguments from researches that report that adult crabs distributed in various areas such as shallow water, nearby rehabilitation mangrove forest, near the estuary and deep creek in the bay (Jindalikhit et al., 2002). Understanding the crab movement pattern would be useful for the policy maker to establish the more efficient crab management policy.

2.4.2. Distribution of blue swimming crabs

In Thailand, blue swimming crabs widely distributed along the coast of Andaman Sea and the Gulf of Thailand. The proportion of these crab populations in the Gulf of Thailand is higher than in Andaman Sea. Juvenile crabs inhabit in seagrass beds and shallow water inside Kung Krabaen Bay for protection from high waves and strong winds during monsoon seasons while adult crabs inhabit in deeper water outside the bay (Tantikul, 1984; Kunsook, 2006). Blue swimming crabs distributed from the intertidal zone to at least deeper water of 50 m depth (Edgar, 1990). The study on the distribution of blue swimming crabs in Chonburi province, Thailand was conducted from January 1999 to December 2000, small size crabs (3.5-6.0 cm in carapace width) was caught nearshore (less than 3 nautical miles from shoreline) and in shallower water stations (less than 10 meters depth). The study indicated the shallow water area was the feeding ground of these crabs. Medium size crabs (6.5-9.0 cm of CW) distributed in the range of 1-8 nautical miles offshore and 3-25 meters depth. Large size crabs (9.5-12.0 cm of CW) were most abundant in the distance more than 4 nautical miles offshore of more than 10 meters depth (Jindalikhit et al., 2002). Moreover, there was the study on the distribution of this crab by Nitiratsuwan et al. (2010) in Trang Province. This study showed that juvenile crabs were found in inshore and related with the seagrass bed area whereas adult crabs were found mostly offshore.

2.4.3. Reproductive biology of blue swimming crabs

In tropical regions, *P. pelagicus* breeds throughout the year (Batoy, 1987), whereas in temperate regions the reproduction is restricted to the warmer months. Previous studies have revealed the reproductive biology of blue swimming crabs varied between locations such as the time of spawning (Potter and de Lestang, 2002) and size at maturity (Chaplin et al., 2001; Jindalikhit, 2002; de Lestang et al., 2003). The spawning of blue swimming crabs in Thailand take places throughout the year with two peaks during high salinity periods (Jindalikhit, 2002; Kunsook, 2006). Average fecundity was two million eggs per batch, with larger crabs producing more eggs than smaller crabs.

The ovarian development was classified by Sumpton et al. (1994) as follow:

Stage 1: Gonad immature, white and translucent

Stage 2: Gonad maturing, light yellow/orange, not extending into hepatic region

Stage 3: Gonad maturing, yellow/orange extending into hepatic region

Stage 4: Gonad mature, dark yellow/orange extending into hepatic region

Stage 5: Ovigerous, female bearing fully matured eggs (pale to dark yellow eggs) externally

Previous studies showed ovigerous females moved offshore to spawn as in mud crab *Scylla serrata* (Hill, 1994) and blue crab *Callinectes sapidus* (Hine et al., 2008). After spawning, eggs would be hatched and developed into various larval stages; zoea megalopa and juveniles. These larvae moved towards the shore for settlements. Water current plays the vital role for larval migration inorder to settle on appropriate habitats. The post larvae crabs choose to settle on habitats that provide refuges and abundant food. They moved sometimes into more beneficial habitats shortly after settlement (Moksnes et al., 2003). Nursing grounds help the probability of survival for juvenile crabs and subsequently contributing to future recruitments (Beck et al., 2001). Seagrass beds provide ideal nursery habitats for juvenile marine crabs by providing refuges from predators and abundance food sources (Jackson et al., 2001). Juveniles of two portunid crabs; *C. sapidus and P. pelagicus* were found associated with seagrass beds. These nursery habitats provided complex structures restricting the movement of larger predators preying on these small juvenile crabs.

2.4.4. Feeding ecology

Natural diets of blue swimming crabs have been widely studied by examining the stomach contents using two methods; frequency of occurrence and percentage point (Patel et al., 1979; Hyslop, 1980; Williams, 1981, 1982; Edgar, 1990). The results indicated that blue swimming crabs were primarily carnivores feeding on a wide variety of benthic animals. Lesser quantities of marine plants and seagrass were also consumed (Wu and Shin, 1998). Blue swimming crabs were considered to be opportunistic predators. Their diets depended on the availability of food items (Williams, 1982). Williams also found that diet compositions slightly changed with size as compared to other brachyurans that prey species changed with increasing size. This finding corresponded with Edgar (1990) that found size-related changes in the diets of crabs. These ontogenetic niche shifts were influenced by the different habitats in small and larger crabs. During the planktonic phase, the larvae were plankton feeders feeding on phytoplankton and zooplankton such as chaetoceros and rotifer (Josileen and Menon, 2004). Natural diet of juveniles and adult crabs in Kung Krabaen Bay were studied by Kunsook (2006) indicating the main food items of immature males were mollusks, fish, and crustaceans. The main food items of mature males were fish, crustacean and mollusks. Immature females feed mainly on fish, mollusks and crustaceans while mature females feed on fish, crustaceans and squids (Table 2.3). Dietary composition of the blue swimmer crab *Portunus pelagicus* in Australia showed that juvenile crabs feed on large quantity of cruataceans, bivalve mollusks while adult crabs feed on polychaetes and crustaceans (de Lestang et al., 1999). Natural diet of juveniles and adult blue swimming crabs were also investigated along the coast of Mandapam, Tamil Nadu, India. The result showed that juvenile crabs (<80 mm CW) feed mainly on debris (41.4%) followed by crustaceans (27.7%), and miscellaneous items (19.2%). In adults (100-140 mm), crustaceans were the principal food item, whereas in the larger size of adults (141-180 mm) feed on fish and miscellaneous materials.

Table 2.3. Ontogenetic niche shift in blue swimming crabs at Kung Krabaen Bay, Chanthaburi Province (Kunsook, 2006)

Stage of development	**Major prey items**	**Other prey items**
Immature male (CW<7 cm)	mollusks, fish, and crustaceans	sand, seagrass , algae
Mature male (CW>/=7 cm)	fish, crustacean and mollusks	organic matter, seagrass, algae
Immature female (CW<8 cm)	fish, mollusks and crustaceans	sand, algae, seagrass
Mature female (CW>/=8 cm)	fish, crustaceans and squids.	mollusks, organic matter

The study on natural diets in blue swimming crabs larvae and juveniles in Kung Krabaen Bay strongly indicated the importance of seagrass bed as the nursery habitat and food sources for crab larval and juveniles. Settlement of megalopa larvae in some habitats provided the protection for crab larvae (Raungprataungsuk, 2009). Migration in the crabs, moreover than for reproductive purposes only but there were clearly related to finding suitable food sources. Food availabilty for crabs are depended on seasonal variation and enviromental changes such as salinity and temperature changes. Ontogenetic niche shift is also affected the migration of brachyuran decapods.

Richard (1992) studied habitat selection and ontogenetic niche shifts in habitat use by the Jonah crab *Cancer borealis.* The result showed that crabs of different sizes selected different alternative habitats.

Chande and Mgaya (2004) studied food habits of the blue swimming crabs *Portunus pelagicus* along the Coast of Dar es Salaam, Tanzania. The result showed that main food items included molluscs (51.3%), crustaceans (24.1%), fish bones (18%) and unidentified food items (6.6%). The dominant food item was the bivalves *Arcuatula arcuatula*. The result also showed that there was no significant difference in the frequency of occurrence of food items among sexes and sizes of *P. pelagicus*, or according to season. However there were significant differences between the different food items and the frequency of their occurrence in the stomachs of ovigerous and non-ovigerous females. The former spend more time grooming their eggs than feeding. The important of food types in the diet differs depending on the nature of the habitat in their life stage. Crabs occupy many different niche and inhabit many different habitat in a variety of geographical areas.

Josileen (2011) studied food and feeding of blue swimming crabs at Coast of Mandapam, Tamil Nadu, India. The result showed crab diets included crustaceans, molluscs, fishes, unidentifiable matter, and debris. In adult crabs, crustaceans constituted the dominant food source of 78.43% of the stomachs analysed. The result also showed no significant differences between sexes in the frequency of occurrence of food items. There were significantly in also the differences in the preference for food items in the different size groups of the crabs differences between the stomachs of ovigerous and non-ovigerous females.

In other portunid crab, *Thalamita crenata* as studied by Canicci (2005) showed that this species fed mainly bivalves and slow moving crustaceans. There was no significance difference in diets between juveniles and adult crabs.

2.4.5. Capture and recapture technique

Generally, capture and recapture technique is used to study movement and migration of marine animal in coastal ecosystem. Targeted animals are caught and attached with tag and released in the capture area. Tagging organisms is an important technique used by fishery ecologist to estimate population size, movement patterns, growth rates and the effectiveness of restocking programs (Bannister et al., 1994). For tagging method to be successful for crab population study, it should not have the effect on the survival rate of these crabs during application. It also should not interfered with the molting process and the inter-molt period. The tag must also have good visibility at capture, while not compromising survival potential or potential for recapture (Begon, 1979). Tagging studies confirm that life cycle movement occurs across a wide range of spatial and temporal scale. Similarly, mark-recapture approaches have previously been used in mud crabs to study age-at-maturity and growth (Hill, 1975; Barnes et al., 2002), as well as migration and distribution (Hill et al., 1982). Depending on the objectives of the studies, long term or short term recaptures intervals are applied. Long term studies are typically designed to estimate growth, migration and recruitment patterns. In contrast, population assessments are usually undertaken over short-term periods (Barnes et al., 2002). There are several techniques to tagged crab such as *Cancer antennarius* were tagged by Floy model FD-65B at 1 cm from the posterior margin of the epimersal suture (Carroll, 1982). Mud crab, *Scylla olivacea*, were tagged by using double tagging attached at the swimmeret position and button tags attached to the carapace (Koolkalaya et al., 2006). Blue swimming crabs in Australia were tagged by using t-bar anchor tags (McPherson, 2002) (Figure 2.7). Williams (1986) assessed plastic anchor tags to study migration and populations of blue swimming crabs and reported no short term effects on the crabs. However there were problems with the visibility of the tag post-capture. For this reason, Williams (1986) also recommended against the use of this plastic tag for population studies but it would be appropriate for short term migration studies. It should not be use for long period due to the complication to the molting process.

Figure 2.7. Tagging techniques

The migratory patterns of blue swimming crabs in Australia were undertaken in Moreton Bay by tagging studies. Movement of blue swimming crabs in Southern Queensland was concluded from these studies (Potter et al., 1987; Sumpton et al., 2003). The results from tagging studies indicated the movement of crabs into the deeper waters as they grew. The tagging studies in Moreton Bay, Queensland have revealed that crabs were capable of travelling the long distance up to 20 km in a single day (Sumpton et al., 1994). Movement patterns appeared to be in the same vicinity. From the tagging studies in Moreton Bay in the 1980s, over 80% of recaptured crabs were caught less than two kilometers from the released points and only 4% were recaptured of more than 10 km from their released point (Potter et al., 1991). Generally, blue swimming crabs migrate to spawn offshore. This migration is thought to be necessary for the survival of the larvae due to lower oxygen levels, low salinity and lack of suitable food in estuaries or inshore (Meagher, 1971; Kangas, 2000).

Furthermore, the study on the movement of blue crab populations *Callinectes sapidus* in Chesapeake Bay, USA showed that female blue crabs were tagged to estimate the annual survival rate of adult female blue crabs. The survival rate was less than 10% in Chesapeake Bay. It found that crabs tagged within the spawning sanctuary were less likely to be recaptured than those tagged outside the sanctuary (Lambert et al., 2006). Tagging study also used to obtain estimates of natural mortality for blue crabs such as mortality due to all causes other than fishing (Hewitt et al., 2007).

2.5. BLUE SWIMMING CRABS MANAGEMENT

In the past, top down approaches in fishery management are widely implemented in Thailand such as the regulations on fishing gears, restrictions on size and sex of animals caught, off season fishing during certain period of the year and restriction on berried females fishing. This, however, proved unsuccessful due to the sharp decline in fishery production in Thailand (Chantharachoti, 1998). Therefore, the new approach of fishery management is introduced such as co-management, community-based management, ecosystem-based management as well as integrated coastal zone management (ICM) (Chua, 2006). The current management in blue swimming crabs in Queensland, Australia based on research findings, proposed several strategies in sustainable management as follows: 1) prohibition on female crabbing 2) minimum size limit 3) gear restrictions 4) limit entry of commercial fishery 5) area closed to fishing. Each year, the production of blue swimming crabs were monitored by the researchers to provide data for adaptive management for future management plan in next year or long term (Sumpton et al., 2003).

2.5.1. Blue swimming crabs management in Thailand

In Thailand, there are many studies on crab management with emphasis on mud crab (*Scylla serrata)* especially in the southern Thailand. The management was based on reproductive biology and migration. Blue swimming crabs management plans were also studied in many areas due to overexploitations and increased importance as economic species such as Pathew district, Chumphon Province, Donsak and Chaiya District, Surat Thani Province, Sikao district, Trang Province. (Petchkamnerd et al., 2004; Srichanngam and Rungruang, 2006; Nitiratsuwan et al., 2004)

The Andaman Sea Fisheries Development Center had attempted to explore the optimum mesh size of crab trap for catching blue swimming crabs (*P. pelagicus*) in Phang-nga Bay, Phang-nga Province in order to solve the conflicts among fishermen. The optimum mesh size was 2.5 inch bottom net resulted in high catch rate of blue swimming crabs. The size at first capture was 8.7 cm which mainly matured crabs. However there are difficulties in terms of practicality in increasing mesh size. Building awareness among fishermen not to catch small crabs was also difficult. The wholesalers should be encouraged not to buy small size crabs. It is hard to enforce in reality (Yoodee, 2002).

Thailand is an important crab production exporter. At present, the production of export crabs to the U.S.A. have continuously declined from 4,000 tonne in 2010 to 3,430 tonne in 2011 (Thai Frozen Foods Association, 2012). This is also true to many countries that exported blue swimming crabs such as Australia, Canada, and Taiwan. Several trade barriers had been laid down by the National Fisheries Institute (NFI), U.S.A. on strict measures for foreign importers outside U.S.A. to participate in sustainable management in blue swimming crabs fishery in particular the restriction on the minimum size/weight of blue swimming crabs to be caught, sold, or traded is 10 cm. Restocking measures were required by setting up a crab bank, protection of seagrass beds and other coastal habitat, and restriction on the catch of gravid females or berried females during spawning season. These measures were carried out in the Philippines Indonesia and Vietnam. However, these measures were not strictly enforced in Thailand. Sustainable management plan for blue swimming crabs is needed.

2.5.2. Blue swimming crabs management in Kung Krabaen Bay

The fishery regulation in blue swimming crab fishery required the limited mesh size of collasible crab traps and crab gill nets. Mesh size of crab trap and crab gill net were 2.5 inch and 8 cm, respectively. There are also the regulations of crab gill net fishery in Kung Krabaen Bay. There was restriction in using crab gill net to harvest blue swimming crabs inside the bay. Again this was not fully enforced.

In term of restocking, there have been the increased in the crab bank projects in many coastal areas of Thailand including in Kung Krabaen Bay. Crab banking was initiated by the officers of the Kung Krabaen Bay Royal Project with supporting fund from the Department of Fishery. These crab banking projects were effective and widely accepted by the fishermen due to low cost and practicality (Figure 2.8). Fishermen were able to cooperate in the crab bank project by donating the ovigerous females to the crab bank of the Royal project. Once the crabs released their eggs, they would be returned to the fishermen. The fishermen in Taclang village were not able to carry out the crab bank project due to location of the village. The village was located further on shore that the tidal level is not appropriated for setting up crab banks.

Figure 2.8. Crab bank project at Klong Klud village, Kung Krabaen Bay

However, the officers of the Kung Krabaen Bay royal project proposed the alternative solution in Taclang fishermen by implementing the crab bank in the old abandoned shrimp ponds. However this had not been successful. Last year, Chanthaburi Provincial Fisheries office, Department of Fishery supported the budget to make a crab bank in Taclang Village and the fishermen in this area can donated the ovigerous females into the crab bank (Figure 2.9). The success of the crab bank would be monitored continuously based on the survival rate of zoea and megalopa after berried female sheded their eggs. Environment factors within the vicinity of the crab bank were also monitored.

A B

Figure 2.9. Crab bank project at Taclang village

A; Crab bank was supported budget by Chanthaburi Provincial Fisheries Office, Department of fishery

B; Donated crab from Taclang fishermen

CHAPTER III
METHODOLOGY

3.1. SITE DESCRIPTION: KUNG KRABAEN BAY

Kung Krabaen Bay, located between latitude 12° 34’-12’N and longitude 101°53’-101°55’E, is a small semi-enclosed estuarine system on the west coast of Chanthaburi Province, the east coast of Gulf of Thailand. The bay size profile is approximately 2.5x4.0 km^2 with an average depth of 2.5 m. The bay area is 10 $km^2$of the total volume of 2.5x10^7 m^3. The bay is connected to the Gulf of Thailand via a channel of 700 m width on the southeastern corner of the bay. The bay is strongly influenced by salinity variations, during dry season (typically November to April) and rainy season (May to October) under the influences of the two monsoons: the north-east monsoon and the south-west monsoon. Maximum rainfall of approximately 800 mmwas from May to October while the minimum rainfall recorded approximately 30 mmin March. The annual average rainfall in the area is 2,800 mm. High diversity of habitat types such as mangrove forest, seagrass beds, coral reefs were found. In Kung Krabaen Bay, blue swimming crabs are widely distributed both inshore and offshore, living in the mud and sandy substrates.The crab populations are overexploited by two fishing gears namely collapsible crab traps often used inshore and crab gill nets used offshore. This area is one of the most important blue swimming crabs fishing ground in Thailand. However overexploitation posed a threat to the crab fishery resources (KKBRDSC, 2003).

3.2. STOCK ASSESSMENT

Stock assessment data is the useful measurable indicator to determine whether the present stock is in crisis or not. These data included growth parameter, relationship between carapace width and weight, sex ratio, total mortality and exploitation rate. The data on reproductive biology also included to support the recruitment of crab larvae.

Sample collections

Crabs were collected monthly for 13 months from October 2008 to October 2009. Collapsible crab traps (mesh size 2 cm) and crab gill nets (mesh size 10 cm) (Figure 3.1) were used in the 27 stations designed to collect the samples in both inside and outside the Kung Krabaen Bay (Table 3.1 and Figure 3.2)

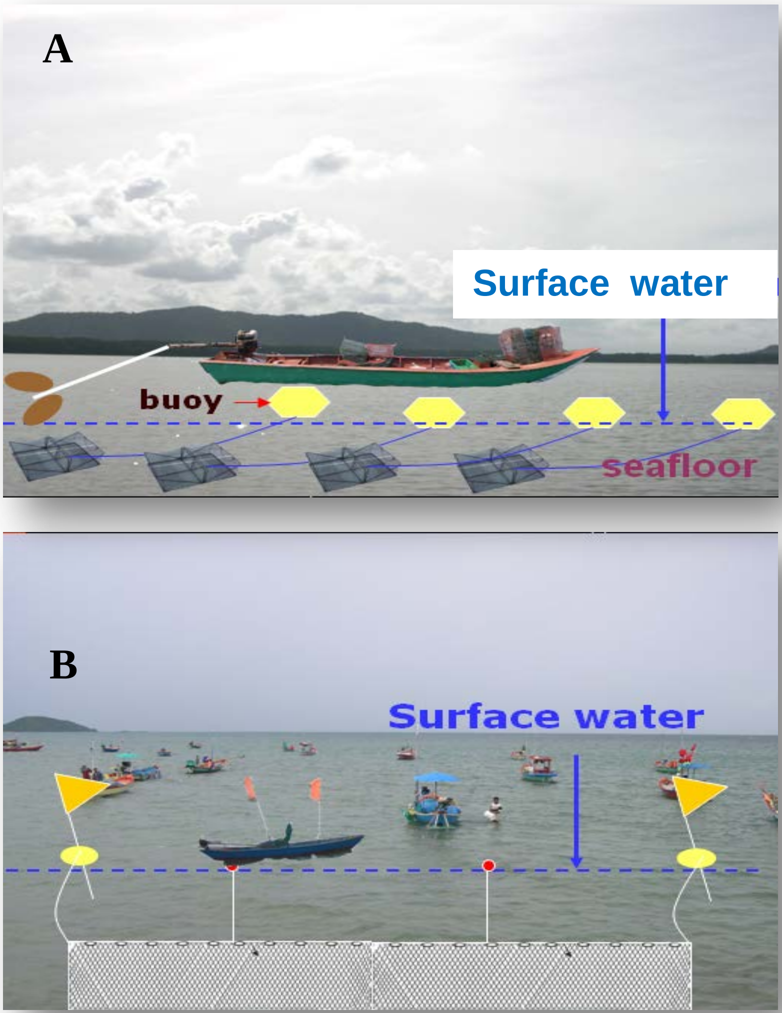


Figure 3.1. Sample collection by (A) collapsible crab traps and (B) crab gill nets

Table 3.1. Sampling stations for stock assessment and movement patterns of blue swimming crabs, *Portunus pelagicus* in Kung Krabaen Bay during October 2008 to October 2009

Group	Number of station	Station	Description of habitat and location
1	6	SG11, SG12, SG13, SG31, SG32, SG33	seagrass bed (*Enhaulus acoroides*)
2	3	SG4, SG5, SG6	seagrass bed (*Halodule pinifolia)*
3	3	M1, M2, M3	near mangrove reforestation
4	3	U1, U2, U3	bare ground
5	3	KV1, KV2, KV3	in front of the Kung Viman Beach
6	3	KB1, KB2, KB3	in front of the Kung Krabaen Bay
7	3	KL1, KL2, KL3	in front of the Chao Lao Beach
8	3	P1, P2, P3	in the vicinity of the mouth of the bay

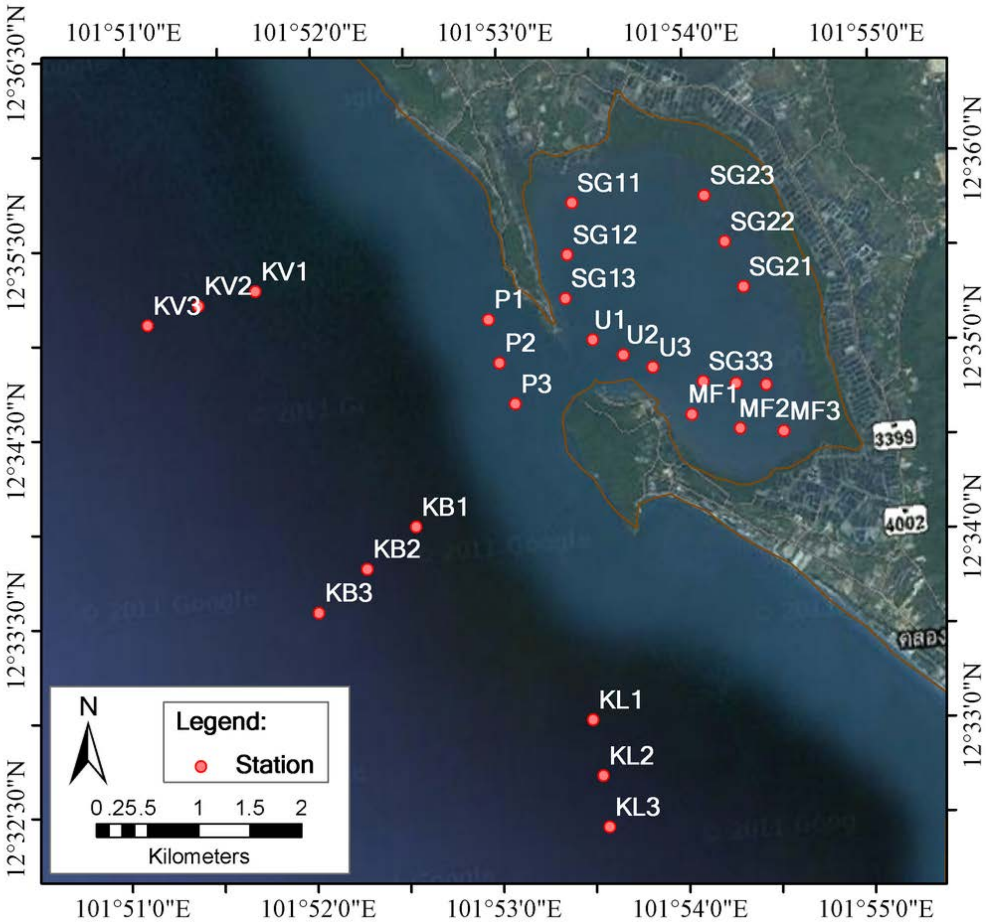


Figure 3.2. Study area of assessment of stock and movement patterns of blue swimming crabs at Kung Krabaen Bay, Chanthaburi Province, Thailand

Remark: SG	=	Seagrass bed	KB = Kung Krabaen Bay
MF	=	Mangrove forest	KV = Kung Viman Beach
U	=	bare ground	KL = Chaolao Beach
P	=	Mouth of Bay	

Environmental factors namely temperature, salinity and dissolved oxygen were monitored monthly at each station. Crabs were sexed and measured the outer carapace width (OCW) and weight (nearly in 0.01 mm and 0.01 g). Thirty adult female crabs were collected for each gonad somatic index and fecundity analysis.

Data analysis: Stock assessment

3.2.1. Stock assessment was evaluated by using FiSAT programme. (FAO, 1998). Growth rate, total mortality, include natural and fishing mortality, recruitment pattern, yield per recruit estimate and the exploitation rate were calculated by this program based on carapace width and frequency distribution (Pauly, 1983; Sparre and Venema, 1998). Crab production structure includes sex ratio, relationship between carapace width and weight. The CW/W relationships for both sexes was described by the allometric relationship, $Y = aX^b$ which was log-transformed for covariance analysis of the CW/W regression lines.

3.2.2. Reproductive biology was studied by examining ovary development, size at maturity, gonad somatic index and fecundity. Stage of ovary development was analysedusing methods described by Svane (2004).

Size at maturity; female blue swimming crabs were classified as mature female when the oval shaped pleonal flap could be separated from the carapace (Smith et al., 2004). The size of female at which 50% (L_{50}) were matured and estimated by fitting a logistic regression curve to the proportion of mature blue swimming crabs for each sequential of 1 mm CW size class as described by King (1995); Oh and Jeong (2003).

$$\text{Proportion ovigerous} = \frac{1}{1+\exp^{(-a+bOCW)}}$$

Where a and b are the equation coefficients,
OCW is outer carapace width of female crab

Gonad somatic index (GSI) was calculated by using formula proposed by Geise and Pearse (1974); Sukumaran and Neelakantan (1998).

$$GSI = \frac{\text{Wet weight of ovary (g)} \times 100}{\text{Body weight of crab (g)}}$$

Fecundity was calculated by counting the number of eggs present on the pleopod in ovigerous female. The egg was removed from the pleopod and immersed them in sodium hydroxide. It was freed from pleopod after 3 hours filtered and weighted to nearest 0.1 mg. A sample of the egg mass thus separated was weighted and counted before total number of whole egg mass was determined using the formula.

$$F = P/P^1 \times n$$

Where P = the weight of egg mass

P^1 = the weight of the sub sample

n = the total number of eggs in the subsample

Sub-samples were taken as 3 replicates and the average number of eggs per subsample was estimated. The total numbers of eggs per egg batch was calculated.

The relationship between size of crab (OCW) and fecundity was estimated separately for each month by fitting linear regression for CW and fecundity (Sukhumaran and Neelakantan, 1997).

3.3. Movement pattern

This measurable indicator was carried out in order to prove the hypothesis that crab populations inside and outside the bay were the same group and were related. Feeding ecology was also studied to determine the relationships between diet type and its habitat. Movement of crab between both sites was studied by short term tagging using double tag. In the preliminary tagging experiment, double tagging was more visible and easy to detect than one tag. Electric line was attached in the carapace of the crab to improve the visibility of the tag for fishermen. This was easily observed than the anchor tag. However, electric line tag was removed during the molting period while the anchor tag was still intacted. This tagging method was proved efficient inshort term period. Short term period is samples to support the study on movement of crabs between inside and outside the bay. Tagging experiment was carried out in various locations in the area of Kung Krabaen Bay during February to March 2010.

Laboratory experiment

Effective of anchor tags and electic line tags include double tag were tested in laboratory. Fifteen blue swimming crabs were catched by collapsible crab trap. Samples were divided in three groups with five crabs each. First group was tagged with anchor tag in the swimming leg area, while the second group was tagged with electric line tag in carapace near the lateral teeth area. The final group was tagged by using both of tags or double tag. After crabs in each group were tagged, they were released in the 1mx1m size cages for the observation on the percentage of survival rate and percentage of disengagement (Figure 3.3). These experiments were conducted in 3 replicates.

A **B**

Figure 3.3. Laboratory design (A) cage (B) Tagged crab

The result in the Table 3.2 showed that survival rate of blue swimming crabs in anchor tag was lowest (33.33%) when compare with the electric line tag and double tag but percentage of disengagement was higher than the electric line tag and double tag. In contrast with the survival rate in electric line tag was higher than other tags and percentage of disengagement was also highest. The survival rate of blue swimming crabs in double tag was high but lower than the electric line tag while percentage of disengagement was lowest. For this study, double tagging was selelcted to use in field experiment by consider the condition of survival rate and disengagement of tag.

Table 3.2. Percentage of survival rate and percentage of disengagement

Type of tag	%survival rate	%disengagement
Anchor tag	33.33%	20%
Electric line tag	60%	40%
Double tag	46.67%	13.33%

Field experiment

Before the field study started, the information about tagged crabs, recapture zone (Figure 3.4) and capture rewards to fishermen were announced to fisherman via village meetings, brochure and community broadcast radios (Potter et al., 1991; Sumpton et al., 2003; Koolkalya et al., 2006, Le Vay et al., 2007). The fishermen were requested to record the data of tag number, capture date, capture location, and capture gear for every tagged crab caught. Captors would received reward of 30 Baht/tagged crab with complete data. This experiment was conducted in during mating season based on the works of Kunsook (2006) and Raungprataungsuk (2009).

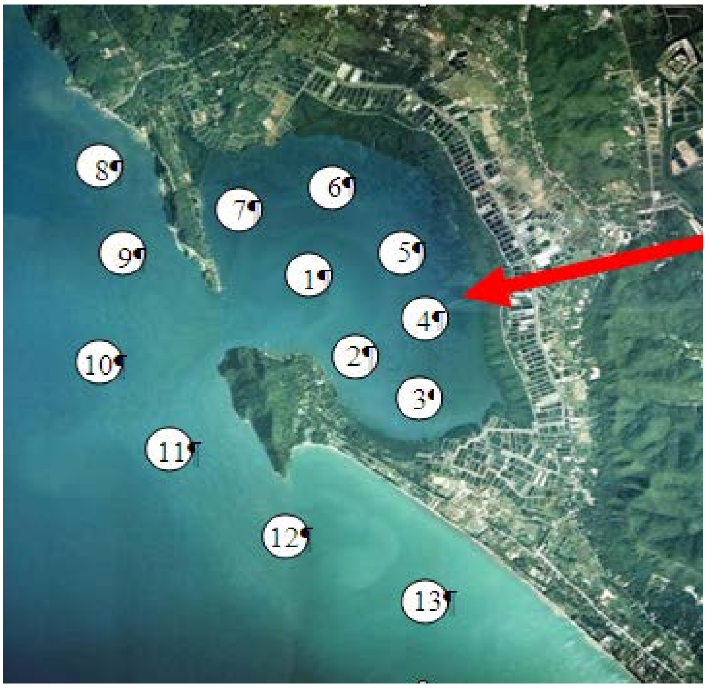


Figure 3.4. Recapture zone of movement patterns study at Kung Krabaen Bay, Chanthaburi Province

The crabs inside the bay were caught by collapsible crab traps. Sex and carapace width were measured. Afterward crabs were tagged by using double tagging with anchor tags (Figure 3.5B) attached at the swimmeret position modified from the method of Potter et al. (2001). Electric line tags (Figure 3.5C) were attached to the carapaces (Figure 3.5D). After the crabs were tagged, they were tested for5 minutes for survival before releasing in the captured area (inside the bay). The date and GPS coordinates (longitude and latitude) were recorded for each release. The tagging methodology is presented in Figure 3.6.

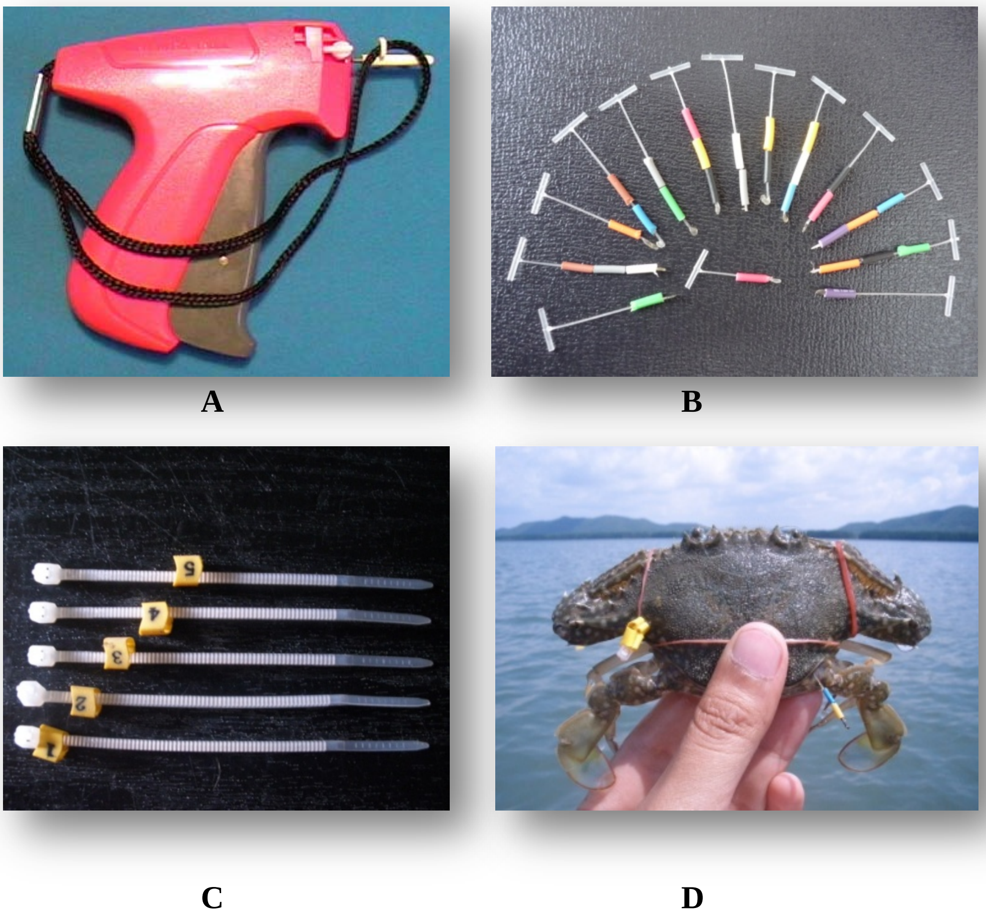


Figure 3.5. Tagging gun, anchor tag, and electric line tag

(A); Tagging gun (B); Anchor tag

(C); Electric line tag (D); Tagged crab

Figure 3.6. Field experiment on the movement pattern study in blue swimming crabs at Kung Krabaen Bay, Chanthaburi Province

Data analysis: movement patterns

3.3.1. Recapture information was used to compute distance move, movement direction, and rate of movement. Straight line distance between recapture and release locations was calculated using Arcview GIS (Hooge and Eichenlaub, 2000). Capture and releasing point were showed in Figure 3.7

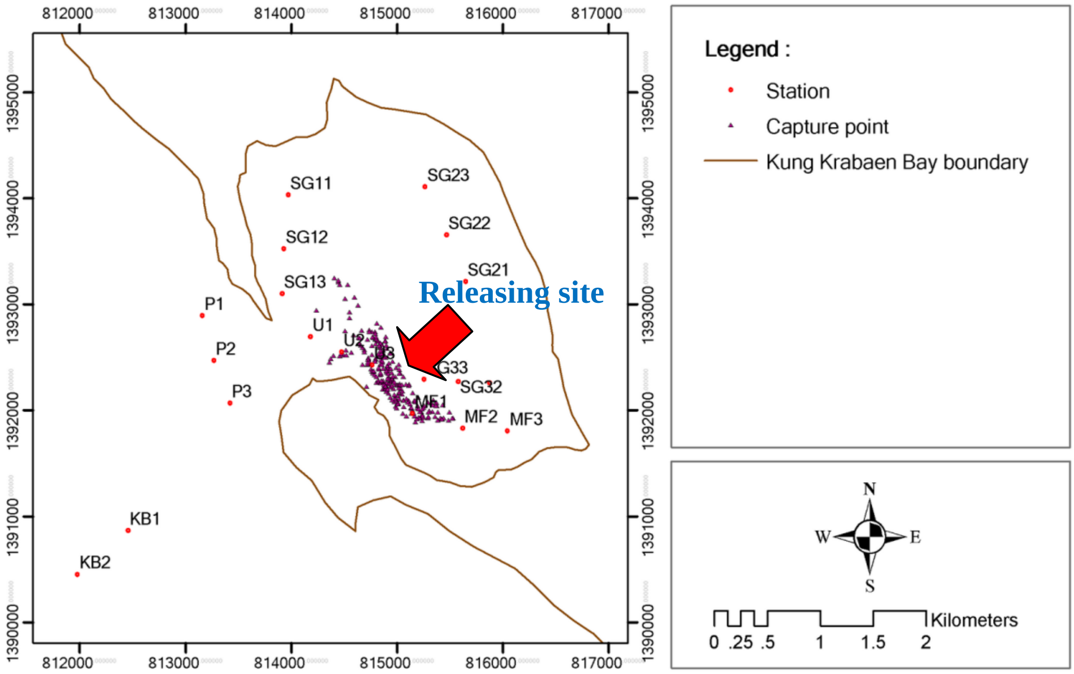


Figure 3.7. Captured and released point of movement patterns study at Kung Krabaen Bay, Chanthaburi Province

3.3.2. Abundance and distribution of crab in Kung Krabaen Bay were studied by monthly collections in various locations. Habitats of young and adult crabs, as well as fishery area were located. Maps of distribution were constructed. Seasonal abundance was calculated by using GPS all the samples collected from all stations during the sampling period, while spatial abundance was calculated by using all the samples collected from each station. Differences in crab abundance between months and stations were analyzed using one-way ANOVA (Zar, 1984). Relationship between crab abundance and ecological factor was calculated by Pearson Correlation.

3.3.3. Natural diet of crabs was studied by the analysis of stomach content and the results were compared between inshore and offshore crabs.

- Individuals of *P. pelagicus* was collected from all study sites using hand at inshore and crab gill net with a 10 cm mesh at offshore. Crabs were preserved immediately in 10% buffered formalin. The foregut of each crab was removed, fixed in formalin, and stored in 70% ethanol for dietary analysis. The carapace width and sex were recorded for each individual. Foregut content was examined under stereo microscope (Figure 3.8). Prey items were sorted into broad taxonomic groupings.

- Dietary composition was analysed by using percentage points, frequency of occurrence method (Williams, 1981; Wear and Haddon, 1987) and the Index of Relative Importance (IRI) (Hyslop, 1980)

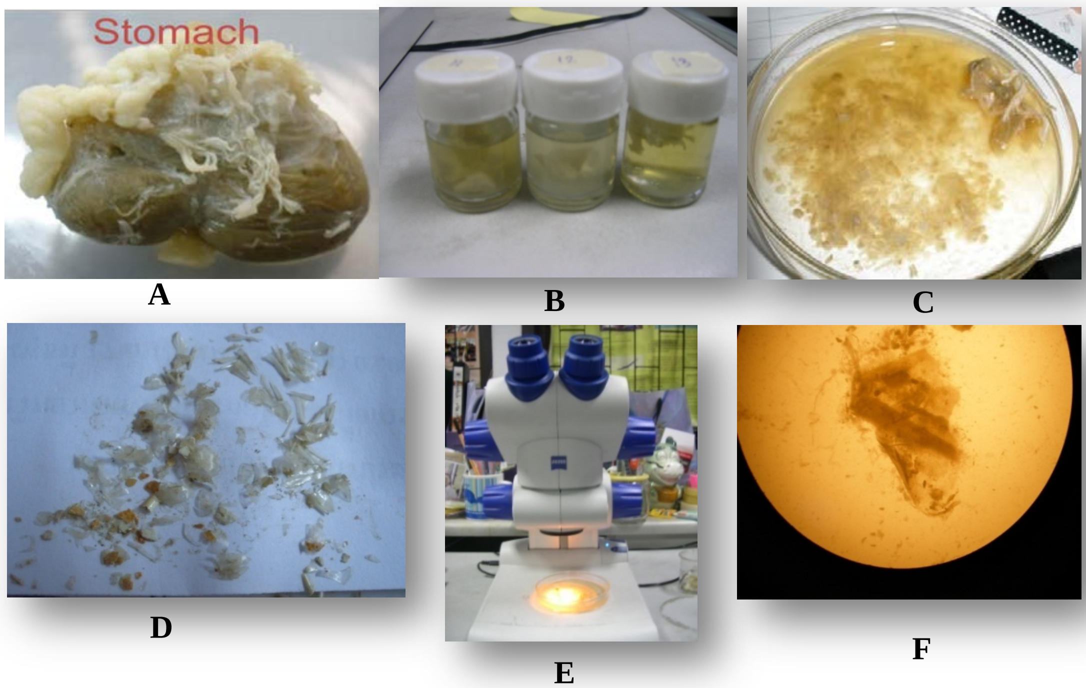


Figure 3.8. Stomach content analysis

(A); Stomach was dissected from the body

(B); Stomach was preserved in formalin immediately for stop the digestion process

(C); Stomach was dissected into the petri dish for identify prey items

(D); Prey items was carapace of crab and fish bone

(E); Prey items was examined under stereo microscope

(F); Image of prey items under stereo microscope

For the *percentage point method*, after the stomach was removed; each stomach was scored from 1-5, according to the degree of fullness, i.e. about 100%, 75%, 50%, 25% and 0%. Food categories were given a value ranging from 0-100, according to the percentage of content its represents with in each stomach. The number of points each category received are weighted according to the real fullness of the stomach in which it was found. For example, in a half full of stomach, contained 25% mollusks and 75% crustaceans, the mollusks was scored 12.5 and crustaceans 37.5 points, respectively.

$$P = (F/A)*100$$

Where P = Percentage points of each prey item

F = Total points of each prey item

A = Total points of all prey item

Frequency of occurrence method was calculated by dividing the number of stomachs which contained a food category by the total number of stomach observed

$$PO = (O/N)*100$$

Where PO = Percentage occurrence of prey item

O = Number of each whose stomachs contained for each prey type

N = Number of crabs in the sample excluding crabs with empty stomach contents

The index of relative important (IRI) (Hyslop, 1980; Bachok et al., 2004) was calculated for all the prey items using the formula:

$$IRI = (C_N + C_P) + F$$

Where: C_N = Percentage of numerical

C_P = Percentage points

F = Percentage of occurrence

3.3.4. Bycatch composition was identified in lowest category and calculated an occurrence index in each group. Retained and discarded species were also studied. An occurrence index (Roper et al., 2004 and Whitehead et al., 1986) expressed as:

$$S_{occc} = (n_i/N) \times 100$$

where S_{occc} = the species occurrence index

n_i = the number of animals occurred

N = the total number of animals

Rare species mean those caught less than 10% of the times;

Uncommon species mean those caught between 10 and 25% of the times;

Common species mean those caught between 25% and 50% of the times;

Very common species mean those caught more than 50% of the times.

3.4. BLUE SWIMMING CRABS MANAGEMENT

Current management of crab fishery in Kung Krabaen Bay was assessed using questionnaires and indepth interviews to obtain socio-economic and fishermen attitude data from local fishermen and other stakeholders. Questions comprised the following topics as in Appendix 13, 14 and 15.

- Household details;
- Fishing practice (number of traps fished, number of crab gill nets, number of soaks per day);
- Fishing area such as inside or outside the bay or both;
- Type of boat;
- State of the resources (stability of the catches, sex, composition of catches);
- Catch rate;
- Species of bycatch;
- Market situation for crabs, price variation, cost and income;
- General problems perceived by the crab fishermen;
- Attitude to conserve blue swimming crabs

- Policy of local government;
- Policy of KKB royal project;
- Corporation between the fishermen in each village;
- Understanding the movement activity of blue swimming crabs

Two participatory workshops were planed to excute in different period. The first participatory workshop aimed to assess the efficiency and problems of the current managements of blue swimming crabs in Kung Krabaen Bay. In this workshop, fishermen from three villages; Taclang, KlongKlud, and Chaolao were the target groups. After the first participatory workshop, problems should be identified and scientific findings were carried out consecutively. These scientific findings were then proposed in the second participatory workshop. This workshop aimed to proposethe sustainable management of blue swimming crabs in Kung Krabaen Bay based on the research findings on stock assessment, movement pattern and feeding ecology. Indepth interviews were also carried out among the participants in order to assess their responses to the proposed blue swimming crab management such as crab bank project and conservation zone. As the in-depth interviews with crab-fishermen were conducted during participatory workshop direct observations in the field and data obtained could verified several questions posed by the fishermen.

CHAPTER IV

RESULTS AND DISCUSSIONS

Two key questions were addressed in this study: 1) whether the blue swimming crabs population in crisis and 2) whether the crab both inside and outside the bay are the same populations. The measurable indicators such as stock assessment, population structure, and reproductive biology were used to prove the first hypothesis. The movement patterns and feeding ecology were used to prove the second hypothesis. The results showed the detail in below:

4.1. STOCK ASSESSMENT

Effective conservation of the blue swimming crabs requires a clear understanding from the stock assessment. It indicates the relationships between exploitation rate, catch, and population abundance. Study of stock assessment of blue swimming crabs can reflect the status of this resource whether being overharvested or not. In the last decade, the major obstacle in the resolution of the fishery management and resource sharing issues has been the lack of current data on crab stocks and fishing effort. In 1998, BBCAC (Bi-State Blue Crab Advisory Committee) which was set up in the states of Maryland and Virginia in the United States endorsed the findings of their technical work groups that the present crab populations were not in a healthy condition. BBCAC identified the following indicators of concern (Miller, 2001b):

- Reduce abundance for all age groups,
- Increase fishing mortality,
- Fishing effort was at near record levels,
- Spawning stock biomass was below the long-term average,
- Decreased average crab size,

- Fishery-independent surveys showed the decreasing percentage of legal size crabs,
- The reproductive potential of the population was of concern because of the reduced size of males and lack of mature females.

In order to provide the better understanding of the present crab stocks in Kung Krabaen Bay, stock assessment of blue swimming crabs were assessed based on 2 types of fishing gears. The data would include the crab fishery inside and outside the bay representing the total crab populations. The criteria to assess whether the population in crisis would be based on Miller (2000b) indicators.

4.1.1. Growth parameters

The selectivity of the gears have greatly influenced the size distribution and composition of the crab catches. Prior to the pooled data from the two fishing gears, the selectivity of each gear were adjusted. After that the probability of capture in crab trap and crab gill net or Lc were calculated and shown in Figure 4.1 and 4.2

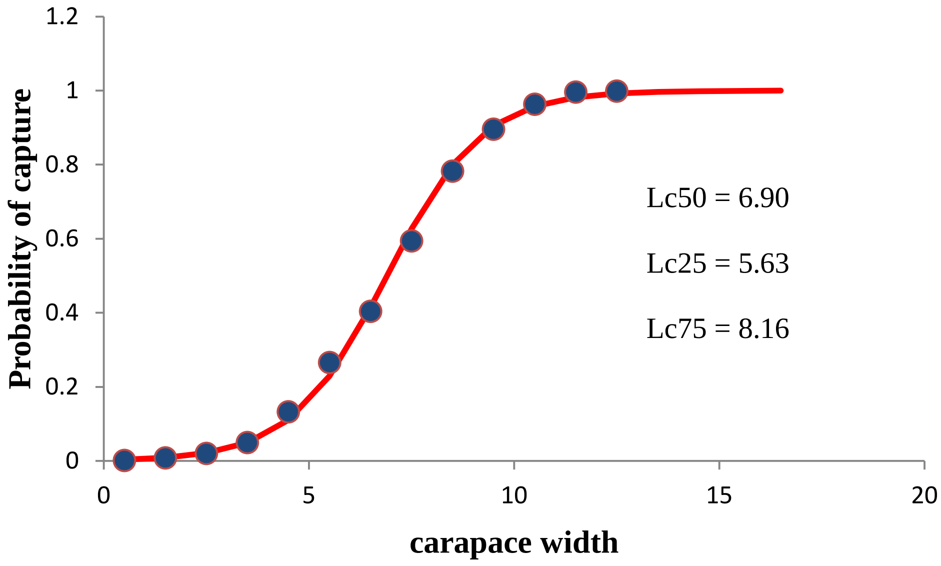


Figure 4.1. Probability of capture of blue swimming crabs in crab traps

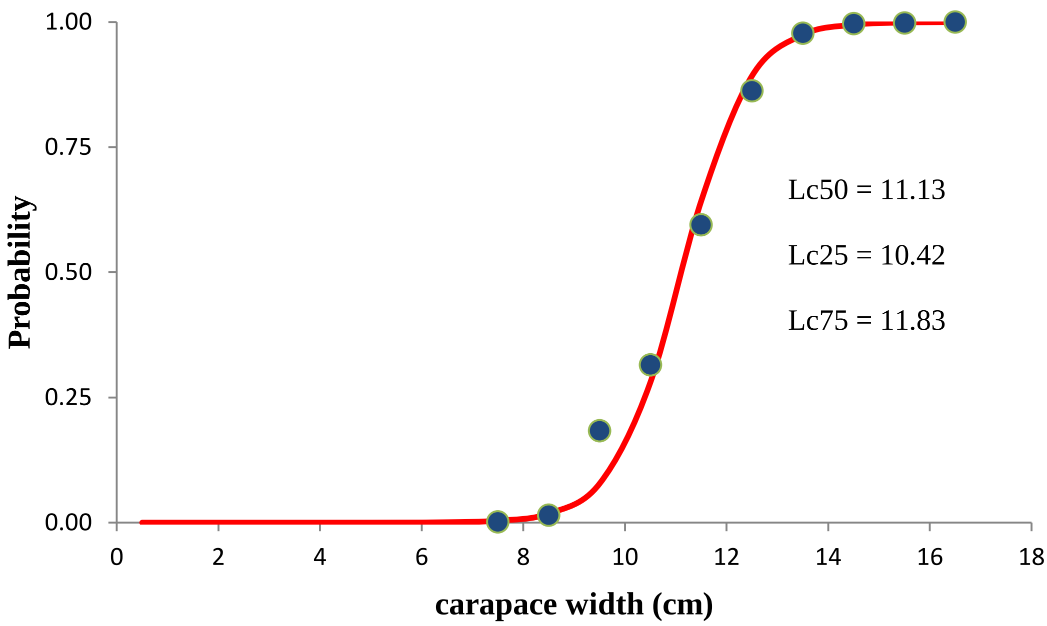


Figure 4.2. Probability of capture of blue swimming crabs in crab gill nets

Growth parameters estimated by Powell & Wetherall method based on monthly size frequency of carapace width (Figure 4.1 and Appendix A) were shown in Table 4.1

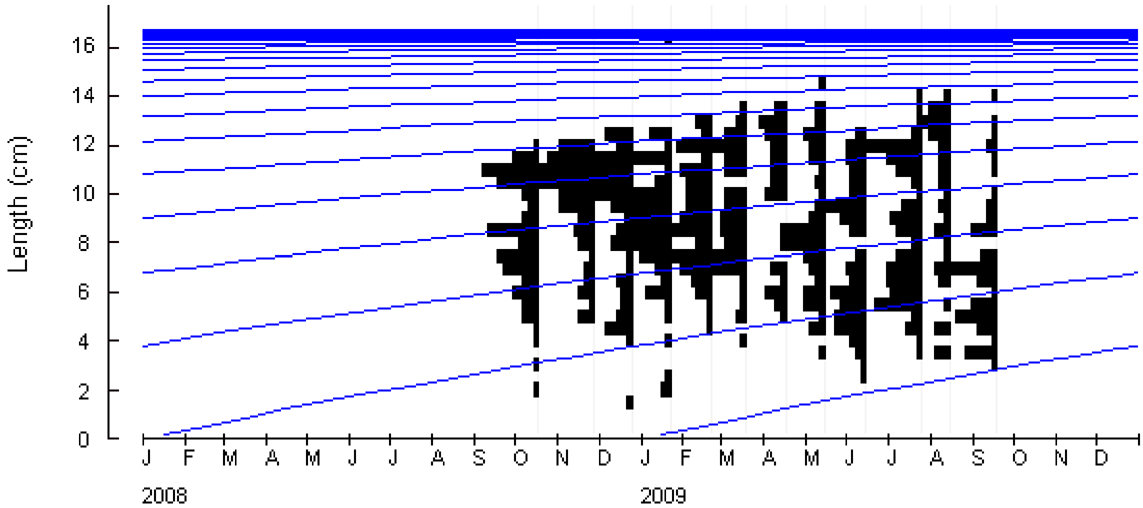


Figure 4.3. The frequency size distribution of carapace width of blue swimming crabs at Kung Krabaen Bay, Chanthaburi Province

Table 4.1. Growth parameter of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province

Characteristic		Carapace width (cm)	K-value (per year)
Sex	: Male	14.26	2.75
	: Female	16.73	1.13
	: Total	16.73	1.46
Gear	: *crab trap*		
	: Male	12.75	0.99
	: Female	13.74	1.69
	: Total	13.74	1.85
	crab gill net		
	: Male	14.26	1.45
	: Female	16.73	1.97
	: Total	16.73	2.22

The difference of growth rate between males and females resulted mainly from the greater reproductive output in females. As crabs became mature, growth often decreased because of the significant amount of energy used for reproduction (Heartnoll, 1982). With the greater energy investment in reproduction, females are usually smaller than males crab at maturity. In this study, the asymptotic size of female crabs were smaller than that of males. This supports the hypothesis that differences in reproductive output may account for differences in male and female growth rate (Heartnoll, 1982; Lee and Hsu, 2003).

The growth rate difference in crab population also resulted from different fishing gears due to the selectivity of fishing gears and fishing ground. Juveniles were more harvested by crab traps because the selectivity of the gear and the fishing ground is near shore or inside the bay. The crab gill net with larger mesh size of 8 cm and larger would catch more adult crabs. The fishermen usually used gillnets offshore or outside the bay.

4.1.2. Length-weight relationship

The relationship between outer carapace width and weight were $W = 0.0002CW^{2.9211}$ and $W = 0.0002CW^{2.8944}$ in male and female crabs, respectively (Figure 4.4 and 4.5). The result showed that the weight of male crab were greater than of female crabs at the same size of carapace width This confirmed with the earlier observation by Sukumaran and Neelakantan (1997a). Growth rate differences between males and females result mainly from the greater reproductive output of females. When the crab becomes sexually mature, growth often decreases (Heartnoll, 1982) because of the significance amount of energy used for reproduction. The value of regression co-efficient "b" obtained for males and females were less than 3 which indicated that the crab exhibited allometric growth after tested by t-test. The correlation coefficient "r" was 0.961 and 0.9346 showing high positive correlation between carapace weight and weight in this species.

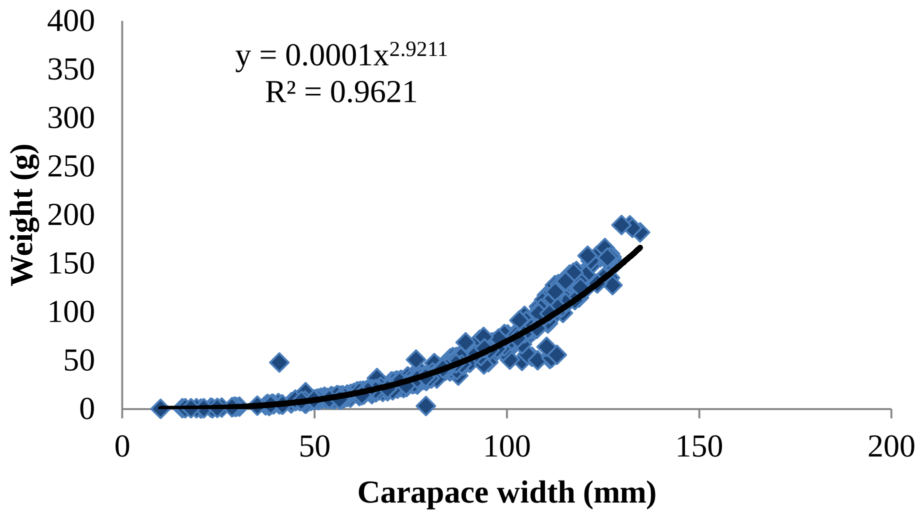


Figure 4.4. Relationship between carapace width and weight of male blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province

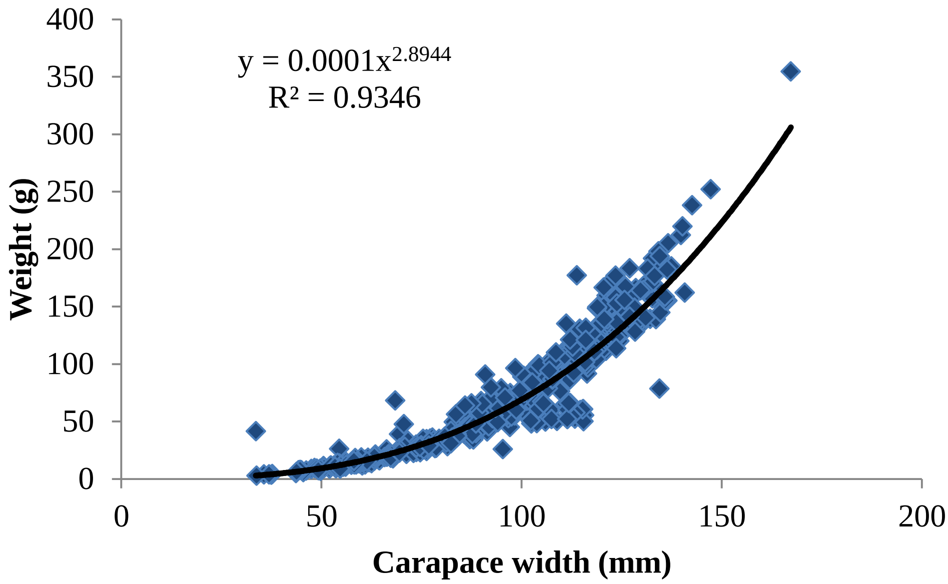


Figure 4.5. Relationship between carapace width and weight of female blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province

4.1.3. Sex ratio

The monthly variations in sex ratio resulting in the overall ratio of males to females equal to 1: 0.92 (Table 4.2). Male crabs were captured more than the female crabs except in November 2008, April, June and October 2009. Sex ratio was related to the total mortality because male crabs were more abundant in the catches. From the previous study showed the period of mating season in this crab (Raungprataungsuk, 2009). The chi-square test indicated that this ratio was not significantly (p>0.05) different from the expected 1:1 ratio. However, variations of sex ratio in the crab populations in Kung Krabaen Bay were observed by different researchers (Kunsook, 2006; Bhatrasataponkul et al., 2008; Raungprataungsuk, 2009) during 2005, 2007 and 2008 in Table 4.3 Since 2005, the sex ratios of blue swimming crabs showed the changing trends with the proportion of males higher than females. The number of female in particular mature females was on the decreasing trend.

Table 4.2. Sex ratio of blue swimming crabs at Kung Krabaen Bay, Chanthaburi Province from October 2008 to October 2009

Month	**Male**	**Female**	**Total**	**Expected**	**$\chi 2$**	**Ratio**
Oct-08	46	31	77	39	1.47	1:0.67
Nov-08	38	46	84	42	0.38	1:1.21
Dec-08	52	51	103	52	0.01	1:0.98
Jan-09	58	42	100	50	1.28	1:0.72
Feb-09	52	45	97	49	0.00	1:0.87
Mar-09	56	30	86	43	0.37	1:0.54
Apr-09	13	28	41	21	0.81	1:2.15
May-09	29	29	58	29	0.14	1:1
Jun-09	35	45	80	40	0.02	1:1.29
Jul-09	46	38	84	42	0.15	1:0.83
Aug-09	28	20	48	24	0.57	1:0.71
Sep-09	35	27	62	31	2.1	1:0.77
Oct-09	15	33	48	24	1.11	1:2.2
Total	**503**	**465**	**968**	**486**	**0.23**	**1:0.92**

Table 4.3. Annual sex ratio and test of variation in sex ratio of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province

Kung Krabaen Bay	**Estimated No.**		**Percentage**		**χ^2 value**
Year/sex	Male	Female	Male (%)	Female (%)	
2005	1116	1132	49.64	50.36	9.71
2007	850	629	57.47	45.53	4.63
2008	292	159	64.75	35.25	0.00
2009	503	465	51.96	48.04	0.23

4.1.4. Reproductive biology of blue swimming crabs

Gonad and ovarian development

Gonad and ovarian development were determined from 30 matured females. The proportion of berried (externally egg-bearing) females, and fecundity were also investigated. Crab ovaries increased in size and undergone color change during development. Morphological study of the ovarian development in *P. pelagicus* showed the 6 stages of development (Figure 4.6);

Stage 1	Gonad immature, white and translucent;
Stage 2	Gonad maturing, light yellow, shape of whole egg is H shape and not extending into hepatic region;
Stage 3	Gonad maturing, dark yellow and extending into hepatic region;
Stage 4	Gonad matured, orange and extending into hepatic region;
Stage 5	Ovigerous, female bearing fully matured eggs (orange eggs) externally;
Stage 6	Ovigerous, female bearing fully matured eggs (black egg) externally. The female will spawn within 24 hours.

Figure 4.6. Stages of ovary development of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province

Stage 1; Gonad immature   Stage 2; Gonad maturing, light yellow

Stage 3 Gonad maturing, dark yellow   Stage 4 Gonad matured

Satge 5 Ovigerous female (bearing orange eggs)

Stage 6 Ovigerous female (bearing black eggs)

The proportion of each development stage were determined monthly was shown in Figure 4.7. Blue swimming crabs breeded throughout the year because the ovigerous females could be found every month. The maximum abundance of berried females (45.71%) was recorded during March 2009 (Figure 4.8). Two peaks of breeding were detected during June to September and another in November to March. This corresponded with the high density of brachyuran larvae during November to March as reported by Tantichaiwanit et al. (2010). Raungprataungsuk (2009) also found two peaks of spawning season. The first peak was found during December 2008 to January 2009 but the second peak was found during April 2009-May 2009. Approximately 27.34 percent of ovigerous females were removed from their habitats and loss the opportunity to release eggs into the sea. This study showed that blue swimming crabs were continuous breeders which corresponded to several studies. Samuel et al. (2004) studied the blue swimming crabs fishery along Parangipettai Coast, South East Cost of India. They found the ovigerous females availability in *Portunus* spp. was all year round with peaks from April to August and October to February. Moreover, Prasad and Tampi (1952) also report the similar result in *P. pelagicus* as a continuous breeder with high peak during September to March on Southeast coast of India. Rajamani and Manickaraja (1998) observed that the maximum breeding of *P. pelagicus* at Tuticorin bay, India during June. The changes in the season of ovigerous females might be due to different monsoon period, current patterns and environmental factors particularly in salinity and temperature change.

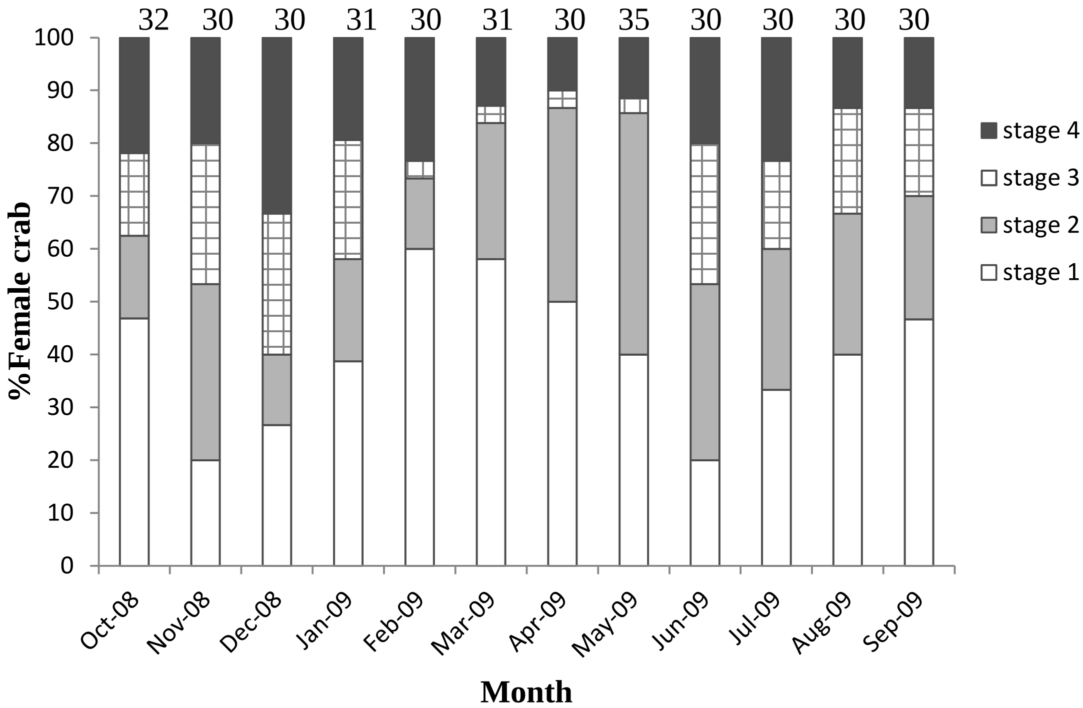


Figure 4.7. Seasonal changes in the proportion of four ovarian development stages of female blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province. Sample sizes above the bars. (note: ovigerous females were studied only in stage 1-4 by weight the body crab and ovary weight in carapace)

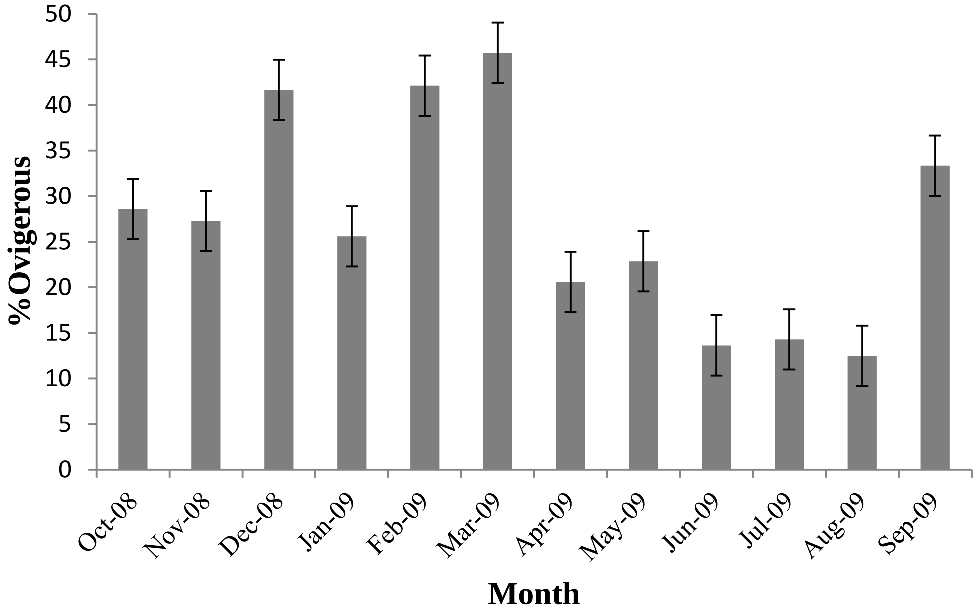


Figure 4.8. The proportion of ovigerous female blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province observed in collapsible crab traps and crab gill nets

Gonad somatic index (GSI)

The monthly variations of GSI in females were shown in Figure 4.9. The GSI values for the 369 specimen of blue swimming crabs ranged from 0.54 to 6.3%. From these results indicated that high spawning periods in blue swimming crabs with 3 peaks in December, March and August. Pillay and Nair (1973) observes gonad somatic index in this species along the southwest coast. They revealed peak breeding during December to January. The steady increase in breeding activity may be attributed to the increase in temperature, salinity and availability of food (Sukumaran and Neelakantan, 1996a). This study showed high breeding activity on dry season than wet season in particular on December and March.

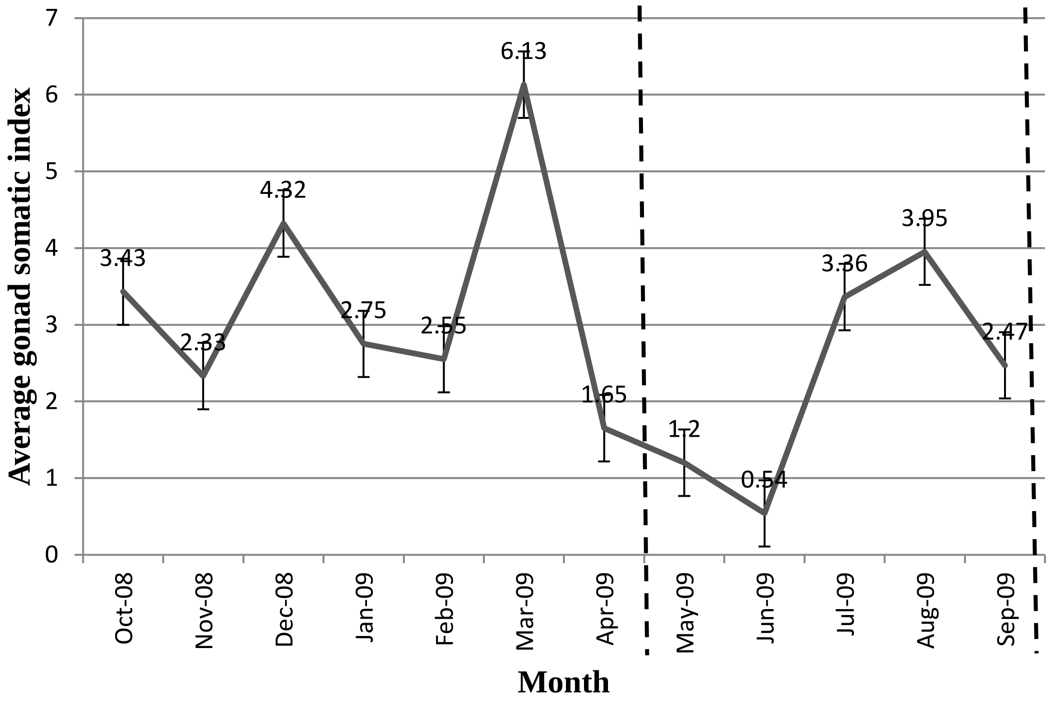


Figure 4.9. Gonad somatic index in female blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province indicated 3 spawning period; November-December, February-March and June-August

First sexual maturity

Size at maturity is important in the context of stock reproductive strategy and output. Large size at maturation is beneficial for a high reproductive potential in general related to fecundity (Stearns, 1992). It has been suggested that high fishing pressure may reduce the size at maturity (Stearns, 1976; Pollock, 1995). The size at which 50% of female blue swimming crabs were sexually matured was estimated to be 10.62 cm CW (Figure 4.10), as compared with the previous study of 8.10±0.39 cm of *P. pelgicus* in the same area (Kunsook, 2006). In Kunsook (2006) study, the crabs were from collapsible crab traps resulting in small size crabs. The result from gonad study also showed that the smallest matured females recorded 5.82 cm while the average size of matured females was 7.52±1.14 cm CW. The smallest ovigerous female *P. pelagicus* observed by Prasad and Tampi (1953), Pillay and Nair (1971) and Dineshbabu et al. (2008) from Mandapam, southwest coast and south Karnataka coast of India, measured 9.2 cm, 9.5 cm and 9.6 cm, respectively. Size at maturity of crabs was found to vary considerably with latitude and location (Cambell and Fielder, 1986; Sukumaran and Nellakantan, 1996a). Most studies in tropics especially in Asian region concluded that blue swimming crabs reaches sexual maturity within one year (Smith, 1982, Sukumaran and Nellakantan, 1996b).

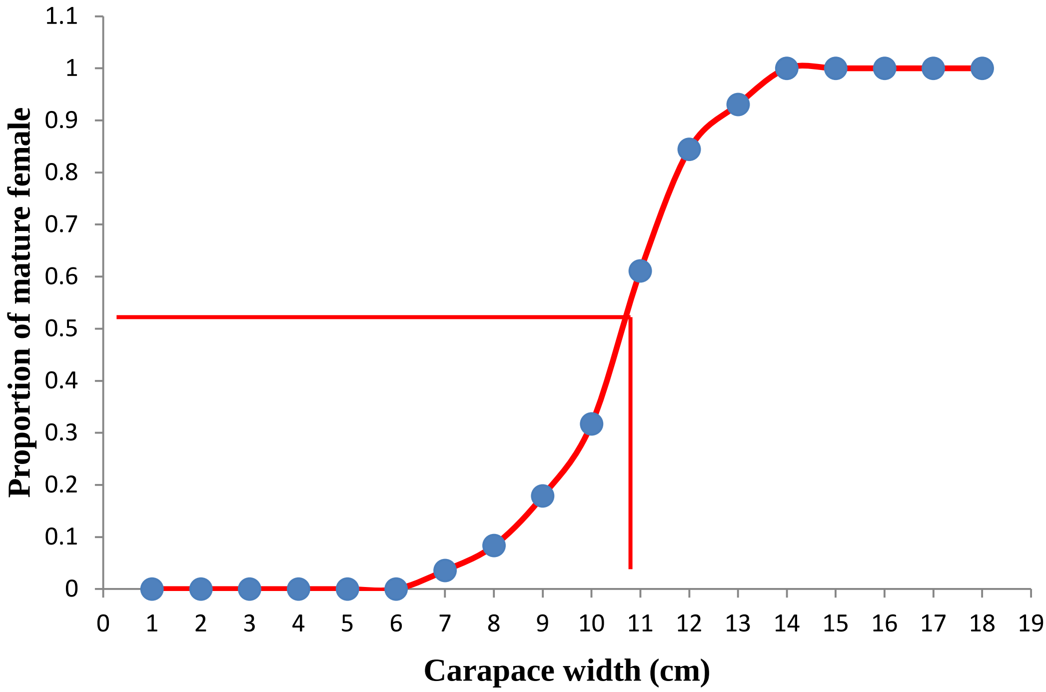


Figure 4.10. A logistic curve showing the proportion of mature females blue swimming crabs in each size category in Kung Krabaen Bay, Chanthaburi Province

Fecundity

The estimated fecundity for individual crabs varied from 148,237.2 to 1,448,180.29 eggs per batch during October 2008 to September 2009. The minimum fecundity was found in a berried female crab having carapace width (CW) of 8.58 cm and body weight (BW) of 62.06 g. The maximum fecundity was found in the berried female crab having carapace width of 13.60 cm and body weight of 186.86 g. The average fecundity was 572,138.18 eggs.± 261,075.56 eggs for the berried female crab with a mean carapace width of 11.88±11.57 mm and body weight of 129.46±27.19 g (Appendix B). The results showed high fecundity in two peaks in December 2008 and

June 2009. The fecundity results were correlated with the peaks of recruitment of crab larvae (Figure 4.11). The fecundity size was directly related to the size of the female crab. These results showed that the declining trend in the fecundity of the blue swimming crab populations as compared to the previous study in the closing area in the Gulf of Thailand (Jindalikhit, 2002). The average fecundity of blue swimming crabs in this study was 712,684.00 eggs.

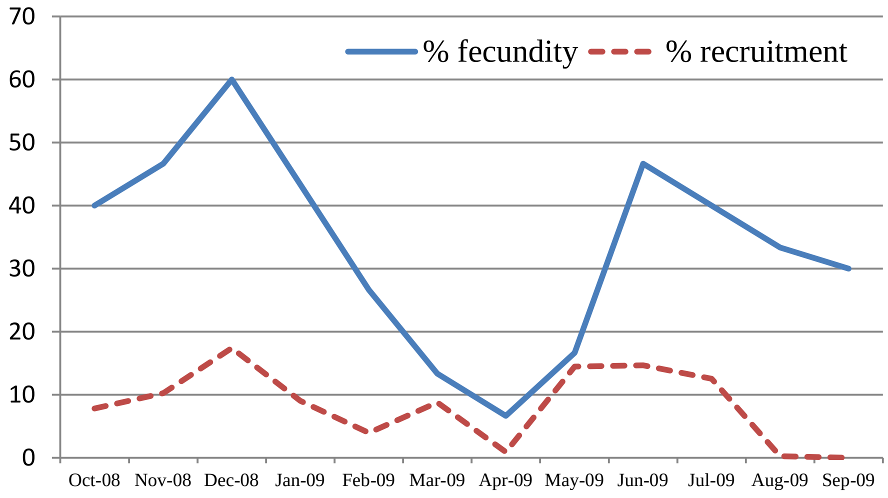


Figure 4.11. High fecundity period of female blue swimming crabs related to the recruitment of larvae at Kung Krabaen Bay, Chanthaburi Province

Relationship between fecundity and carapace width

From a total of 132 berried female crabs ranging from 8.58 to 13.6 cm in carapace width, the significance linear relationship was observed between fecundity and carapace width ($p<0.05$) (Figure 4.12). The estimated linear equation was:

$$\text{Fecundity} = 17931CW - 2 \times 10^{6}$$

The result showed that fecundity increased with carapace width. Relationship study between fecundity and carapace length were studied in South-East Australian Estuary. The result found the fecundity of female crabs is size dependent and increase up to a carapace width of 134 mm and decrease thereafter (Kumar et al., 2003).

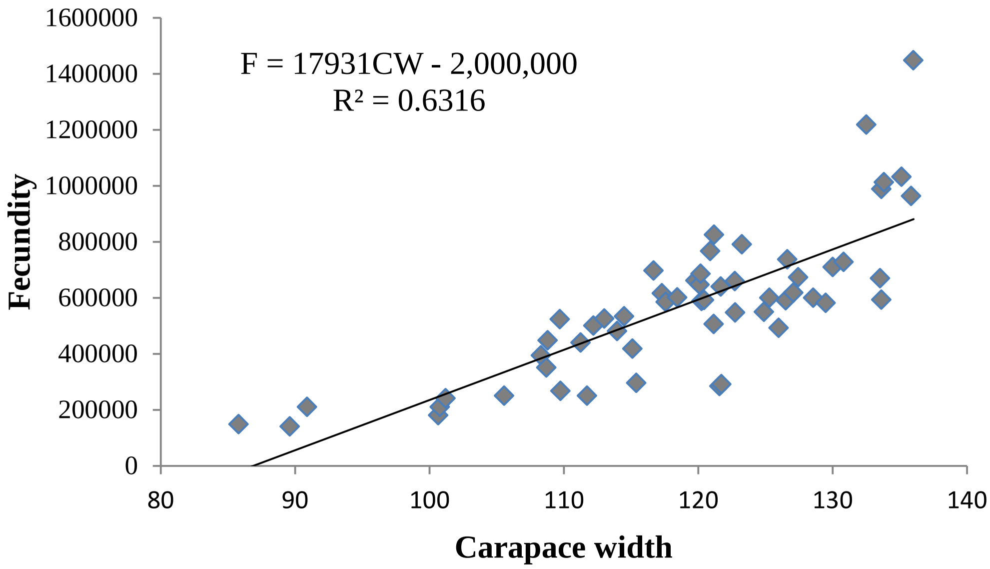


Figure 4.12. Fecundity-carapace width relationships for females blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province

Biology of blue swimming crabs in the Upper Gulf of Thailand was studied **(**Jindalikhit, 2002), compared with this study. The result showed detail in Table 4.4

Table 4.4. Fecundity of blue swimming crabs at Kung Krabaen Bay, Chanthaburi Province in 2002 and 2012

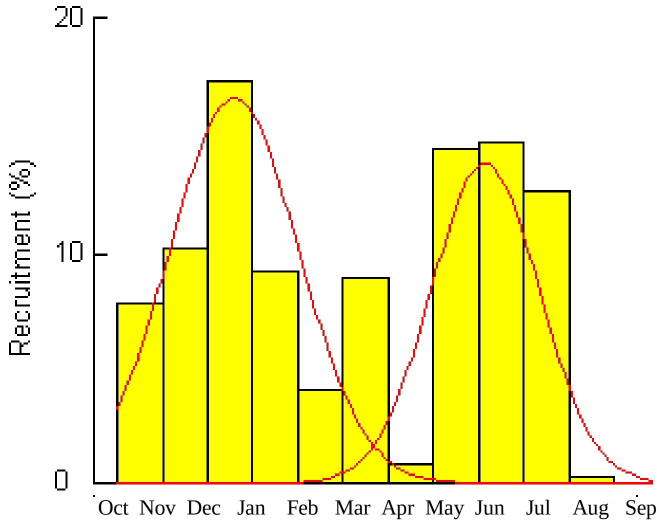
Research	**carapace width at 50%**	**maximum egg number**	**average fecundity**
Jindalikhit (2002)	4.35	1,413,150	712,684.00
This study (2012)	10.62	1,448,180.29	572,138.18

From the Table 4.4 showed that fecundity of berried female crabs in Kung Krabaen Bay was lower than the fecundity of blue swimming crabs which was studied by Jindalikhit (2002). This parameter clearly indicated that blue swimming crab populations in Kung Krabaen Bay was in crisis because when the size of matured female became small so the fecundity also decreased lower the recruitment. Johnson et al. (2010) reported the fecundity of blue swimming crabs in a South-East Australian were 463,000 to 1,781,000 eggs/batch. In the contrast the estimation on fecundity and size at first maturity in this study were different from those reported from the other parts of the world. There were strong regional differences in the biology of blue swimming crabs (Johnson et al., 2011). Shields et al. (1990) noted that the variations in fecundity amongst brachyuran crabs may caused by several factors including climatic regimes, habitat and biological constraints.

4.1.5. Recruitment pattern

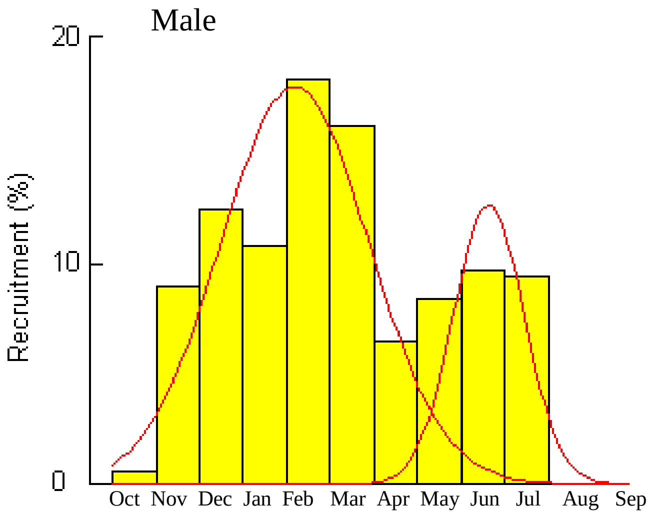
The recruitment period occurred throughout the year with two prominent peaks. The first peak was during October 2008 to April 2009 and the second peak was during May to September 2009 (Figure 4.13). As the result there are new recruits to the fishery all year. This corresponded to the study of Raungprataungsuk (2009) that found two peaks of recruitment at the same period. As revealed by the several studies, many coastal areas in Thailand have been facing the crisis in the reduction of larval and juvenile crab populations including Kung Krabaen Bay because of ovigerous females crabbing during spawning season (Bhattarasatapornkul, 2008; Raungprataungsuk, 2009). Therefore, there were low recruitment of juvenile crabs in the fishery system. The recruitment patterns of males and females presented in Figure 4.14 and 4.15. The high recruitments of male crabs showed peaks in February and May whereas female crabs showed high peak of recruitment in December and August. This concluded that the recruitment of blue swimming crabs in this study occurred all year round with two peaks. This corresponded to Pauly (1982)'s finding that this was the characteristics of most tropical fish stock with seasonal variations. All year round recruitment was to compensate for the high fishing mortality rates from fishery (Abowei et al., 2010). Changes in total crab catches, which most probably reflect changes in population abundance were determined by the variations in recruitment (Beverton and Holt, 1957; Ricker, 1957; Sharov et al., 2003). These recruitment in turn were affected by physical and biotic factors both before and after settlement (Wahle, 2003). Large fluctuations in recruitment have been the major source of uncertainty sustainable management of fisheries (Jenning et al., 2001). Environmental factors governing included the water temperature, salinity, predations, availability of food (de Lestang et al., 2003a) and habitat availability (Pile et al., 1996). The recruitments also related to the size of the reproductive biomass (Zheng and Kruse, 1999), the rate of density-dependent mortality (Lipcius and Van Engel, 1990) and the rate of emigration (Pile et al., 1996). In this study clearly indicated that the recriutment of larvae and juvenile was related to the fecundity and size at maturity in female crabs. Thus the restriction on the catch of gravid females or berried females during spawning season should be enforced in the fishery management.

Total



Relative time	Percent recruitment (%)
Oct	7.82
Nov	10.23
Dec	17.32
Jan	8.99
Feb	3.97
Mar	8.52
Apr	0.90
May	14.13
Jun	14.55
Jul	12.36
Aug	0.22
Sep	0.00

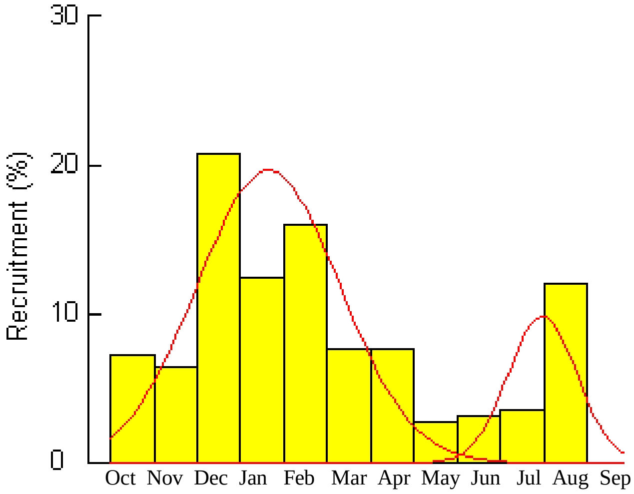
Figure 4.13. The recruitment pattern of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province



Relative time	Percent recruitment (%)
Oct	0.61
Nov	8.7
Dec	12.32
Jan	10.76
Feb	18.11
Mar	15.88
Apr	6.34
May	8.27
Jun	9.72
Jul	9.2
Aug	0.08
Sep	0.00

Figure 4.14. The recruitment pattern of males blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province

Female



Relative time	Percent recruitment (%)
Oct	7.33
Nov	6.40
Dec	20.74
Jan	12.33
Feb	16.04
Mar	7.73
Apr	7.71
May	2.81
Jun	3.37
Jul	3.44
Aug	12.09
Sep	0.00

Figure 4.15. The recruitment pattern of female blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province

4.1.6. Mortality and exploitation rate

Increase fishing mortality in the crab populations often indicated the declining population. The total mortality in male and female crabs estimated by the length converted catch curve (Table 4.5 and Figure 4.16) were 8.15 and 6.95 per year, respectively. The result showed that male crabs were harvested more than female crabs. The exploitation rate was estimated by the knife-edge selection in Figure 4.17. The exploitation rate (E_{max}) that give maximum relative yield per-recruit was 0.81 whereas the exploitation rate at optimum level was 0.37. However the present yield was 0.71. This indicated that blue swimming crabs were overexploited because the present exploitation rate had greatly exceed than the optimum exploitation rate.

Table 4.5. Estimated mortality parameter of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province

Crabs	Total mortality (Z)	Natural mortality (M)	Fishing mortality (F)
Total	5.83	1.69	4.14
Male	8.15	3.98	4.53
Female	6.95	2.07	4.88

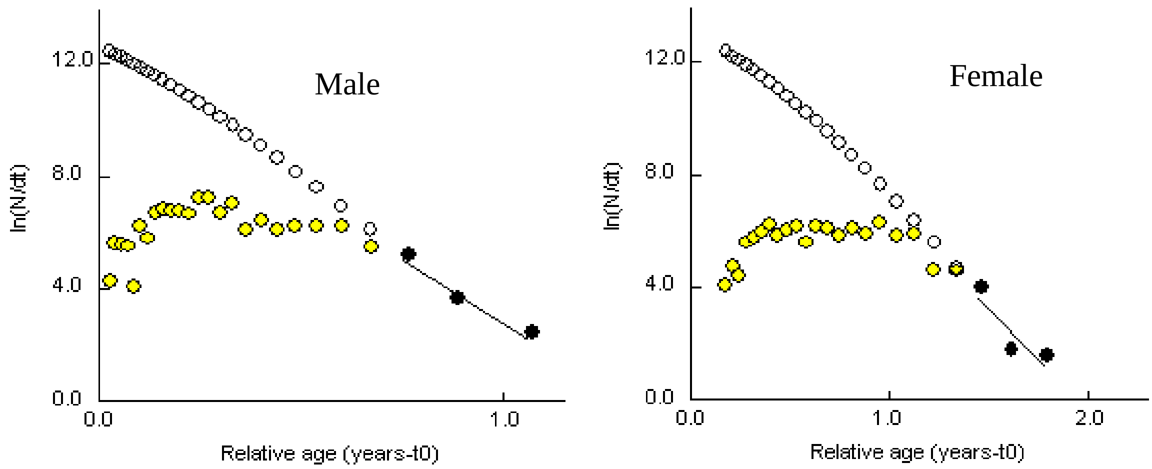


Figure 4.16. Length converted catch curves of male and female blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province

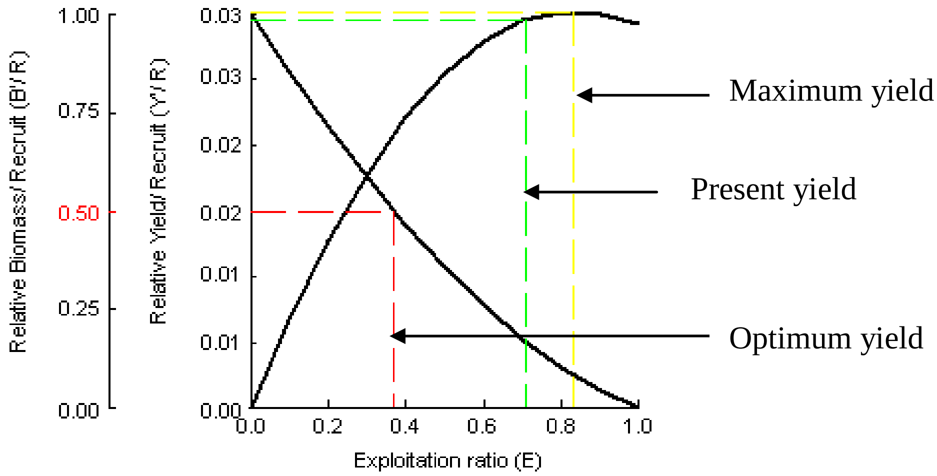


Figure 4.17. Exploitation rate of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province

This study also showed that fishing mortality was higher than natural mortality. It can infer that stock of blue swimming crabs in this area was under excessive fishing pressure based on the assumption that the optimum exploited stock, natural and fishing mortality should be equal or E = F/Z=0.5 (Gulland, 1971). Survivalship curves of early juveniles of benthic invertebrates are often Type III (Deevey, 1947), where mortality rates were high for young stages and decreased with older individuals (Hunt and Scheibling, 1997). Exceeding 90% of juvenile mortality in marine invertebrates dramatically reduced the initial number of postlarvae (Gosselin and Quian, 1997). In decapod crustaceans, crabs have high mortality rates after settlement during the early benthic phase. Previous studies suggest that early juvenile mortality play the important role in determining the crab population structure.

Scientific findings from stock assessment and reproductive biology of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province

Stock assessment was carried out to assess the status of blue swimming crabs in this area. Several measurement indicators clearly indicated that the status of blue swimming crab population was in crisis or overharvested. Fishing mortality and percentage of ovigerous female that were removed from the habitat had increased as compared to previous studies. The exploitation rate of 0.71 had greatly exceed the optimum rate of 0.38. First size maturity, size of mature females and the average fecundity also decreased as compared to Jindalikhit (2002) and Bhattarasatapornkul (2008). The fecundity data correseponded with the peak of recruitments in December and June. The results were summarized in Table 4.6 and 4.7.

Table 4.6. Measurement indicators at Kung Krabaen Bay, Chanthaburi Province

Indicators	**Criteria indicating declining population**
Fishing mortality	Increased (88.16%)
Exploitation rate	0.71* (optimum exploitation rate = 0.38)
Size of mature female	Decreased (6%)
Number of ovigerous female removed from population	Increased (Lost 45.7% per year)
The average fecundity	Decreased (19.72%)

Table 4.7. Time-line of stock assessment of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province

Kunsook (2006)	Bhattarasatapornkul (2008)	Raungprataungsuk (2009)	Kunsook (2012)
↓	↓	↓	↓
2005	2007	2008	2009

L∞, =	13.23,	13.81	12.23	16.73
K	0.87	1.52	0.56	1.46
Total mortality	2.96	3.77	1.31	5.83
Natural mortality	1.84	2.94	0.82	1.69
Fishing mortality	1.12	0.83	0.49	4.14
Exploitation rate	0.38	0.25	0.37	0.71
Peak of recruitment	February to March 2005 and July toOctober 2005	June to September 2007	June to August 2008 and December 2008 to February 2009	October 2008 to April 2009 and May to September 2009
Sex ratio	1:1.19	1:0.93	1:0.5	1:0.92

4.2. MOVEMENT PATTERN

There has been misunderstanding among the local fishermen in Kung Krabaen Bay that the crab inside and outside the bay were of different groups and not related. This was because of the lack of information on the migratory movements in the crab populations. This misunderstood lead to conflicts among fishermen and also the ineffective measures for conservation zone. These measures did not receive full cooperations from the fishermen. The movement patterns in blue swimming crabs were studied in order to understand the relationship between crabs living inside and outside the bay. Movements between habitat types were critical to the maintenance of populations in an area. It may also greatly affect the local distribution in crab pupulations (Moksnes, 2002). Crab movement patterns were related to mating, spawning, nursery area and feeding ground. Movement in crab life cycle divided into three phases involving 1) movement of planktonic eggs and larvae; 2) movement of juveniles to shallow water areas for feeding and nursery area; and 3) movement of adults to deep water to feed and to spawn (Pittman and McAlpine, 2003). Tagging method was used to detect the crab movements inside and outside the bay. If tagging study was carried out only inside the bay, the tagged crab should not found outside the bay. But if two groups of crabs were the same group, tagged crab would be found both in inside and outside the bay. The results were showed as below:

4.2.1. Movement patterns from recapture data

A total of 513 blue swimming crabs were captured, tagged, and then released inside the bay to prove the migration assumption. Several crabs were recaptured more than one time to fourth times based on the following details.

The first recaptured crabs

During the recaptured period, a total of 155 tagged crabs (30.21%) were recaptured both in- and outside the bay in different zones (Table 4.8, Figure 4.18 and Appendix C). There were 59 males and 96 female crabs of which 59 were the ovigerous females. Carapace width ranged 5.65 to 6.98 cm in 4 immature male crabs. The weight of these immature males ranged between 20 to 30 g. All of them were found in seagrass beds *Enhalus acoroides* (Zone 4). Immature male crabs were not found in outside the bay. Carapace width ranged 5.59 to 7.76 cm of 5 immature female crabs. Their weight ranged between 20 to 40 g. Immature females were also not found outside the bay. Approximately 76.27% of mature males were found inside and while 16.95% of mature males found outside the bay. The carapace ranged 7.49 to 12.00 cm were recorded in these mature males. Mature female crabs of 56.76% were found inside and of 29.73% found outside the bay. These mature females were with the carapace width of 8.05 to 12.30 cm. The ovigerous females were found both inside and outside the bay in the same proportion of 54.2% and 45.8%, respectively.

The result indicated that 69 % of recaptured crabs inside the bay inhabited in the seagrass bed *Enhalus acoroides* (zone 1 and zone 4), and reforestation mangrove (zone 3). For the blue swimming crabs outside the bay, mature males, mature females and ovigerous females were recaptured in front of bay mouth (zone 10) Chaoloa Beach (zone 12, average distance and zone 13) and Kung Viman Beach (zone 8 and zone 9). Average distance of blue swimming crabs was showed in Table 4.9. The result showed that mature crabs were able to move in great distance than the immature crabs. Ovigerous females can move within the longest distance as compared to other stages.

Table 4.8. Descriptions of the 155 recaptured blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province in the first recaptured classified by sex and their state (immature, mature in both sex and ovigerous females).

	Male (n=59)		**Female (non-ovigerous) (n=37)**		**Ovigerous female (n= 59)**	
	Range	**mean±SD**	**Range**	**mean±SD**	**range**	**mean±SD**
Carapace width (cm)	5.65-12.00	8.76±1.24	5.39-12.30	9.26±1.40	5.51-12.80	9.29±1.26
Weight (g)	20-120	56.83±22.45	20-140	65.35±31.40	15-150	62.83±24.84
Time between release and recapture (day)	0-13	4.20±3.35	0-14	4.59±3.35	0-13	4.34±4.02
Migration distance (km)	0.02-5.94	1.34±1.23	0.15-6.17	1.90±1.72	0.13-5.54	1.69±1.17
No. of crab inside the bay, zone 1-7	Immature = 4 (6.78%) Mature = 45 (76.27%)		Immature = 5 (13.51%) Mature = 21 (56.76%)		32 (54.2%)	
No. of crab outside the bay, zone 8-14	Immature = 0 (0%) Mature = 10 (16.95%)		Immature = 0 (0%) Mature = 11 (29.73%)		27 (45.8%)	

Table 4.9. Average distance (km) of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province

Immature males	Mature males	Immature females	Mature females	Ovigerous females
0.97±0.27	2.03±1.79	0.92±0.6	1.37±1.26	2.43±1.16

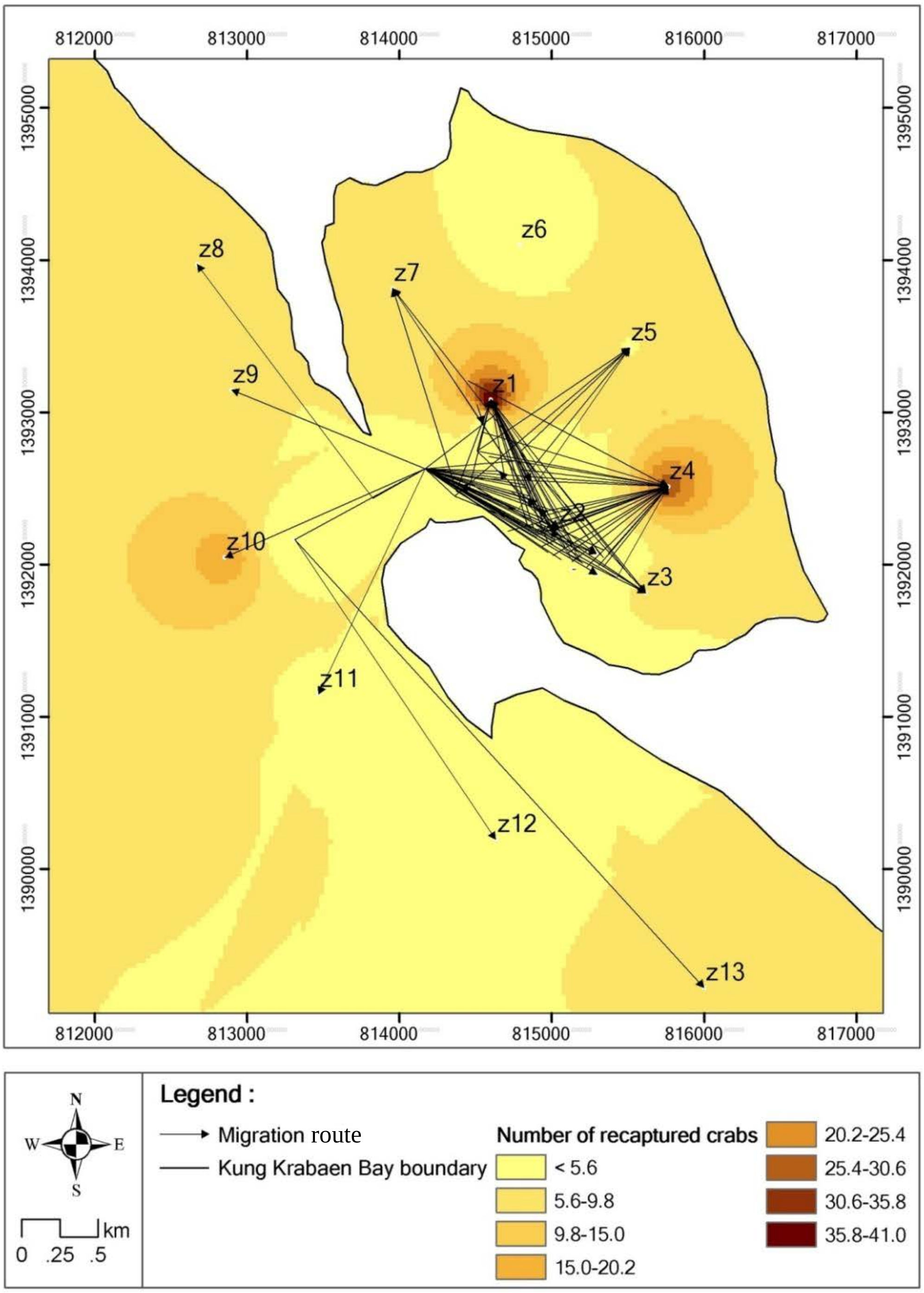


Figure 4.18. Movement route of the blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province from the release points.

Duration of 0-14 days after tagged and released for the detection of movements

(Note: 0 = half a day after tagged and released)

In term of movement, most of the immature males of 6.78% and female crabs of 13.51% traveled inside the bay. Most of mature male and females of 76.27% and 56.76 tend to migrate from inside to outside the bay. The movement of ovigerous females detected inside the bay particularly in seagrass bed (zone4) and outside the bay at the mouth of the bay (zone 10).

Time at liberty between released and recaptured ranged from half a day to 14 days, with an average of 4-5 days (Figure 4.19). In general, recapture rate reduces when time increases (Aguilar et al., 2005). The maximum distance of movement found in a female crab moving from the captured point to Chaoloa Beach (zone 13 in average distance 5.54±0.27 km). From the field information, this crab has 8.35 cm in carapace width and 35g in weight. The maximum distance of 6.17 km took this female to travel in 3 days.

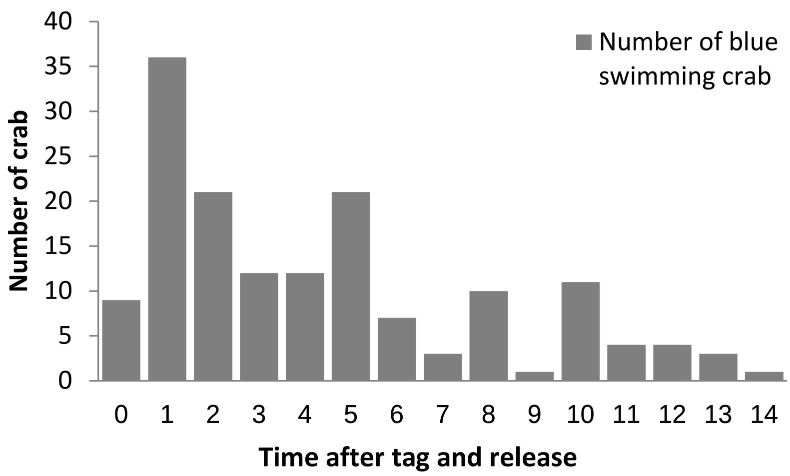


Figure 4.19. Numbers of blue swimming crabs recaptured in Kung Krabaen Bay, Chanthaburi Province in different time interval after releasing

(Note: 0 = half a day after tag and release).

The second recaptured crabs

Among the 155 first recaptured crabs, only 22 (14.2%) of them were recaptured twice. The descriptions of the second set of recaptured crabs were showed in Table 4.10. The proportion of crabs were six males, one immature female, one mature female and 13 ovigerous females. Inside the bay, carapace width of mature male ranged from 8.89 to 12.00 cm while carapace width of mature male was 9.31 cm. In the second recapture, mature females were not found inside the bay but they were found outside the bay at the mouth of the bay (zone 10). The movement pattern of male crabs was similar to those reported in the first recapture. Most males of 83.3% were found inside the bay. In case of female crabs, the movement pattern was in contrast to the first recapture. Most of female crabs of 84.62% migrated to outside the bay. Time at liberty between first and second recapture ranged from half a day to 10 days which is shorter than time interval from tag and first recapture, 0-14 days. Mean distance in berried females (4.49±2.79 km) was higher than male and female (non-ovigerous). The ovigerous female crabs moved to spawn offshore (Gillander et al., 2003; Pittman, 2002).

Table 4.10. Descriptions of the 22 recaptured blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province in the second recaptured classified by sex and their stage (ovigerous and non-ovigerous).

	Male (n=6)		**Female (non-ovigerous) (n=3)**		**Ovigerous female (n= 13)**	
	range	**mean±SD**	**range**	**mean±SD**	**range**	**mean±SD**
Carapace width (cm)	8.89-12.00	9.90±1.18	7.76-11.39	9.85±1.88	5.51-11.00	9.11±1.41
Weight (g)	55-100	71.67±17.51	40-135	98.33±51.07	20-110	56.54±24.10
Time between first and second recapture (day)	0-5	2.50±1.87	3-10	5.33±4.04	0-10	5.38±4.27
Time between release and second recapture (day)	2-13	6.83±4.26	7-11	9.67±2.31	1-12	10.15±2.97
Migration distance from release point (km)	1.09-7.76	2.61±2.55	1.33-2.99	2.15±1.17	0.49-9.22	4.49±2.79
No. of crab inside the bay, zone 1-7	Immature 0 (0%) Mature 5 (83.3%)		Immature 1 (33.3) Mature 0 (0%)		2 (15.4%)	
No. of crab outside the bay, zone 8-14	Immature 0 (0%) Mature 1 (16.7%)		Immature 0 (0%) Mature 2 (66.7%)		11 (84.6%)	

The movement pattern of crabs since released and second recapture is presented in Figure 4.20. They can move from 0.49 to the maximum of 9.22 km. Based on the field observation, a berried female, 8.56 cm in size and 40g in weight was detected to demonstrate the longest movement within one day. Average distance of ovigerous females was 4.50±2.79 km while the average distance of mature males was 2.62±2.55 km.

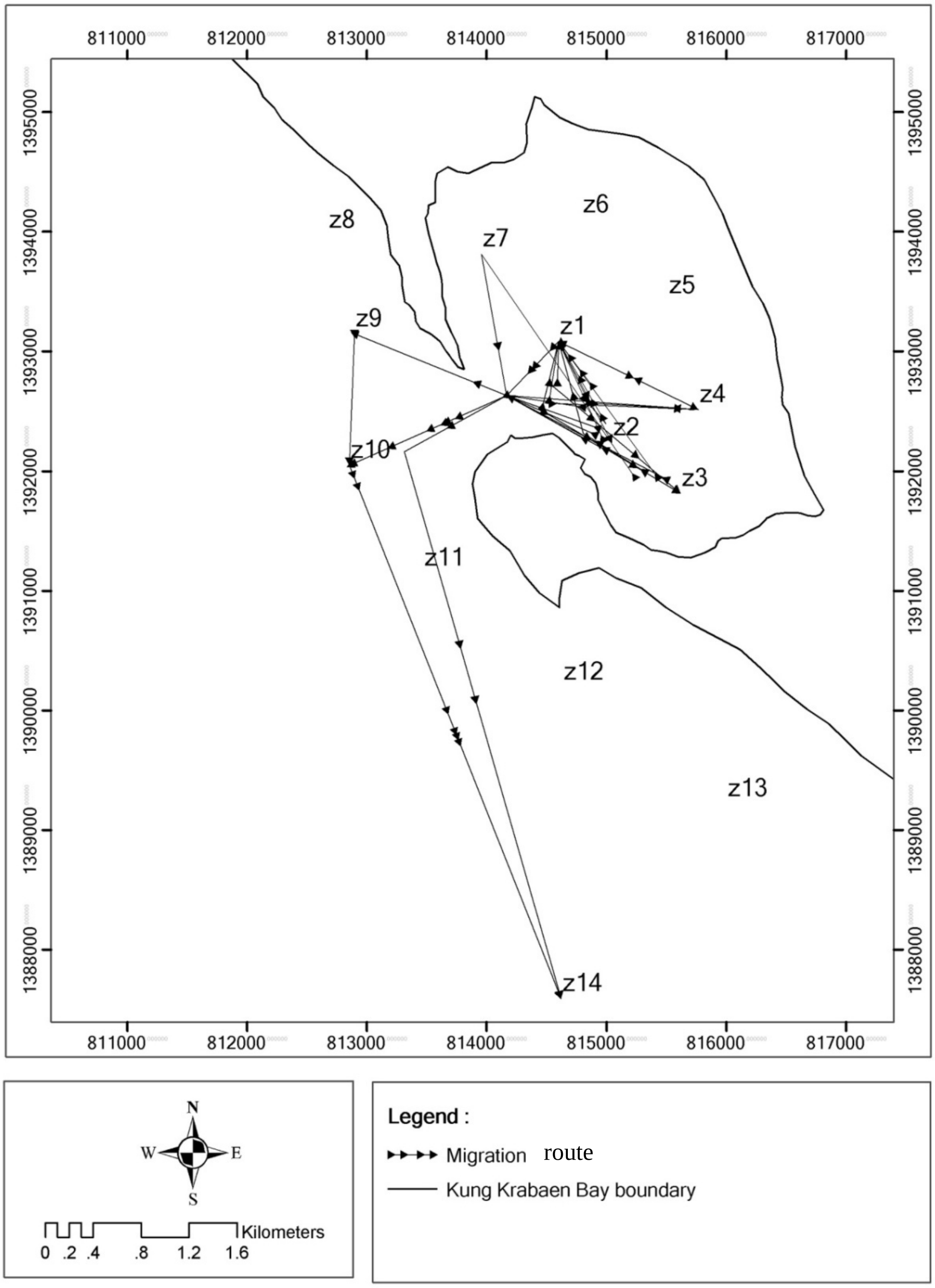


Figure 4.20. Movement route of the blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province from the released points (second recapture) Duration of 0-10 days after first recaptured for the detection of movements

(Note: 0 = half a day after tag and release, Density map is not produced due to small crab samples).

The third and fourth recaptured crab

Only one female crab, 11.39 cm in carapace width and 135 g in weight was recaptured for third and fourth times. It was first recaptured at seagrass beds *Halodule pinifolia* (zone 7), one day after release. Ten days later, on March 11, it was recaptured for the second time outside the bay (zone 10). Then, it traveled in this area before the third recapture the day after. Thereafter, it moved to Chaoloa Beach (zone 14) that is very far away from the moth of bay (Figure 4.21). It was the fourth recaptured on March 14. Therefore, it can move up to 9.25 km in 15 days since tagged and released. After the fourth recaptured in mid-March, no more crab was caught in both the gill nets and the collapsible traps until June when the experiment terminated

This low return rate might be underestimated due to the intense fishing activities in this area. Some tagged crabs might be caught but the fishermen failed to report to the researcher. Although the incentives were provided 30 Baht per tag reported which was lower than price of sold directly to the market. Therefore, the cooperation with local fishermen and higher incentive are required for effective future works. The other possible reason for underestimation due to molting in tagged crabs, and the effectiveness of the tags. Future, researches on suitable tagging methods for juvenile crabs are required.

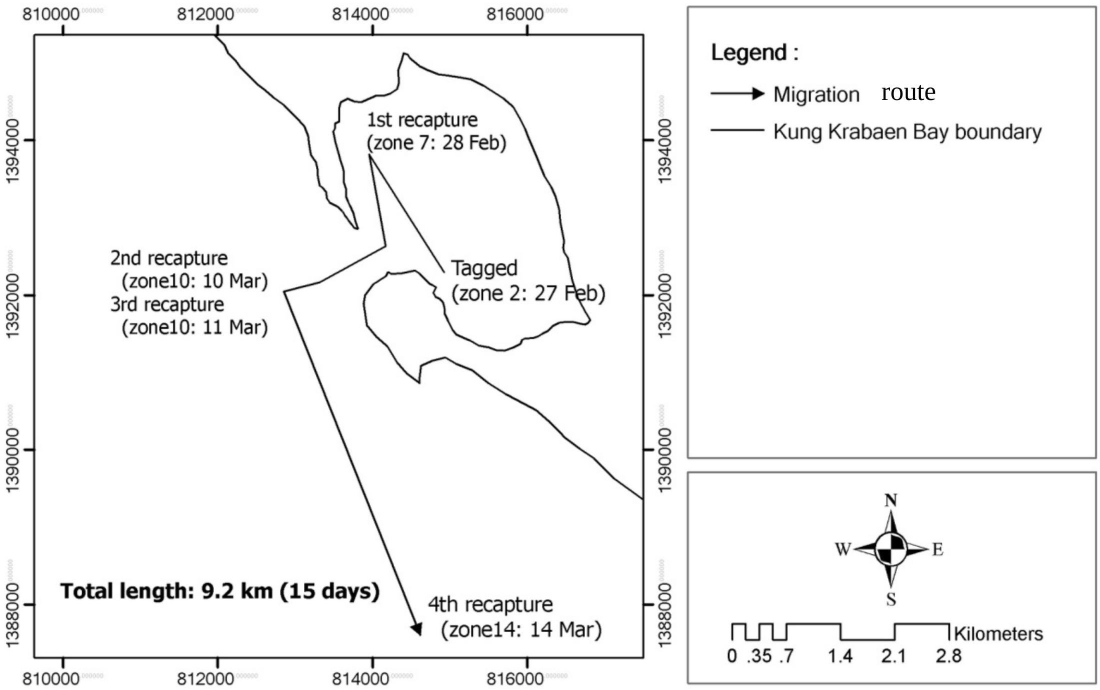


Figure 4.21. Migration route of female blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province from the released point

Duration of 15 days after tag for this 9.25 km movement

4.2.2. Average speed of movement

Table 4.11 shows the movement speed of 155 blue swimming crabs in this study. The result from the first recapture revealed that a male crab able to travel up to 5.49 km in one day (carapace width 9.8 cm, weight 100g). This is a long distance compared with its body sizes. In case of second and fourth recapture, the average speeds were 0.52 and 0.62 km/day, respectively. Speed of movement of adult crabs was faster than juvenile crabs but slower than ovigerous females (Table 4.12).

Table 4.11. Moving distance and speed of movement of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province in different time at liberty before recaptured in first, second and fourth times

	First recapture Distance (km)						**Second recapture** Distance (km)						**Fourth recapture** Distance		
Time (day)	no crab.	Min	Max	Mean	SD	Speed (km/day)	no crab.	Min	Max	Mean	SD	Speed (km/day)	no crab.	(km)	Speed (km/day)
1	28	0.02	5.49	1.34	1.12	1.34	1	1.45	1.45	1.45	0.00	1.45	-	-	-
2	18	0.10	4.63	1.36	1.18	0.68	1	1.89	1.89	1.89	0.00	0.95	-	-	-
3	12	0.02	6.17	1.94	1.79	0.65	1	1.35	1.35	1.35	0.00	0.45	-	-	-
4	10	0.64	2.87	1.44	0.80	0.36	-	-	-	-	-	-	-	-	-
5	19	0.15	5.94	2.03	1.93	0.41	1	1.42	1.42	1.42	0.00	0.28	-	-	-
6	6	1.49	5.82	3.39	1.92	0.56	-	-	-	-	-	-	-	-	-
7	3	0.54	1.19	0.89	0.33	0.13	1	1.33	1.33	1.33	0.00	0.19	-	-	-
8	9	0.13	3.95	1.12	1.14	0.14	2	0.49	2.19	1.34	1.20	0.17	-	-	-
9	1	1.25	1.25	1.25	0.00	0.14	-	-	-	-	-	-	-	-	-
10	9	0.66	2.70	1.81	0.79	0.18	3	1.09	4.29	2.66	1.60	0.27	-	-	-
11	3	1.09	1.69	1.36	0.30	0.12	6	2.99	9.22	6.26	2.53	0.57	-	-	-
12	2	1.40	2.41	1.90	0.72	0.16	4	2.21	6.90	3.77	2.13	0.31	-	-	-
13	3	0.97	2.82	2.21	1.07	0.17	1	7.76	7.76	7.76	0.00	0.60	-	-	-
14	1	2.80	2.80	2.80	0.00	0.20	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	1	9.25	0.62
Average speed in each recapture period						0.37						0.52			0.62
Average speed in all recapture period															**0.50**

Table 4.12. Average speed of movement (km/day) of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province

Immature male	**mature male**	**immature female**	**mature female**	**ovigerous female**
0.15±0.10	0.68±0.91	0.49±0.46	0.60±0.49	0.71±0.68

4.2.3. Feeding ecology

Organisms are constantly faced with choices for feeding, habitat, and breeding. It is correlated with evolution theory. These choices serve to enhance the fitness of future generations (Krebs and Davies, 1997). Food availability was one of the important factors determining the distribution and abundance in crab populations. In decapod crustacean, migration has often been associated with the ontogenetic niche shift in habitat use (Pittman and McAlpine, 2003) as evidenced in *Callinectes sapidus* and *Necora puber* (Ruiz et al, 1993; Lee et al., 2004). Moreover, feeding ground was determined by local abundance and availability of prey. The feeding ecology in the blue swimming crabs was studied in depth in order to support the movement pattern study. The result of this study showed below:

Food items

Analysis on stomach contents of 262 blue swimming crabs were carried out, including 140 male crabs with carapace width ranging 4.49-14.26 cm and 122 female crabs with carapace width ranging 4.07-16.73 cm, respectively. The frequency of occurrence method showed major prey items in the stomach contents of blue swimming crabs were teleost fish (29.61%), organic matter (20.69%), crustaceans (18.3%) and shell mollusks (11.46%), respectively (Figure 4.22). The teleost fish in stomach content can not be identified to species due to the crushing and grinding in the feeding behaviour in the blue swimming crabs. However the dominant fishes in the area can be observed in bycatch composition. Teleost fish in this area are *Mugil dussmeri*, *Therapon jarbua*, *Parapocryptes serperaster*, *Monacanthus chinensis*, *Drepanae punctata*, *Platycephalus indicus*, *Lutjanus russelli*, *Pseudorhombus arsius*, *Megalops cyprinoides* and *Dasyatis imbricatus*.

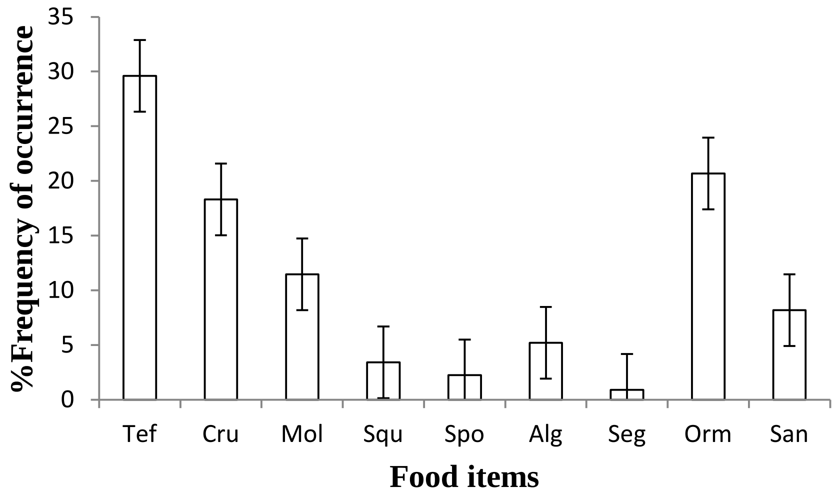


Figure 4.22. Food items of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province was calculated by frequency of occurrence method

Key: Tef, teleost fish; Cru, Crustacean,; Mol, Molluska; Squ,Squid; Alg, Algae,; Seg, Seagrass; Orm, Organic matter; San, Sand

The percentage point method showed the similar trend as the frequency of occurrence method that teleost fish were the major food items in the stomach content of 29.62%. Crustacean, organic matter and mollusk ranked as the next major food items in respective order of 21.2%, 18.36 and 18.21. Sand (4.22%), squid (2.93%), algae (2.61%), sponge (2.29%) and seagrass (0.56%) were found in smaller quantity (Figure 4.23).

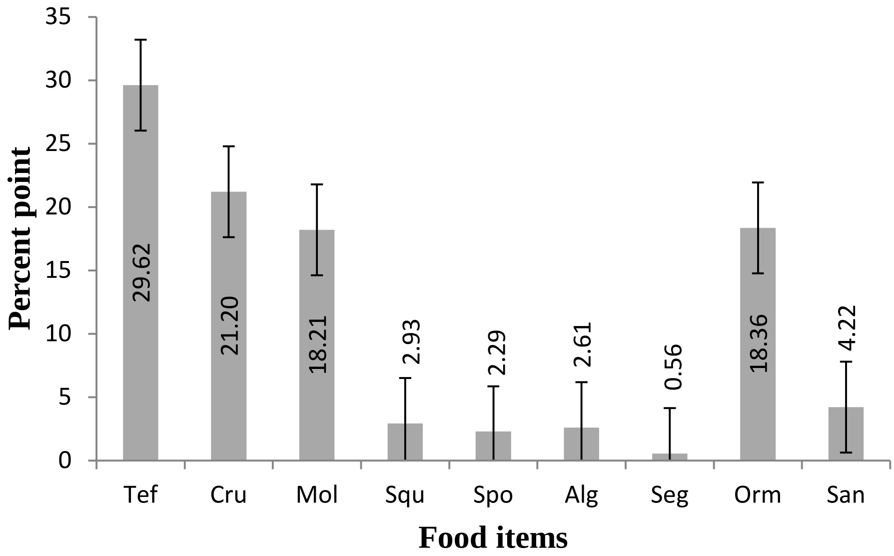


Figure 4.23. Food items of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province was calculated by percentage point method **(**Key: Tef, teleost fish; Cru, Crustacean,; Mol, Molluska; Squ,Squid; Alg, Algae,; Seg, Seagrass; Orm, Organic matter; San, Sand)

Index of relative Importance (IRI) in the food items confirmed with the major prey items ranged from 41.18% to 0.07% with the highest percentage index of relative importance recorded for teleost fish (41.18%) and the lowest (0.07%) for the seagrass (Table 4.13).

Table 4.13. Index of relative importance (IRI) and percentage (IRI) of food items of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province in the stomach

Food items	Freq. occur. (FO)	%FO	Point (PT)	%PT	Numerical (N)	%N	IRI	%IRI
Tef	199	29.61	1010	29.62	322	20.60	1487.19	41.18
Cru	123	18.30	723	21.20	473	30.26	942.03	26.09
Mol	77	11.46	621	18.21	192	12.28	349.43	9.68
Squ	23	3.42	100	2.93	89	5.69	29.52	0.82
Spo	15	2.23	78	2.29	35	2.24	10.11	0.28
Alg	35	5.21	89	2.61	97	6.21	45.93	1.27
Seg	6	0.89	19	0.56	38	2.43	2.67	0.07
Orm	139	20.68	626	18.36	205	13.12	651.03	18.03
San	55	8.18	144	4.22	112	7.17	93.18	2.58
	672		3410		1563		3611.08	

NS = No significant variation ($p>0.05$)

* = Significance variation ($p<0.05$)

Ontogenetic niche shift

The significant differences were found in diet composition between juvenile and mature crabs ($p<0.05$) (Table 4.14). The major food items of juvenile male crabs were teleost fish (31.65%), crustaceans (18.99%) and mollusks (17.72%), respectively while the major food items of adult male crabs were teleost fish (30.13%), organic matter (22.59%) and crustacean (19.25%) (Figure 4.24). Sponge were absent in stomach of juvenile male crab but were found in adult crabs. Moreover, algae and seagrass are dominant food in stomach of juveniles (Figure 4.24, 4.25). This study confirmed the importance of seagrass beds as feeding grounds for juveniles which correlated to the movement pattern within the bay. The major food items in juvenile and adult female blue swimming crabs, followed the similar trend as those reported for male crabs (Figure 4.26, 4.27).

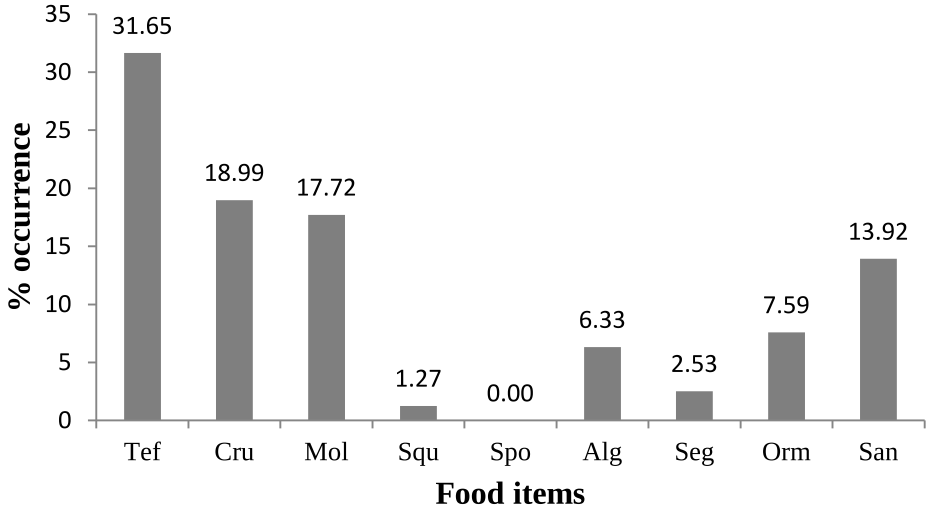


Figure 4.24. Percent occurrence of food item of immature male blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province **(**Key: Tef, teleost fish; Cru, Crustacean,; Mol, Molluska; Squ,Squid; Alg, Algae,; Seg, Seagrass; Orm, Organic matter; San, Sand)

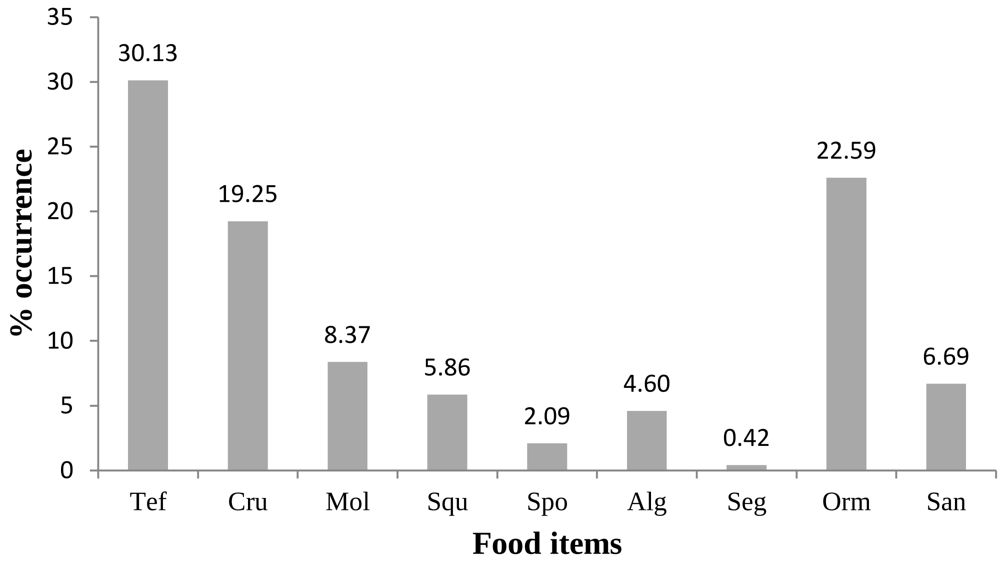


Figure 4.25. Percent occurrence of food item of mature male blue swimming crab**s** in Kung Krabaen Bay, Chanthaburi Province **(**Key: Tef, teleost fish; Cru, Crustacean,; Mol, Molluska; Squ,Squid; Alg, Algae,; Seg, Seagrass; Orm, Organic matter; San, Sand)

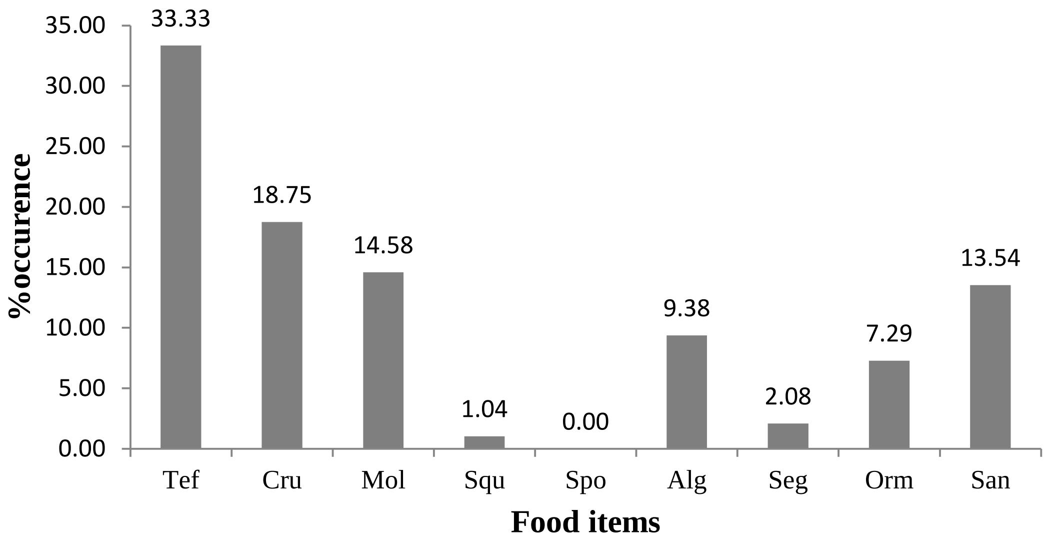


Figure 4.26. Percent occurrence of food item of immature female blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province **(**Key: Tef, teleost fish; Cru, Crustacean,; Mol, Molluska; Squ,Squid; Alg, Algae,; Seg, Seagrass; Orm, Organic matter; San, Sand)

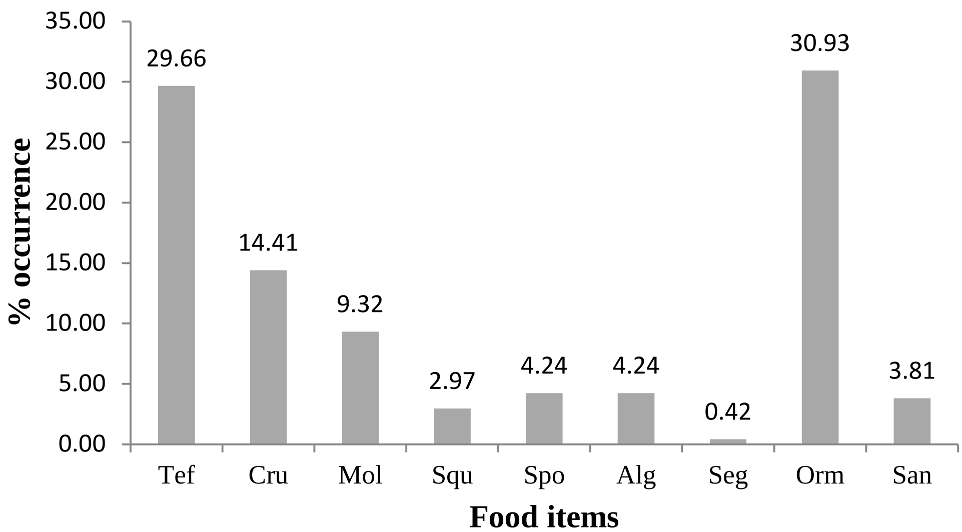


Figure 4.27. Percent occurrence of food item of mature female blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province**(**Key: Tef, teleost fish; Cru, Crustacean,; Mol, Molluska; Squ,Squid; Alg, Algae,; Seg, Seagrass; Orm, Organic matter; San, Sand)

Significantly differences in food items between crab inside and outside the bay were found ($p<0.05$) (Table 4.14). The major food items of crab inside the bay were teleost fish, crustaceans, mollusks and organic matter while the major food items of crab outside the bay were organic matter, teleost fish, sand, and crustaceans. The minor food of crabs inside the bay were mollusks (13.76%), organic matter (13.76%), sand (7.57%), algae (5.73%), squids (5.28%) and seageass (1.15%). Sponges were absent inside the bay but they were found in the stomach content of crabs outside the bay, while squids and seagrass were found only in the crab stomach contents inside the bay. Moreover organic matter in found in high percentage in the stomach contents in crabs outside the bay (Figure 4.28). Moreover, from the data of bycatch found that species of teleost fish inside and outside the bay are differnt. The dominant species of teleost fish inside the bay were *Mugil dussmeri*, *Therapon jarbua*, *Parapocryptes serperaster* and *Monacanthus chinensis* while dominat species of teleost fish outside the bay were *Drepanae punctata*, *Platycephalus indicus* and *Dasyatis imbricatus*. This indicated that food sources of blue swimming crabs inside and outside the bay were different.

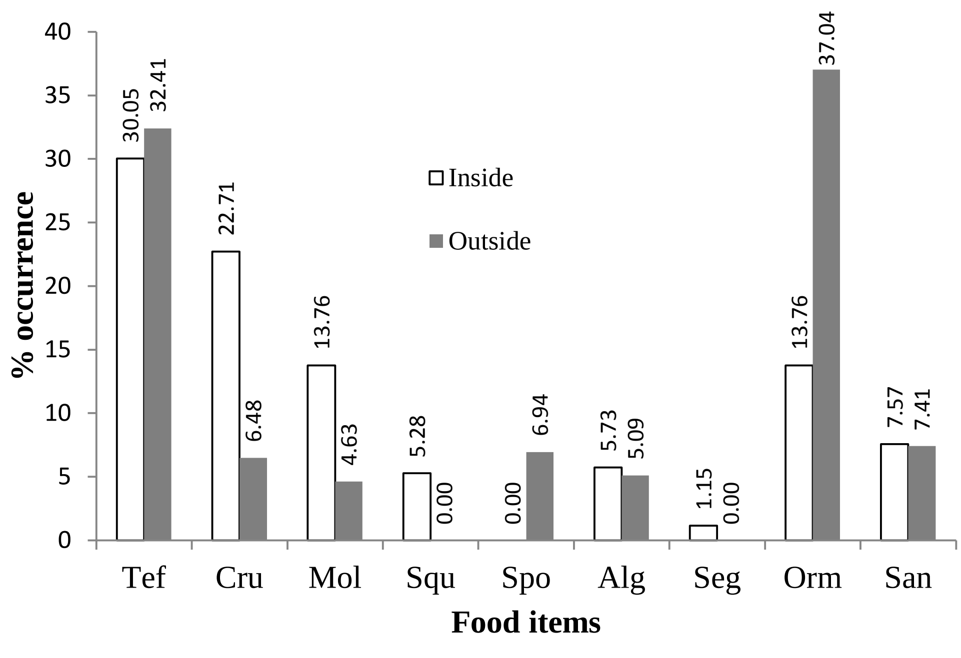


Figure 4.28. Percent occurrence of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province (inside and outside the bay) **(**Key: Tef, teleost fish; Cru, Crustacean,; Mol, Molluska; Squ,Squid; Alg, Algae,; Seg, Seagrass; Orm, Organic matter; San, Sand)

Male and female crabs shared the major food items, including teleost fish, organic matter and crustaceans in similar proportions, with slightly higher frequencies of most food types in female crabs except for organic matter and sponge (Figure 4.29). Chi-square test result showed that no significant difference was detected between the diets of male and female crabs (Table 4.14).

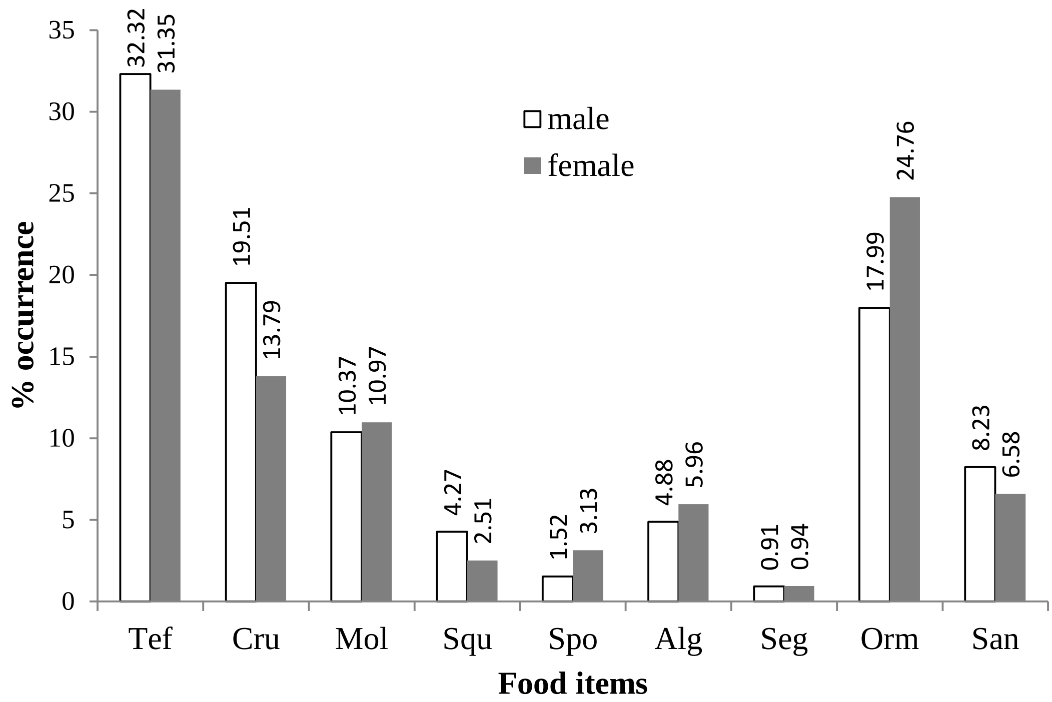


Figure 4.29. Percent occurrence of food item of male and female blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province **(**Key: Tef, teleost fish; Cru, Crustacean,; Mol, Molluska; Squ,Squid; Alg, Algae,; Seg, Seagrass; Orm, Organic matter; San, Sand)

Table 4.14. Difference in the quantity of food between of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province different sexes, size, season and habitat (see detail in Appendix D-H)

Source of variation	χ^2	df	P
Males vs female	10.98	8	n.s.
Small male vs large male	23.11	8	<0.05
Small female vs large female	38.78	8	<0.05
Wet vs Dry season (male)	48.22	8	<0.05
Habitat_inside vs outside	114.12	8	<0.05

However, seasonal diet composition was significantly different between crabs collected in wet and dry season ($p<0.05$) (Table 4.14). In dry season, teleost fish, organic matter and crustaceans were the most frequently consumed items, while in wet season, teleost fish, crustacean and organic matter were the major food items. Moreover, some food items such as sponge and seagrass which were found in dry season but absent in wet season (Figure 4.30).

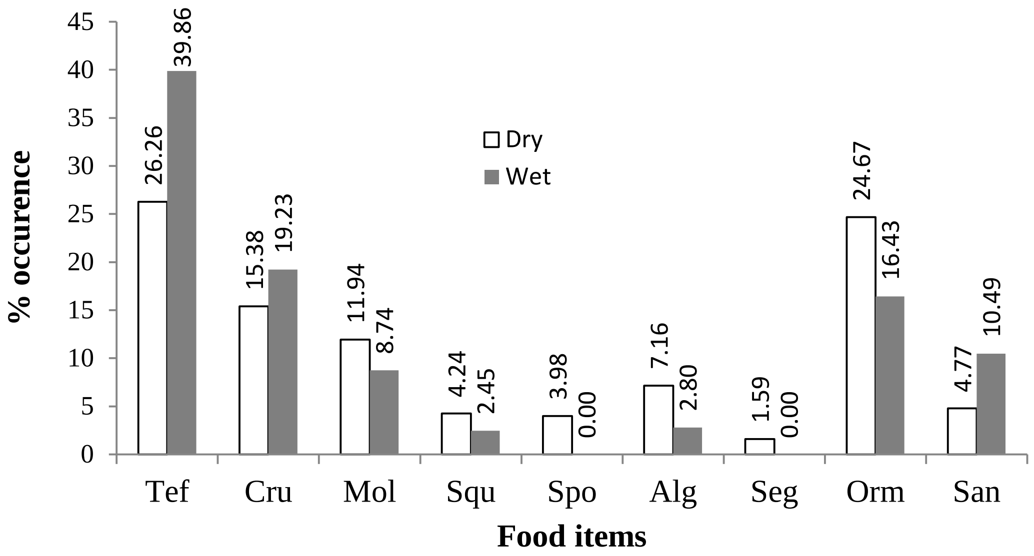


Figure 4.30. Percent occurrence food of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province in dry and wet season **(**Key: Tef, teleost fish; Cru, Crustacean,; Mol, Molluska; Squ,Squid; Alg, Algae,; Seg, Seagrass; Orm, Organic matter; San, Sand)

Comparisons of diets in Kung Krabaen Bay and in other coastal marine water

Ontogenetic niche shift of blue swimming crabs were also studied in Coast of Dar es Salaam, Tanzania, it was found that there was no variation in the diet of *P. pelagicus* in relation to sex, crab size and season because crabs probably change to larger-size food items of the same taxa as they grow (Chande and Mgaya, 2004). In addition in the Mortan Bay, Williams (1982) also studied similarity in diet between sexes and among crabs of different sizes. The high density of the available prey species within each designated food taxon was taken as the most plausible explanation.

At Kung Krabaen Bay, blue swimming crabs is predominantly carnivorous and scavenger, feeding on primarily teleost fish and invertebrate preys, which include mollusks and crustaceans. In contrast to previous reports of natural diets of blue swimming crabs elsewhere (Williams, 1981, 1982; Patel, 1979; Wassenberg and Hill, 1987; Edgar, 1990; Wu and Shin, 1998; Chande and Mgaya, 2004), blue swimming crabs feed mostly on sessile or slow moving invertebrates. Therefore the dominance of teleosts in diet of blue swimming crabs in Kung Krabaen Bay may reflect the scavenging activity by the crab. The species of crustacean which occurred in stomach contents of crabs were *Charybdis feriatus*, *Thalamita crenata* and *Matuta banksii*. Blue swimming crabs were also included because of cannibalism behaviors. This result correlated with the report by Kunsook (2006) that portunid crabs were dominant preys being abundant in the area. Therefore, feeding of crabs was closely correlated to the distribution and density of preys. Algae and seagrass were of minor importance in the diet of blue swimming crabs even through seagrass species, *Enhalous acoroides* and *Halodule pinifolia*, were prevalent in Kung Krabaen Bay. This suggested that plants materials may be ingested accidentally as prey items are gleaned from among algae and seagrass (Williams, 1981). Moreover, this study indicated that most juvenile blue swimming crabs inhabit in this area. Several study showed that seagrass beds are often cited as nursery habitat for juvenile marine animals because they provide refuge from predators and a greater abundance of food (Jackson et al., 2001).

Feeding patterns of blue swimming crabs in Kung Krabaen Bay

There was no variation in the diet of blue swimming crabs in relation to sex of crab. Williams (1982) noted that males and females of crabs ate similar types and of same quantities of food. Edgar (1990) found no sexual difference in food types of blue swimming crabs of Western Australia, but a larger quantity of food was found in stomachs of female crabs than male crabs, suggesting that female crab need more energy for ovogenesis. Similarly, Cannicci et al. (1996) found that female *Thalamita crenata*, one of the portunid species, consumed more food that male crabs. Chande and Mgaya (2004) reported that no significance difference in food types were observed among sex, size and seasons. However significance differences were recorded among the various food items.

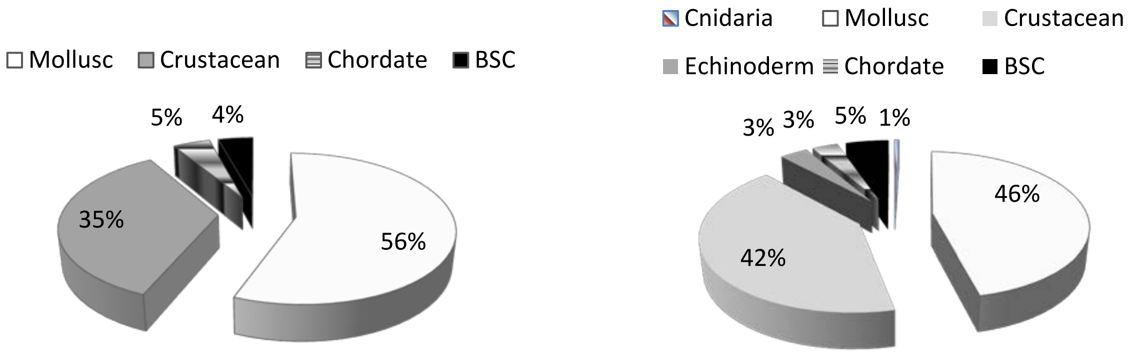
The result also showed the different feeding patterns in juvenile and mature crabs. This reflected the ontogenetic changes. Juvenile crabs go through several frequent molting stages during growth in which calcium is required; therefore juvenile crabs would prefer fish bone, shell mollusks and crustaceans (Williams, 1982; Cannicci et al., 1996). Feeding ecology of juvenile and mature crabs was supported from the bycatch data in clollapsible crab trap and crab gill net. Moreover, different feeding between seasons and habitat type were occurred in this study because the abundance and distribution of prey was different in each season and habitat type. Species composition of prey or food of crab can be observed in details by the bycatch composition as below.

4.2.4. Bycatch composition

Species compostion of bycatch indicated the feeding ground of blue swimming crabs inside and out side the bay. According to natural diet of blue swimming crabs inside the bay a total of 41 species of bycatch identified from collapsible crab traps (Appendix I). The blue swimming crabs, the dominant and target species, constituted on average 4.23% of total catches in numbers. The mollusk *Clithon oualaniensis Nassarius livescens* and *Babylonia areolata* represented 25.35 18.2% and 9.22% of total catch, respectively. The remaining 29.53% included mostly the crustacean especially crab group, such as long-claw hermit crab *Clibanarius longitarsus*, *Clibanarius infraspinatus*, *Thalamita crenata*, *Charybdis affinis* and *Charybdis anisodon*. Bycatch data from collasible crab trap were showed the natural diet inside the bay especially *Nassarius livescens*, *Thalamita crenata*, *Charybdis affinis* that distributed inside the bay particulary in seagrass bed. Some groups of bycatch such as teleost fish were used to indicate the food source inside the bay such as *Mugil dussmeri*, *Therapon jarbua*, *Parapocryptes serperaster*, and *Monacanthus chinensis*. These fish are usually herbivores and omnivores.

A total of 37 species of bycatch from crab gill nets were identified (Appendix J). The blue swimming crabs, the dominant and target species, constituted on average 5.33% of total catches in numbers. *Murex trapa*, *Malleus* sp. *and Spondylus croceus* are dominant mollusk in this gear. Total catch represented 15.83%, 10.91% and 10.23%, respectively. For the crustaceans, *Calappa philargius* (14.28%) and *Hyastenus* sp. (7.26%) were dominant crabs. The remaining prey was echinoderm (3.45%), chordate (3.18%) and cnidaria (0.51%), respectively. Similar to the result in crab traps, bycatch data of crab gill nets showed the additional food sources for blue swimming crabs outside the bay especially the echinoderms. Moreover some teleost fish such as *Drepanae punctata*, *Platycephalus indicus*, *Lutjanus russelli*, *Pseudorhombus arsius*, *Megalops cyprinoides* and *Dasyatis imbricatus* were the food source of blue swimming crabs outside the bay. These fishes are carnivorous.

The result showed the bycatch composition from collapsible crab traps and crab gill nets, the target animal in each gear represented only 4.23% and 5.33% in the contrast bycatch composition represented 95.73% and 94.67%, respectively. Although the fishermen can sell or consume the bycatch but the coastal ecosystem was disturbed due to loss of discarded bycatch represented over than 81% and 82% in the catches respectively (Figure 4.31). This result revealed that the collapsible crab traps have more negative effect on bycatch diversity especially mollusk, crab, prawn and demersal fish. The result corresponded to those reports on the blue swimming crabs fishery in the southern Gulf of Thailand and Banten Bay in West Java Indonesia (Dechboon and Somchanakij, 2006; Suadela, 2004).



Trap **Gillnet**

Figure 4.31. Species compositions of bycatch from collapsible crab traps and crab gill nets fishery of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province

4.2.5. Size distribution

Size distribution of crabs from two fishing gears in Kung Krabaen Bay ranged from 1.0-16.73 cm with the average size of 8.9 cm. The population covered almost every size class. The maximum abundance in males were at 7-8 cm and 11-13 cm CW whereas the females predominate from 11 cm to 13 cm CW (Figure 4.32). Regarding the proportion of size in inside the bay, immature males (23%) and females (22%) were found only inside the bay. However, from the movement pattern data revealed that immature crabs can migrate to outside the bay but only in small proportion. In contrast to immature crabs, the mature males and females were found both inside and outside the bay. Mature females were found outside the bay in the large proportion (Figure 4.33). Ovigerous females can be found outside the bay in a higher proportion than inside the bay. This corresponded to Jindalikhit (2002) that reported on large crabs mostly inhabited in the deep water than in shallow waters. In contrast, small size crabs distributed in the shallow waters. The differences in the distribution of *P. pelagicus* in different habitats according to size could be related to their swimming ability, as large individuals able to withstand strong waves in more open and deeper waters (Chande, and Mgaya, 2003). Sumpton and Williams (2002) reported that blue swimming crabs inhabited in a wide range of habitats depending on different stages of life cycle. Juvenile crabs inhabited in shallow seagrass beds, sand, mud banks and estuaries. Adult crabs generally inhabited in deeper waters and shallow sandbank areas within a bay and in estuary. Not only the blue swimming crabs *Portunus pelagicus* showed the segregration of habitats between adults and juveniles but this pattern of habitat use was also found in other portunid crabs such as *Callinectes sapidus* (Darnel, 1959), *Carcinus meanus* (Klein Breteler, 1976) and *Scylla serrata* (Hill et al., 1982).

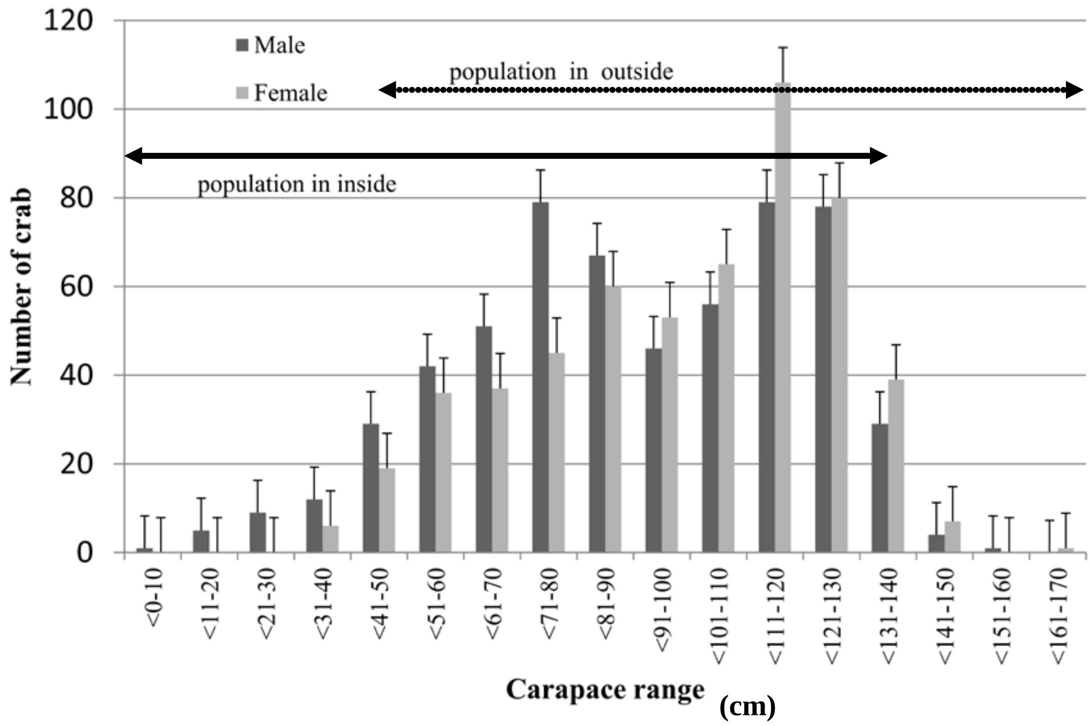


Figure 4.32. Size distribution of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province

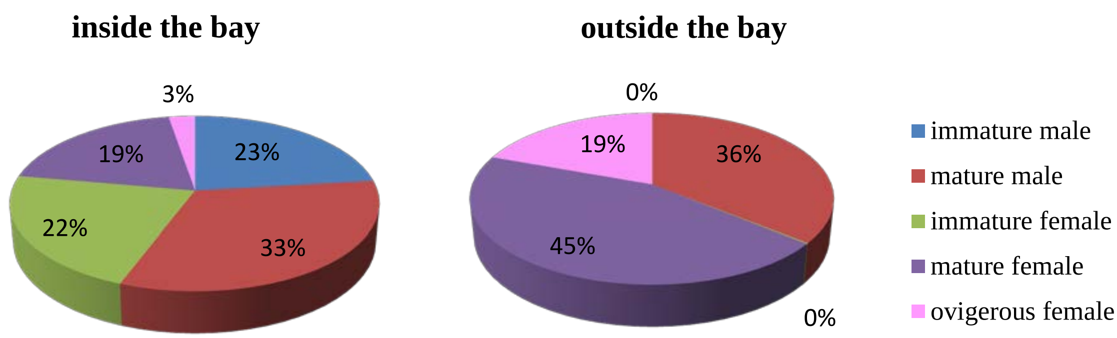


Figure 4.33. Proportion between juvenile and adult blue swimming crabs in inside and outside the Kung Krabaen bay, Chanthaburi Province

4.2.6. Seasonal abundance and distribution

Blue swimming crabs occurred throughout the months of October 2008 to September 2009 in Kung Krabaen Bay. The male contributed 51.96% of the population (503 individuals) and females 48.04% of the total crab caught totalled to 465 individuals. The monthly distribution of crabs in the whole year catches is presented in Figure 4.34.

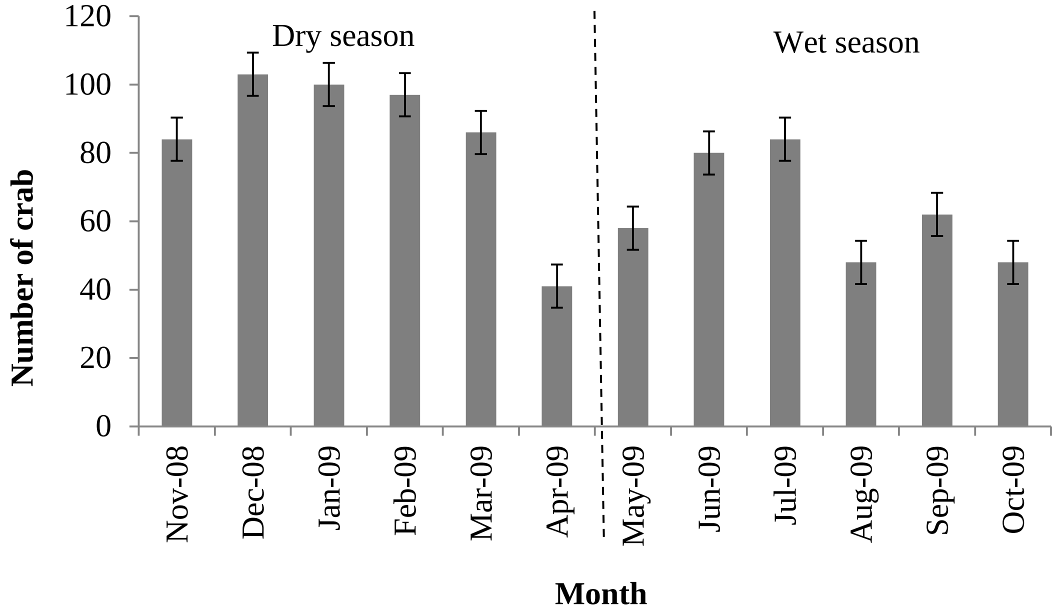


Figure 4.34. Monthly distribution of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province

In the twenty seven stations surveyed, crabs were mainly collected at stations KL, SG and U. The highest crab abundance were recorded at stations KL and SG2. However, the abundance of crabs was significantly different among stations ($p < 0.05$), but not significantly different in season ($p > 0.05$) (Appendix K). Moreover, abundance of crabs in dry season has trend to higher than wet season, peak fishing season for crabs was during December to January and June to July. In dry season, high density was occurred in Chaolao beach (zone KL3), Chaolao beach (zone KL2), bare ground without vegetation coverage (zone U1 and U2) while in wet season, high density of crabs occurred in segrass bed *Halodule pinifolia* (zonr SG22, SG23), bare ground without vegetation coverage (zone U1 and U3 and Chaolao beach (zone KL3) (Figure 4.35).

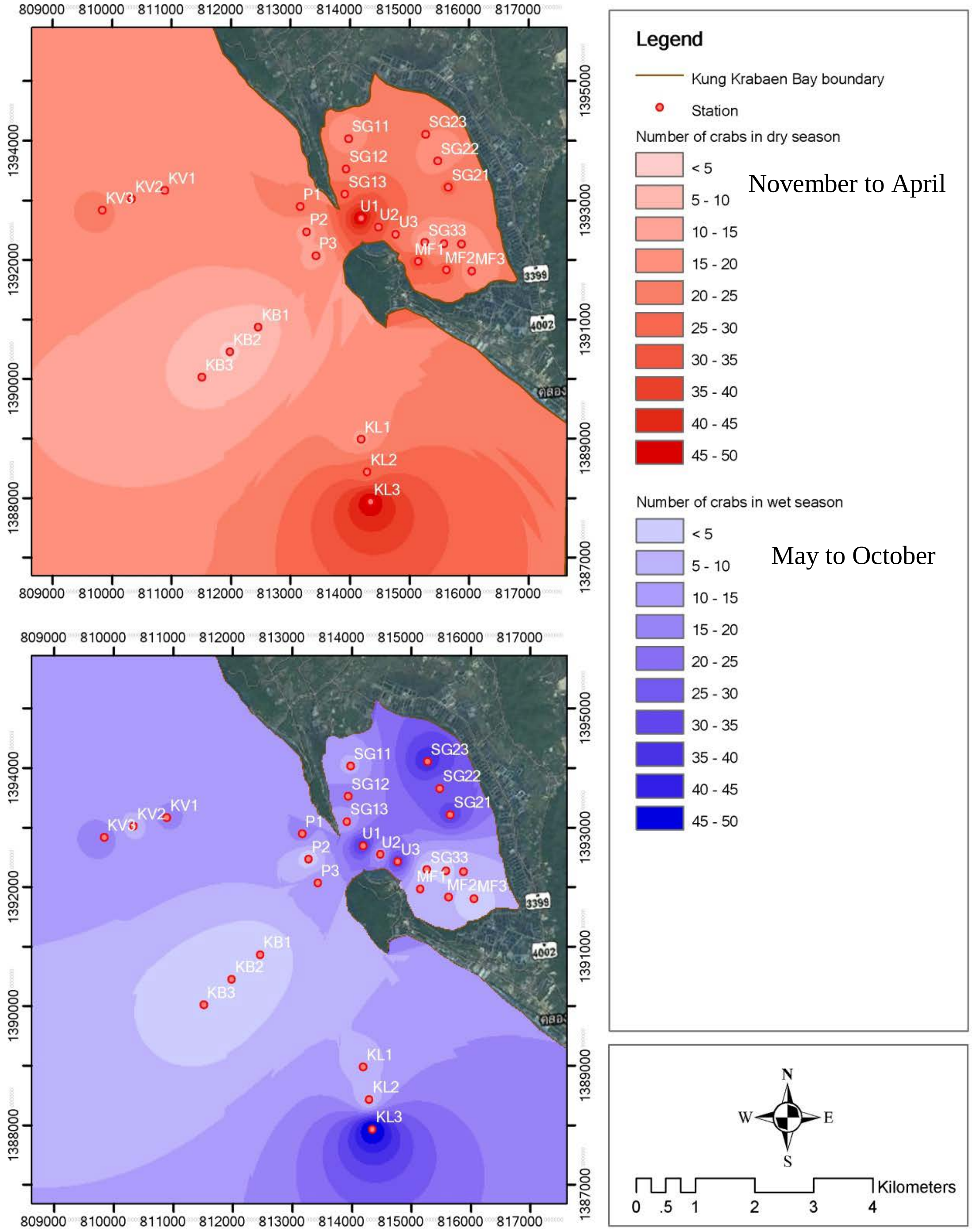


Figure 4.35. Seasonal distribution of blue swimming crabs in dry and wet season in Kung Krabaen Bay, Chanthaburi Province

In dry season, the large proportion of mature males (47%) were found inside the bay in particular the bare ground (U1). While outside the bay, large proportion of mature females (33%) and ovigerous females (46%) were found. In wet season, immature males (24%) and females (28%) were found inside the bay in the same proportion. While outside the bay, mature males (39%) and females (37%) were also found in the same proportion (Figure 4.36).

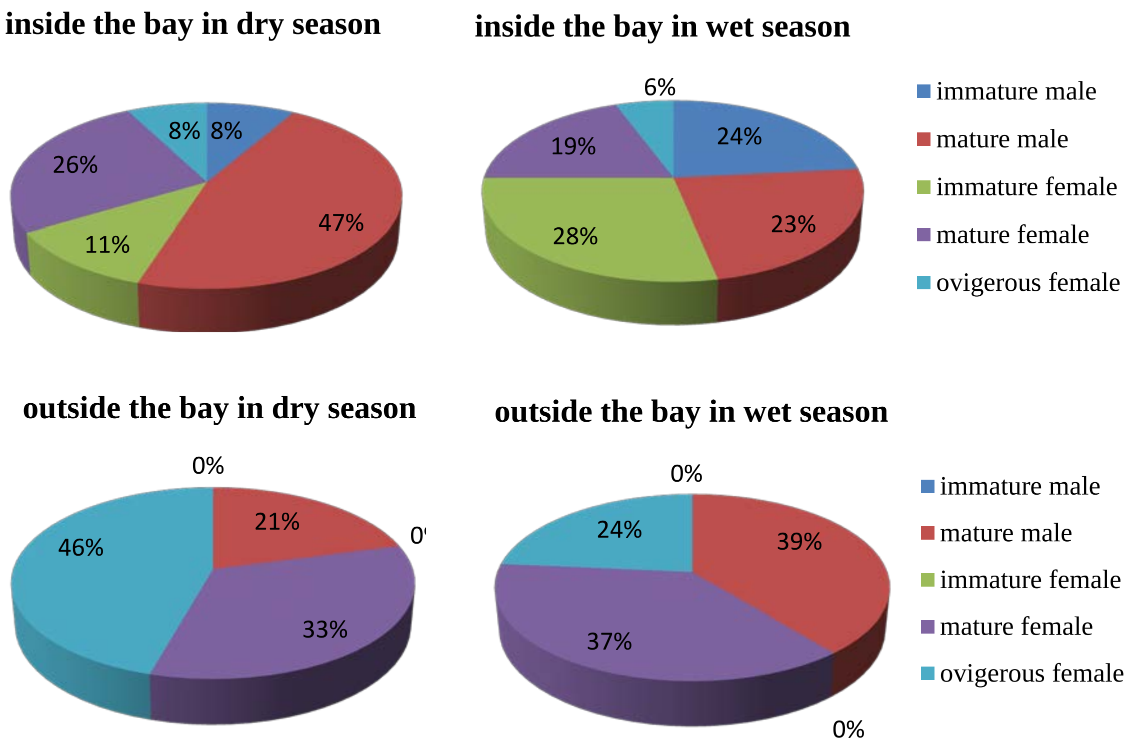


Figure 4.36. Proportion of immature, mature males and females and ovigerous female blue swimming crabs in inside and outside the Kung Krabaen bay, Chanthaburi Province in dry and wet season

This result supports the movement pattern data and feeding ecology that mature female find the food resource and spawning site to released eggs. This reason was also supported by data of environmental factor in particular salinity and temperature. Defeo and Cardoso (2002) indicated that environmental factors such as water temperature, may affect crab growth rate. The growth rate of marine crabs was faster in warm water than in cool water (Leffler, 1972). Moreover, Potter et al. (1983; 1998) suggested that blue swimming crabs migrate to open water when the salinity in the coastal water decreased. They moved closer shore when the normal salinity of the coastal waters observed. Potter et al. (1991) reported that the planktonic stage of the blue swimming crabs required high salinity for growth development. The optimal salinity and temperature for larvae of blue swimming crabs were 28-39 ppt. and 24-27°C. Regarding the data from reproductive biology, spawning periods were found three peaks. High peak of spawning were found in the dry season on December and March which the environmental factors in Kung Krabaen Bay are suitable for spawning of ovigerous females. The average of salinity in dry season was 32.21±0.89 ppt and average temperature was 29.5±1.72 °C. In wet season, average salinity was 29.5±1.88 ppt and average temperature was 29.51±1.55 °C.

Salinity and temperature were the major environmental factors in controlling the crab distribution according to Pearson correlation ($p<0.05$) as in Table 4.15 (Appendix L)

Table 4.15. Correlation between physical factors and blue swimming crabs distribution in Kung Krabaen Bay, Chanthaburi Province

Physical factor	**Pearson correlation**
Depth	-0.056
Transparency depth	0.044
Temperature	0.136*
Salinity	0.117*
Dissolved oxygen	0.021
pH	-0.027

*Significance at 0.05% level

4.2.7. Overview of the movement pattern

Based on the results from the movement pattern, the crabs living inside the bay were the same population as those living outside the bay. This study on the movement pattern coupled with reproductive biology and feeding ecology supported the movement theory of decapod crustacean live nearshore having a tri-phasic life cycle. The tri-phasic life cycle movement patterns involved 1) movement of planktonic eggs and larvae to seek for refuges and food 2) movement of juveniles to shallow water areas to seek for food and nursery area; and 3) movement of adults to deep water for food and spawning. Tantichaiwanit (2005) and Raungprataungsuk (2009) studied life cycle of blue swimming crabs in planktonic phase and juvenile phase, respectively. This study support the movement of adult crabs moving into deep water. Male crabs tend to inhabit inside the bay, while female crabs tend to migrate to the outside the bay according to their ovarian development to spawn. The ovigerous female crabs fed inside the bay until their eggs developed to late state before hatching. Most ovigerous female crabs recaptured in the second time outside the bay had already sheded their eggs. Non-ovigerous female could be found outside the bay in the mouth of the bay, in front of Kung Krabaen Bay and Chaoloa beach. The purpose of migration for finding food source was supported by feeding ecology and by catch composition. In decapod crustacean, migration has often been associated with an ontogenetic niche shift in habitat use (Vagelli, 2004). This study strongly indicated differences in feeding habit of juvenile and adult crabs. Effective swimming ability allowed the adult crabs to migrate in great distances than juveniles. They were able to store sufficient energy for migration in long distance. Generally, blue swimming crabs migrate to spawn offshore (Gillander et al., 2003; Pittman and McAlpine, 2001). This study indicated that adult male and female crabs can migrate in long distance from inside to outside the bay. This migration is thought to be necessary for the survival of planktonic-stage larvae due to lower oxygen levels, low salinity and lack of suitable food (Meagher 1971; Kangas 2000). Planktonic larvae of blue swimming crabs required the optimal high salinity ranged 28-39 ppt.

Proposed movement in the summarized life cycle of adult blue swimming crabs was in Figure 4.37. Movement in adult blue swimming crabs was related to the feeding and spawning grounds. Male crabs tend to inhabit inside the bay, while female crabs tend to migrate to the outside the bay according to their ovarian development to spawn. From the feeding ecology data, adult crabs feed some food items such as sponge and squid that were not found inside the bay. However, most adult males in the first recapture data inhabited in inside the bay in paticular in the seagrass beds as the feeding ground to storage sufficient energy for the migration in long distance. Ovigerous females required high salinity and temperature to spawn. The movement of ovigerous females aimed to find the optimal condition to spawn and for survival of the planktonic larvae.

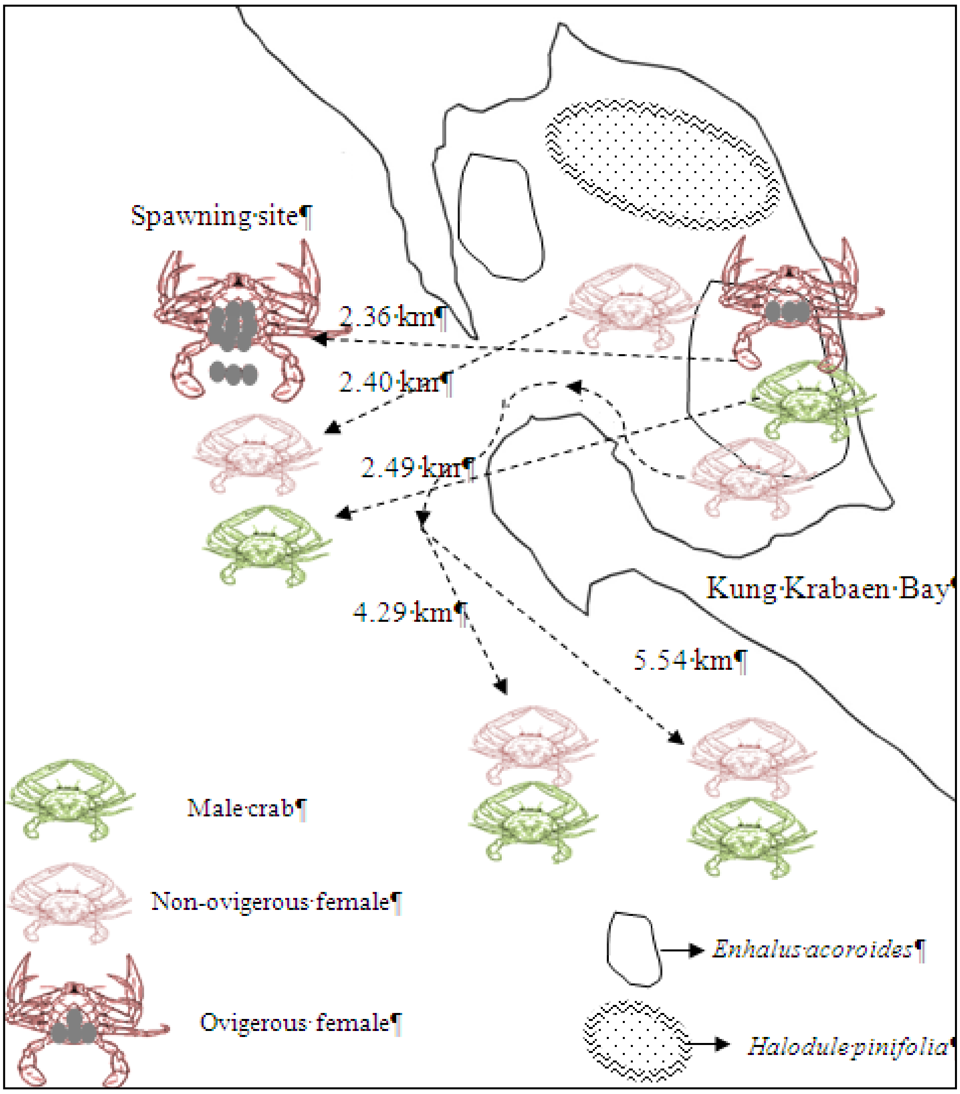


Figure 4.37. Movement in adult phase in the blue swimming crabs life history in Kung Krabaen Bay, Chanthaburi Province

Movement pattern of blue swimming crabs in planktonic and juvenile phases were showed in Figure 4.38. Movement pattern of blue swimming crabs in these stages were related to the feeding ground and nursing ground. After spawning, eggs were hatched into zoea stage. The planktonic larvae passed through several zoeal stages. They prefer the seagrass beds for settlement and developed into megalopa stage (Pittman and McAlpine, 2001; Potter et al., 1991). The estimation on the success of planktonic development to settlement was higher in the *E. acoroides* seagrass beds than *H. pinifolia* and bareground. Juvenile crab prefered the *H. pinifolia* beds while adult crabs prefered the bare ground (Raungprataungsuk, 2009). This phase of blue swimming crabs require nursery area to seek refuges from predators and to feed on phytoplankton and zooplankton such as green algae, chaetoceros, and rotifer which were abundant in the area (Tantichaiwanit, 2005). Megalopae developed into young crabs and juvenile stage. Juveniles used the seagrass bed area as nursing ground and feeding ground. The feeding ecology from this study showed that major food items of juvenile crabs are teleost fish, crustaceans and mollusks that were highly abundant in this area. The juvenile blue swimming crabs develop until they are in adult phase (Pittman and McAlpine, 2001). This study showed the important role of seagrass beds as nusery ground and feeding ground in this economically important crab. In order to sustain the blue swimming crab stocks, it is essential to include the conservation of nursery ground and spawning grounds as one of the management measures. The restoration of seagrass beds is also required to sustain the blue swimming crab populations.

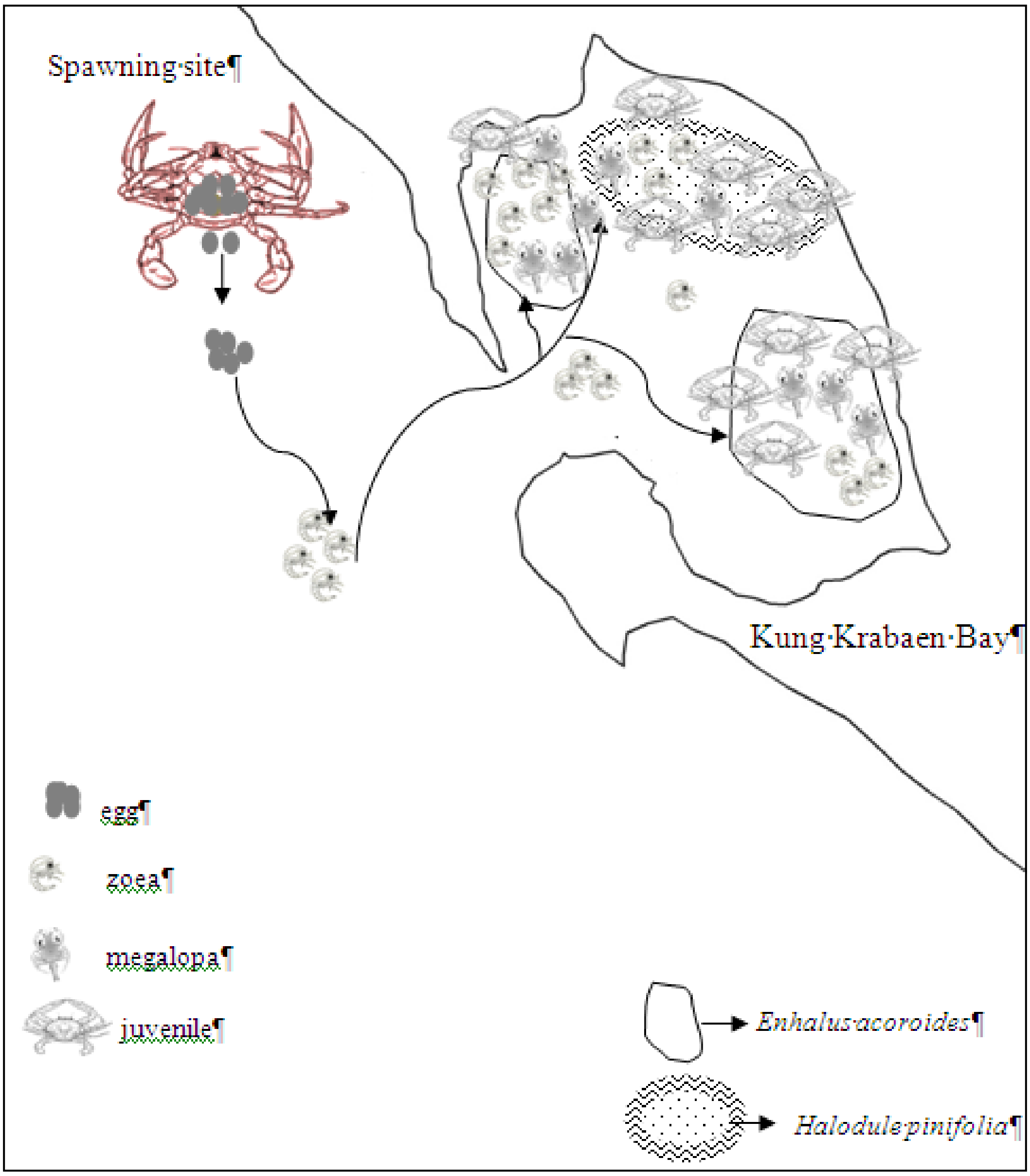


Figure 4.38. Movement in planktonic and juvenile phase in blue swimming crabs life history in Kung Krabaen Bay, Chanthaburi Province

The tagging method used in this study may result in the underestimated migration distances and speed of movement, especially for individuals at liberty for a period of time, because crabs do not travel in straight lines. However, this technique was used in numerous studies in many crab species to estimate the migration distances

(Aguilar et al., 2005; Edward; 1958; Fischler and Walburg, 1962; Potter et al., 1991). The maximum migration distance in blue swimming crabs in Kung Krabaen Bay was 5.49 km within one day with the longest distance of 9.25 km within 15 days. The average speed of movement was 0.5 km/day. The migration distance and speed of movement were related to several factors such as food availability, spawning activity, tidal, current, crabs' size, and human fishing activity (Aguilar et al., 2005; Bellchambers et al., 2006; Hyland et al., 1984; Potter et al., 1991).

This finding is consistent with other studies in portunid crabs in tropical area. For instances, a tagging study in *Portunus peagicus* in Moreton Bay, Australia found that over 80% of recaptured crabs were caught less than 2 km from the release point and only 4% were recaptured at more than 10 km from their release point (Potter et al., 1991). The study on mud crabs *Scylla olivacea* in Andaman sea, Thailand showed that the average distance and speed of movement for female and ovigerous female crabs were 5.12 km and 0.47 km/day and 12.5 km and 0.51 km/day, respectively (Koolkalya et al., 2006).

In summary, the findings from the movement pattern study increased the understanding of fishermen on the relationship of crabs between inside and outside the bay. In addtion to, the information on distance movement is helpful to set up the boundary of conservation zone to be managed such as seagrass bed area and spawning site for this economic species.

4.3. PRESENT STATUS OF BLUE SWIMMING CRAB POPULATION

The assessment on blue swimming crabs in Kung Krabaen Bay revealed that the populations were in crisis based on the measurement indicators below:

- Increased fishing mortality,
- Exploitation rate exceeded the optimal exploitation rate,
- Decreased on first size maturity,
- lack of mature females,
- reduce size of ovigerous female

Movement pattern study revealed the crab populations inside and outside the bay were the same group. The movement patterns of blue swimming crabs were related to feeding ground, nursery ground and spawning. These scientific findings were presented in the workshop for stakeholders in order to fill the gaps in the blue swimming crabs management in Kung Krabaen Bay.

4.4. PROPOSED MANAGEMENT

4.4.1. Present management and measure

Kung Krabane Bay is in the Eastern Gulf of Thailand (Area I). This area covers 3 provinces i.e. Trad, Rayong and Chanthaburi Province (Pundisto et al., 2004). The blue swimming crabs fishery operations in this area was categorized by size of gear and vessels. Two types of fishery operations were commercial fishing gears with boat longer over than 14 meters and small scale fishing gear with boat lesser than 7 meters. The commercial fishing gears included the purse seines, the pair trawls and the otter board trawls. The small scale fishing gears included gillnet or entangled nets, traps and hooks. Only medium, small and local fishing vessels were now presented in Thai waters.

The fishery situation data was collected from the fishermen in 3 coastal villages: 1) Chaolao village, 2) Klong Klud village and 3) Taclang village in Tamai district, Chanthaburi Province (Figure 4.39). These villages have settled along coastal area of Kung Krabaen Bay, Chaolao Beach and Kung Viman Beach. These villagers made a living by harvesting aquatic animals such as marine fish, squids, and shrimps including blue swimming crabs. Questionnaires were used to interview the fishermen in 3 villages who harvested this crab species (Appendix M). The characteristic of blue swimming crabs fishery in three villages were summarized in Table 4.16.

Figure 4.39. Three fishermen villages at the area of Kung Krabaen Bay, Chanthaburi Province

Table 4.16. Profiles of the blue swimming crabs fishery in the three villages in Kung Krabaen Bay, Chanthaburi Province

Village name	Number of blue swimming crab fishermen home & percentage in proportion to total village' homes	Blue swimming crab fishermen distribution per fishing area	Blue swimming crab fishermen distribution per fishing gear type	Blue swimming crab fishermen distribution per fishing gear number
Thaclang	100 (=50%)	bay (10%), sea (10%), both (80%)	trap (30%), net (70%)	mean around 5-10 nets, or 150-250 traps
Klongklud	25 (=40%)	bay (100%)	trap (100%)	mean around 200 traps
Chaolao	100 (=50%)	sea (100%)	net (100%)	mean around 20 nets (20% inshore, 80% offshore – outside our domain)

The first workshop was conducted at Klong Klud Village in November 2009. There were 12 participants from three villages. This workshop aimed increase the fishermen understanding on the movement pattern of blue swimming crabs. The workshop was focusing on their awareness and understanding by using questionnaires coupled with focus group discussion among stakeholders. The result from this workshop showed that most of the fishermen observed 83.3% of them think that blue swimming crabs has no movement between inside and outside the bay while 8.3% of the fishermen believed that the movement in crabs occurred in limited area whether inside and outside the bay. The latter group experienced crab movement themselves during night time (Appendix N). The results from the qestionnaires also showed that each village gained different advantages in the management of this crab. This result is shown in Table 4.17.

Table 4.17. Advantages of blue swimming crabs management through SWOT analysis in Kung Krabaen Bay, Chanthaburi Province

Village name	Location to shore	Distance	Crab management	Leadership	Community strength	Village income
Thaclang	Not good	Far (from KKB Royal project)	No	No	weak	Low
Klongklud	Good	Near	Crab bank	Few	Strong	Medium
Chaolao	Good	Far	Crab condo	Have	Strong	High

Questionaires, indepth interview coupled with the first workshop were used to analyse the existing blue swimming crabs management and measures in Kung Krabaen Bay. Four problems were identified; 1) drastic decline in production of blue swimming crabs in Kung Krabaen Bay harvested by collasible crab traps 2) the degradation of seagrass bed *Enhalus acoroides* 3) crabbing of ovigerous females all year round in particular in the spawning period and 4) misunderstanding in stock assessment and movement patterns. Several measures were outlined and carried out to solve these problems. Tabale 4.18 showed the measures carried out to solve the existing problems in the blue swimming crabs management.

Table 4.18. Problems and measures in the present blue swimming crabs management at Kung Krabaen Bay, Chanthaburi Province

Problems	**Measures**
Declining population and reduced catch size	Limitation on the mesh size of crab traps
Seagrass bed degradation	No specific measure
Crabbing of ovigerous females	Crab bank
Awareness on stock assessment and migration pattern	Not existed leading to conflicts among fishermen

4.4.2. Proposed management to stakeholders

The second workshop was conducted at Kung Krabaen Bay Royal Development Study Centre on October 2010 in collaboration with researchers from CIRAD, France (Figure 4.40). Fifteen stakeholders from Klong Klud and Taclang village, one officer from Kung Krabaen Bay Royal Project and the heads of two villages attended this workshop. The objective of this workshop was to made a better understanding among the stakeholders at Kung Krabaen Bay on the movement pattern of blue swimming crabs and the sustainable management of this crab based on the scientific findings was proposed. Major management measures included offseason during the spawning period, assigning the conservation zone in seagrass beds and spawning site, habitat rehabilitation, crab bank, restocking and continued enforcement on the fishing regulation in mesh size of fishing gears. The outcome of the workshop showed that most fishermen have gain the better understanding on the movement pattern and learned that crabs inside and outside the bay were the same stock. They have to be more careful on the exploitation rate. Moreover, crab bank was the interested issue because the fishermen believed that crab bank can enhance the production of blue swimming crabs in this area. This reflected from 80% respondants in the questionnaire (Appendix N).

Figure 4.40. Participatory workshop with stakeholders in cooperation with researchers from CIRAD and officer from Kung Krabaen Bay Royal Project in Kung Krabaen Bay, Chanthaburi Province

The results from the workshop as proposed by stakeholders from focus group discussion as follows:

1. Set up the conservation zone inside the bay in cooperation with Taclang village and Klongklood Village in particular the seagrass bed species *Enhalus acoroides*
2. Improve the success of crab bank and set up the donation measure of ovigerous female crabs
3. Increase awareness and understanding among stakeholders in the movement pattern of blue swimming crabs to the other coastal area of Chanthaburi Province such as Laemsing district, Paknam Pangrad village and Bang-gachai village

After the workshops, the workshop participants were monitored and followed up on the management measures. Two stakeholders from Klong Klud Village decided to set up crab bank in front of their households. Another stakeholder from Taclang village also set up the crab bank in the fishing ground outside the bay because the tidal condition in his village was not appropriate. Furthermore the distance between the crab bank set at KKB Royal project and the village was too far away.

This study also revealed that in each coastal area has specific problem. Each village also has difference conditions so that the policy maker should not follow the same specific blue print in the management at all locations/sites. Blue swimming crabs management in Kung Krabaen Bay has the chance of being successful in the future because most stakeholders, especially the fishermen gained the full understanding of the real situation. They were facing the situation of lowest production of crabs and were not able to harvest other marine animals. They were more than willing to participate in the sustainable management plan proposed. Scientific findings in this study which supported the problems, gaps and measures proposed were shown in Table 4.19.

Table 4.19. Scientific findings on the assessment of stock and movement pattern of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province as basis to the proposed management plan

Scientific findings	**Proposed measures**
Crab stock in crisis	o Increase awareness among stakeholders on situation of stock assessment o Restocking of crab larvae
Movement pattern in life cycle that crab populations inside and outside were the same group	o Conflict between fishermen solved o More cooperations on exploitation rate
First sexual maturity size of mature females identified	o Support the exising measure of limiting mesh size of collapsible crab traps and crab gill nets
Spawning site and nursery ground located	o Measure on proposed conservation zones o Measure on habitat restoration-seagrass beds
Spawning period identified	o Measure on closed season to crabbing

Proposed sustainable management of blue swimming crabs in Kung Krabaen Bay is showed below:

1. Closed season to crabbing in the bay during spawning season proposed in December, March and August based on data on gonad somatic index (GSI) (Figure 4.41)

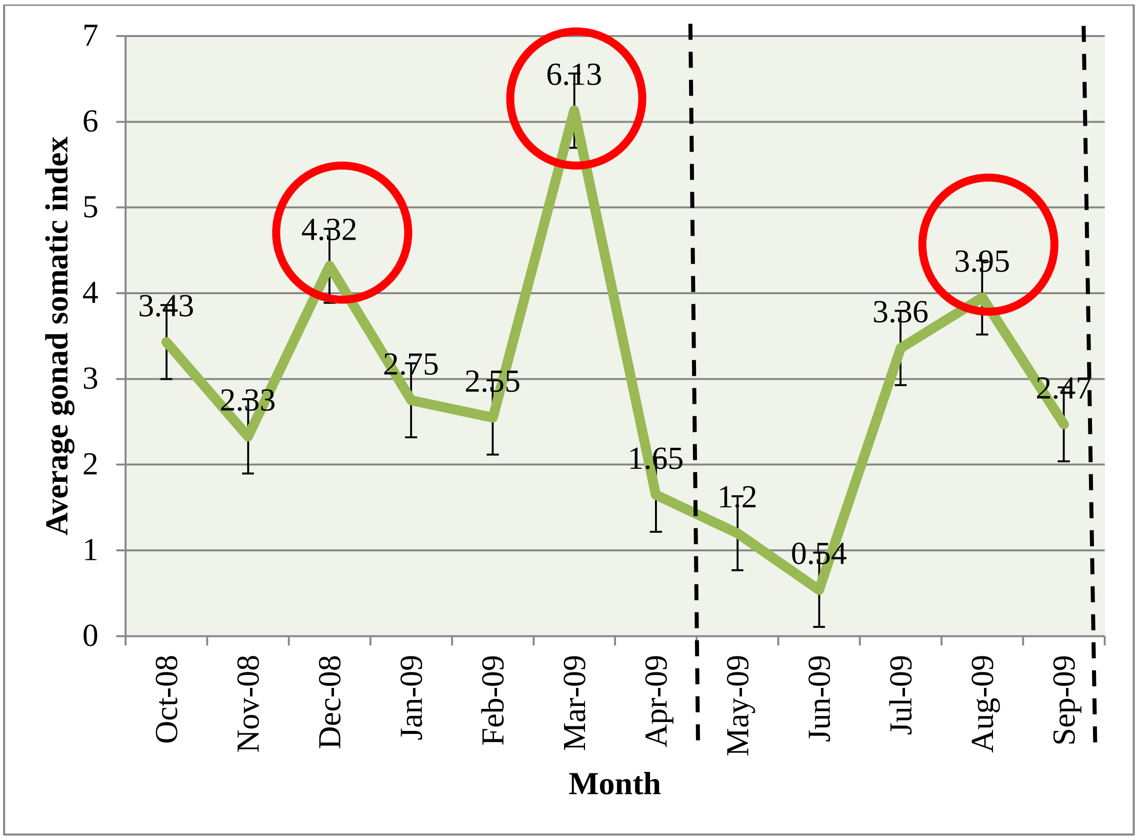


Figure 4.41. Spawning period of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province

2. Conservation zones proposed at seagrass beds area and spawning site outside the bay. In these area, fishermen were prohibited to harvest the blue swimming crabs and they have to also monitor other fishermen who will harvest this crab and other marine animals. (Figure 4.42)

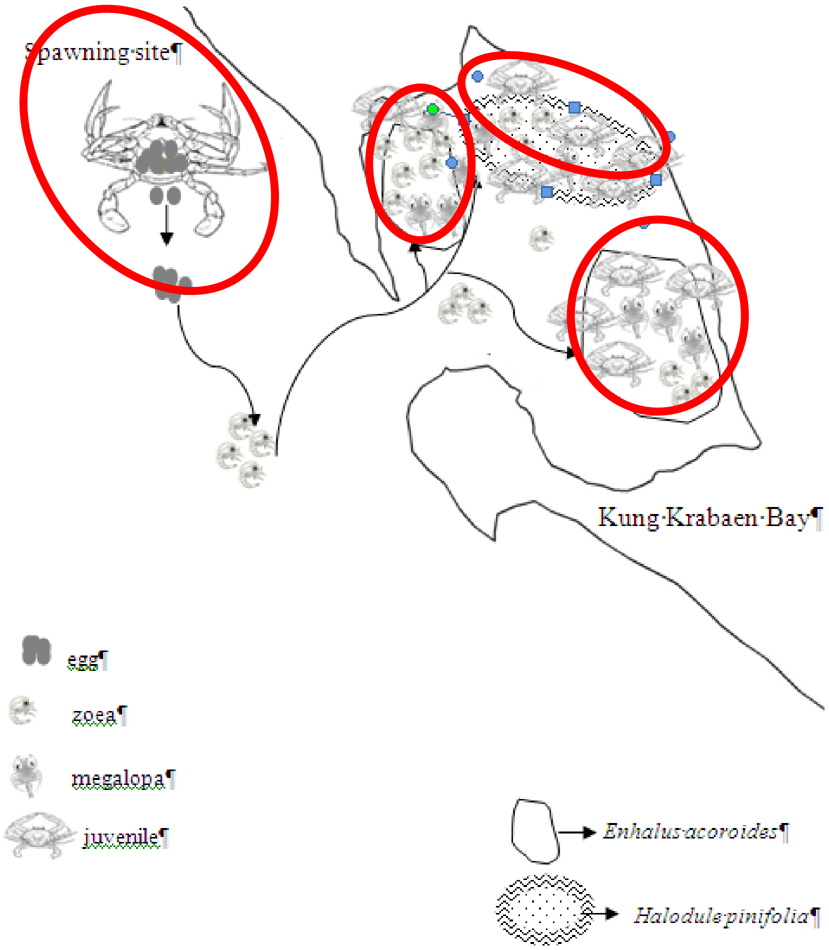


Figure 4.42. Proposed conservation zones of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province

3. Restoration of seageass bed *Enhalus acoroides* for feeding and nursery ground of blue swimming crabs such as plug method.
4. Present management of limiting mesh size of fishing gear should be continued to reduce the catch of mature females. Mesh size sould not less that 2.5 inch for let the crab which has the carapace width lower than 8 cm to survive and banned berried female crabbing due to first size maturity of

female crabs were 7.52 cm and loss the percentage of ovigerous females was 40.57% removed from the habitat.

5. Introducing crab banks in the area of bay mouth because in this area, the environmental factors such as temperature, salinity and depth are suitable for the crab larvae and donating the ovigerous females to their crab bank in particular ovigerous females in stage 6 for increase the percentage of survival rate of crabs (Figure 4.43).

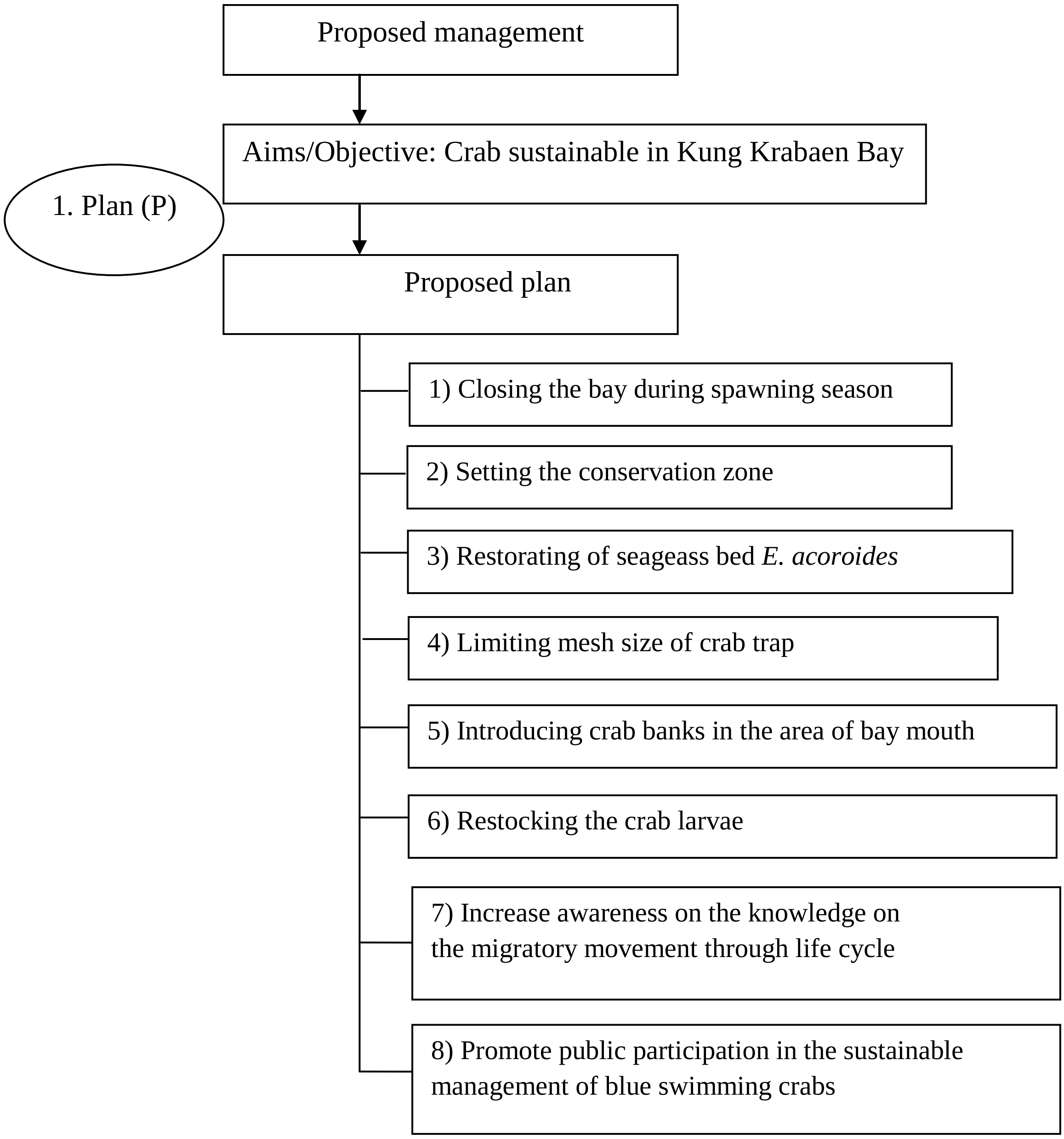
Figure 4.43. Berried female blue swimming crabs in stage 6 in Kung Krabaen Bay, Chanthaburi Province

6. Restocking the crab larvae until they developed into young crabs for increasing the percentage of survival rate and release them into the seagrass bed area whereas there are appropriate environmental condition such as salinity, temperature, shelter for escape the predator and food availablity (Josileen, 2011).
7. Increase awareness on the knowledge on migratory movement of blue swimming crabs to other village to provide better understand on crab restocking and crab bank project (Figure 4.44).

Figure 4.44. Increase awareness on the knowledge of blue swimming crab movement pattern in Kung Krabaen Bay, Chanthaburi Province

8. Promote public participation in the proposed sustainable natural resource management in term of full cooperation among all stakeholders and through networking of local communities, government agencies and NGOs. Local people can monitor the crab situation by these indicators such as catches, sex ratio and the percentage of ovigerous females. They can control fishing pressure by control catch rate by themselve. The government should be provide the funding for supporting the crab management such as enhancing the crab production in crab bank, reserch project on optimal mesh size of fishing gear and setting up the conservation zone etc.

Sustainable crab management in Kung Krabaen Bay was concluded in Figure 4.45.



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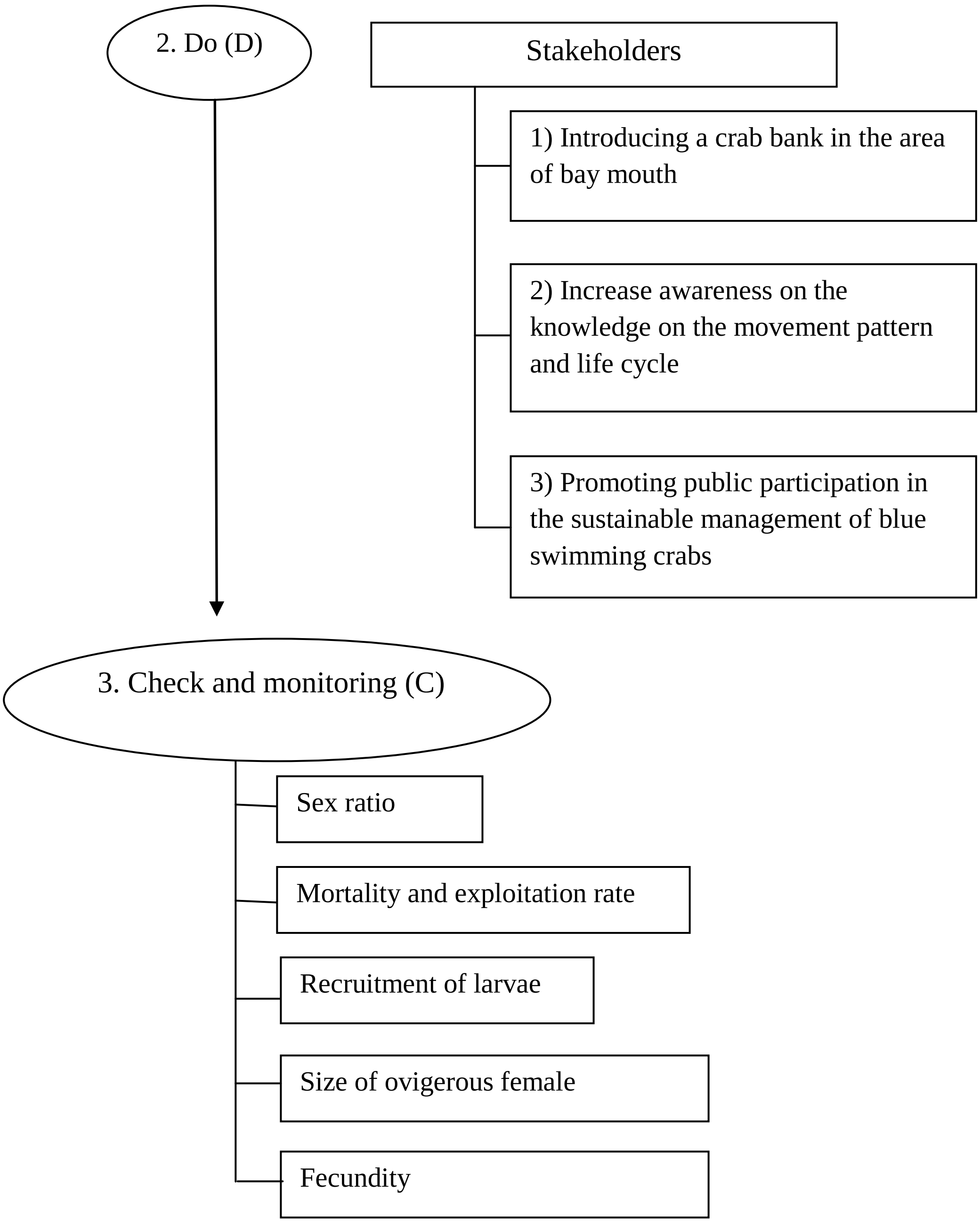

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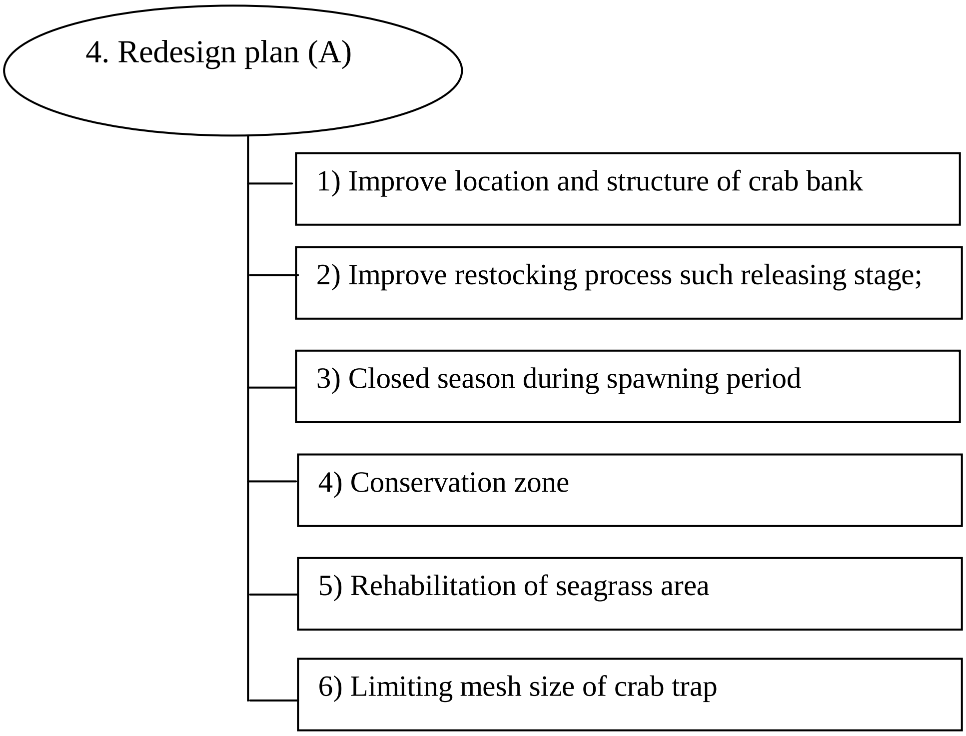

Figure 4.45. PDCA for blue swimming crabs sustainable management in Kung Krabaen Bay, Chanthaburi Province

CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

Based on two hypotheses of this study, the assessment on stock and population structure and reproductive biology of blue swimming crabs in Kung Krabaen Bay, Chanthaburi province revealed the present status of crab population was in crisis. Moreover, the crab production depended on the recruitment of larvae which in turn depended on the reproductive biology. Movement patterns and feeding ecology were used to prove the hypothesis that stocks of the blue swimming crabs living inside and outside the bay were the same. Finally, socio-economic data on the crab fishery resulted from participatory workshop and focus group discussion lead to the proposed sustainable management of this crab based on the scientific findings.

Several measurement indicators indicated that status of blue swimming crabs in Kung Krabaen Bay was in crisis or overharvested. Fishing mortality and percentage of ovigerous females removed from the habitat increased when compared with the previous studies. The exploitation rate was 0.71 and far exceed the optimal exploitation rate of 0.38. First size maturity, size of mature females and average fecundity were decreased.

The movement theory of decapod crustacean live nearshore having a tri-phasic life cycles involving: 1) movement of planktonic eggs and larvae; 2) movement of juveniles to shallow water areas; and 3) movement of adults to deep water. Tantichaiwanit (2005) and Raungprataungsuk (2009) have studied the life cycles of blue swimming crabs in planktonic phase and juvenile phase, respectively. This study concentrated on the adult phase of crab. The results found that male crabs tend to inhabit inside the bay, while female crabs tend to migrate to the outside the bay according to their ovarian development to spawn. The ovigerous female crabs fed inside the bay until their eggs developed to late stage before hatching. Most ovigerous female crabs that were recaptured in the second time outside the bay had already sheded their eggs. Non-ovigerous females could be found outside at the mouth of the bay, in front of Kung Krabaen Bay and Chaoloa beach. The purpose of movement pattern was to find food sources with evidences by the feeding ecology and by catch composition. This study also showed that movement patterns often associated with the ontogenetic niche shift in habitat use**.**

Movement patterns of blue swimming crabs in adult phase were related to the feeding ground and spawning ground. Adult males and females crabs tend to migrate outside the bay in great distance**.** Adult males from the first recapture data inhabited in inside the bay in paticular in the seagrass beds. These seagrass provided the feeding ground to storage sufficient energy for movement in long distance. The movement of ovigerous females aimed to find spawning area with optimal condition for them to spawn and their larvae to survive.

Movement patterns of blue swimming crabs in planktonic and juvenile phases were related to the feeding ground and nursing ground. After spawning, eggs were hatched into zoea stage. As the zoea developed, they prefered the seagrass beds for settlement and developed further into the megalopa stage. This phase of blue swimming crabs required the nursery area to avoid the risk of predation. They also feed on phytoplankton and zooplankton which were abundant in the area. Megalopa further developed into juveniles and young crabs. Juveniles used the seagrass bed area as nursery ground and feeding ground. Major food items of juvenile crabs as revealed from the feeding ecology were teleost fish, crustaceans and mollusks that were found in high abundant in this arae. The juvenile blue swimming crabs developed until they reached the adult phase.

Sustainable management of blue swimming crabs in Kung Krabaen Bay, Chanthaburi Province based on scientific findings from this study were proposed to stakeholders in below;

1. Closed season to the crabbing in the bay during the spawning season in December, March and August based on data on gonad somatic index (GSI) and other indicators of reproductiove biology such as ovarian development and fecundity.
2. Conservation zones were proposed in seagrass beds and spawning site outside the bay

3. Restoration of seagrass bed *Enhalus acoroides* as feeding and nuresery grounds of blue swimming crabs
4. The present management of limiting the minimum mesh size of fishing gear should be continued to reduce the catch of mature females. Mesh size should not less that 2.5 inch. Banned on berried female crabbing should be enforced.
5. Introducing the crab bank in the area at the mouth of the bay.Donation of the ovigerous females to the crab bank
6. Restocking the crab larvae by culturing of crab larvae until they developed into young crab prior to the release into the seagrass bed area
7. Increase awareness on the knowledge on migratory movement of blue swimming crabs to other village to provide better understand on crab restocking and crab bank project
8. Promote the public participation in the sustainable natural resource management in particular blue swimming crabs based on the full coopertation among all stakeholders and networking.

5.2. RECOMMENDATION

1. As the crab populations were in crisis, the sustainable management is urgently needed. Successful management should be based on the scientific findings. Increase awareness in these scientific findings in particular the ecology of the crab populations would enhance the success. We have to accept that the recovery of the natural resources were in the long process. Restocking is one of the interesting choices for increasing the population of blue swimming crabs in this area. However, there are many problems of restocking arising from the crab bank project such as low success in the crab bank project, low crab survival rate, and low number of donations of ovigerous females. I would like to specified that for Ta Clang village with the lowest tide, the location of crab bank should be considered in particular the suitable position and suitable physical factor such as salinity and temperature, in order to the crab larvae to survive and support the fishery. In Klong Klud Village, the position of the crab bank was not the problem because in this area the level of water was appropriate to set up the crab bank. It can set up in front of the household of villagers

by themselve if they want. In addition, the more effective crab bank can be obtained by setting up crab bank in the closed area in the pen of KKB royal project.

Grazing intensity from fish and other marine animal resulted in high mortality rate in the planktonic stage. Restocking by releasing crab larvae into the sea in the crab bank or in the nursery ground should considered the larval stage to be released. The survival rate from megalopa to first crab instar during settlement the planktonic phase of zoea stage. If the government budget fell short, the donation of ovigerous females would be affected.

Under the pressure of overharvested, the fishermen have no choice in selecting the crab size for sale. They need the money from the fishery products to support their families. In return for the donation of ovigerous female stages, the fishermen get the money. The ovigerous females stage 5 with egg that can hatch in 3-4 days. As for ovigerous females stage 6, eggs can hatch from the pleopod with in 24 hours. The crab bank should be allowed to receive the ovigerous females in stage 6 becauese the hatching period is shorter than stage 5. But in the area where high fishing pressure occurred, the crab bank should be allowed to receive ovigerous females at all stage.

2. This study strongly indicated that seagrass beds were important in term of nursery grounds for juvenile crab. Stakeholders including fishermen, policy maker, local government and other villagers should cooperated in the rehabilitation efforts for this habitat such as culturing of seagrass bed especially in the species *Enhalus acoroides* or transplanting seagrass. Other strict regulations on the prohibition of trawlers and push nets to harvest marine crabs in the area were enforced.

3. Cooperations among all stakeholders are essential for the successful crab sustainable management. As the crab production is on the declining trend coupled with the trade barriers that the United States, the major market for crab meats, put forward as strict regulations, Thailand has no other choice other than turning to the sustainable management following the strict measures of minimum size/weight of blue swimming crabs to be caught or sold, restocking measures, conservation and rehabilitation of seagrass beds and restrictions on the catch of ovigerous females during spawning season. Moreover the Thai frozen Food Association needed to

ensure the quality of the crab meat for food safety to the international standards. The full coopertaion from all stakeholders are required in order to make the Thai crab production more competitive in the world market.

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APPENDICES

Appendix A Size frequency of carapace width in monthly at Kung Krabaen Bay

Carapace range	Oct 08	Nov 08	Dec 08	Jan 09	Feb 09	Mar 09	Apr 09	May 09	June 09	Jul 09	Aug 09	Sep 09
10	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	1	0	0	0	0	0	0	0	0	0
20	1	0	0	2	0	0	0	0	0	0	0	0
25	0	0	0	1	0	0	0	0	1	0	0	0
30	1	0	0	0	0	0	0	0	1	0	0	1
35	0	0	0	0	0	0	0	1	2	1	3	6
40	1	0	1	1	0	1	0	0	3	1	0	1
45	1	0	5	0	1	0	0	3	6	3	3	4
50	3	3	3	1	1	2	1	1	6	2	0	8
55	3	1	2	1	1	1	2	4	5	9	1	5
60	5	3	2	5	3	1	4	4	7	6	0	1
65	3	2	3	2	4	1	1	2	3	7	2	4
70	7	2	1	3	6	7	3	3	4	7	1	12
75	8	1	1	6	11	16	0	4	2	5	1	3
80	4	3	4	9	3	4	1	7	0	2	1	0
85	10	4	3	9	8	5	1	7	3	5	3	5
90	3	3	1	9	6	5	0	3	5	6	1	2
95	2	7	4	9	5	4	0	0	10	4	2	2
100	3	7	10	10	5	4	4	1	3	1	1	1
105	8	14	13	3	5	0	3	2	3	2	2	0
110	11	18	18	1	6	4	3	1	3	5	2	1
115	5	9	14	10	2	4	3	3	4	7	2	1
120	1	7	3	1	7	9	3	3	4	12	2	2
125	0	0	5	4	2	4	4	4	2	2	4	1
130	0	0	0	0	3	2	5	2	0	1	5	1
135	0	0	0	0	0	1	2	2	0	1	4	0
140	0	0	0	0	0	0	0	0	0	1	1	1
145	0	0	0	0	0	0	0	1	0	0	0	0
150	0	0	0	0	0	0	0	0	0	0	0	0
155	0	0	0	0	0	0	0	0	0	0	0	0
160	0	0	0	0	0	0	0	0	0	0	0	0
165	0	0	0		1	0	0	0	0	0	0	0

Appendix B Fecundity of berried female

Month	No.	CW	W	Egg batch weight	Fecundity
Feb-09	7	85.8	62.06	9.45	148,237.20
Mar-09	39	89.61	59.21	9.12	140,624.32
Feb-09	8	90.89	83.05	11.47	210,076.87
Sep-09	57	100.66	74.99	10.19	180,315.44
Feb-09	13	100.78	85.54	11.78	210,398.65
Apr-09	49	101.22	90.38	12.52	240,984.96
Feb-09	18	105.57	97.12	13.48	250,143.87
Dec-08	3	108.30	98.60	18.9	394,178.40
Apr-09	47	108.72	98.59	17.8	350,470.13
Sep-09	56	108.80	96.94	20.23	448,553.05
Feb-09	22	109.72	112.49	23.14	523827.893
Apr-09	46	109.76	115.45	14.63	267611.96
Jul-09	54	111.25	96.81	20	440386.667
Mar-09	37	111.73	120.45	13.5	250641
Mar-09	27	112.2	127.37	24.5	500992.333
Mar-09	38	113.02	129.56	25.12	525476.907
Feb-09	17	113.98	128.47	24	480896
Jul-09	55	114.5	130.62	25.13	533543.407
Apr-09	45	115.11	127.45	19.79	418677.24
Jan-09	6	115.39	119.09	15.4	296049.6
Apr-09	48	116.69	129.45	30.83	697477.367
Feb-09	12	117.31	130.74	29.45	616349.233
Feb-09	21	117.59	135.45	28.93	585832.5
Mar-09	34	118.44	134.63	30.7	601269.733
Mar-09	33	119.8	138.45	31.52	661457.707
Dec-08	5	120.12	139.28	30.34	647374.693
Mar-09	32	120.19	140.42	32.62	686390.04
Mar-09	29	120.25	139.94	29.99	588443.787
Dec-08	4	120.45	139.47	29.85	591706.6
Feb-09	15	120.90	147.36	35.16	767378.72
Nov-08	1	121.17	146.16	24.63	506589.84
Nov-08	2	121.19	159.71	40.27	825159.147
Mar-09	24	121.59	115.12	15.48	284635.92
Feb-09	11	121.68	129.36	31.55	640633.267
Mar-09	23	121.74	114.49	15.43	292079.613
Mar-09	31	122.74	139.45	31.18	658999.693
Jul-09	53	122.76	130.03	27.83	547842.827
Feb-09	16	123.27	145.31	34.62	791020.84

Appendix B (Cont.)

Month	**No.**	**CW**	**W**	**Egg batch weight**	**Fecundity**
Apr-09	41	124.91	146.02	27.45	549677.1
Feb-09	19	125.31	139.14	28.45	599953.6
Feb-09	14	125.99	142.23	24.69	492713.64
Feb-09	20	126.51	130.23	28.47	590600.66
Mar-09	40	126.64	139.54	32.67	736948.08
Mar-09	35	127.09	140.62	30.47	618581.627
Mar-09	36	127.45	139.96	29.92	672900.8
Feb-09	10	128.57	140.26	27.78	599770.2
Apr-09	44	129.5	141.55	25.55	582267.467
Mar-09	26	130.02	139.53	30.03	710349.64
Mar-09	25	130.84	140.51	30	727860
Apr-09	43	132.51	180.4	51.47	1217917.45
May-09	50	133.55	139.12	28.88	669669.44
Apr-09	42	133.63	135.87	26.67	593745.32
May-09	52	133.65	167.36	41.52	989006.4
Mar-09	30	133.83	169.03	41.77	1012838.96
Mar-09	28	135.14	176.73	42.39	1032309.54
Feb-09	9	135.86	175.23	40.62	963858.44
May-09	51	136.03	186.86	58.28	1448180.29
Average		11.57098	27.18665	26.62	261075.556

Appendix C Tagging experiment data during 23 Febuary-13 March 2010

ID1	IDCap	CRABNb	Date_Cap	Zone_Cap	Zone_R1	Dater1	CW_cm	W_g	Sex	Stage	Zone_R2	Dater2	Zone_R3	Dater3	Recap4	Dater4
2	70	C700	23-ก.พ.-10	z0	z4	6-มี.ค.-10	8.11	50	F	F						
8	3	C30	23-ก.พ.-10	z0	104	26-ก.พ.-10	6.68	30	M	M						
10	17	C170	23-ก.พ.-10	z0	z1	4-มี.ค.-10	9.62	70	F	F						
14	124	C1240	23-ก.พ.-10	z0	z10	5-มี.ค.-10	7.35	30	M	M						
15	18	C180	23-ก.พ.-10	z0	z1	27-ก.พ.-10	7.76	40	F	F	z2	2-มี.ค.-10				
16	71	C710	23-ก.พ.-10	z0	z4	2-มี.ค.-10	8.60	60	M	M						
21	97	C970	24-ก.พ.-10	z0	z5	7-มี.ค.-10	8.02	55	M	M						
23	1	C10	24-ก.พ.-10	z0	80	25-ก.พ.-10	9.84	80	M	M						
26	2	C20	24-ก.พ.-10	z0	80	24-ก.พ.-10	10.61	100	M	M						
27	98	C980	24-ก.พ.-10	z0	z5	26-ก.พ.-10	9.31	70	M	M						
28	116	C1160	24-ก.พ.-10	z0	z9	1-มี.ค.-10	11.22	120	F	F						
34	125	C1250	25-ก.พ.-10	z0	z10	7-มี.ค.-10	12.80	95	F	O						
35	19	C190	25-ก.พ.-10	z0	z1	27-ก.พ.-10	12.00	100	M	M	z4	27-ก.พ.-10				
36	5	C50	25-ก.พ.-10	z0	151	28-ก.พ.-10	9.50	70	M	M						
37	62	C620	25-ก.พ.-10	z0	z3	27-ก.พ.-10	10.50	85	M	M	z3	28-ก.พ.-10				
38	20	C200	25-ก.พ.-10	z0	z1	2-มี.ค.-10	8.50	50	M	M						
39	21	C210	25-ก.พ.-10	z0	z1	26-ก.พ.-10	11.00	110	F	O						
40	72	C720	25-ก.พ.-10	z0	z4	25-ก.พ.-10	10.00	60	M	M						
41	22	C220	25-ก.พ.-10	z0	z1	25-ก.พ.-10	8.00	50	M	M						
42	59	C590	25-ก.พ.-10	z0	z2	25-ก.พ.-10	9.00	50	F	F						
43	99	C990	25-ก.พ.-10	z0	z5	26-ก.พ.-10	8.90	65	F	F						
44	4	C40	25-ก.พ.-10	z0	124	26-ก.พ.-10	11.00	110	F	O	z3	26-ก.พ.-10				

ID1	IDCap	CRABNb	Date_Cap	Zone_Cap	Zone_R1	Dater1	CW_cm	W_g	Sex	Stage	Zone_R2	Dater2	Zone_R3	Dater3	Recap4	Dater4
49	117	C1170	26-ก.พ.-10	z0	z9	12-มี.ค.-10	11.59	110	F	F						
50	126	C1260	26-ก.พ.-10	z0	z10	2-มี.ค.-10	10.12	80	F	F						
51	8	C80	26-ก.พ.-10	z0	169	28-ก.พ.-10	8.97	55	M	M						
52	23	C230	26-ก.พ.-10	z0	z1	27-ก.พ.-10	8.97	55	F	F						
56	127	C1270	26-ก.พ.-10	z0	z10	1-มี.ค.-10	8.45	40	F	F						
57	6	C60	26-ก.พ.-10	z0	153	28-ก.พ.-10	11.62	150	F	O						
58	24	C240	26-ก.พ.-10	z0	z1	6-มี.ค.-10	9.33	50	F	F						
59	147	C1470	26-ก.พ.-10	z0	z13	27-ก.พ.-10	9.80	100	M	M						
61	102	C1020	26-ก.พ.-10	z0	z7	10-มี.ค.-10	8.50	40	F	F						
62	7	C70	26-ก.พ.-10	z0	162	28-ก.พ.-10	7.50	30	F	F						
63	25	C250	26-ก.พ.-10	z0	z1	2-มี.ค.-10	7.00	20	M	M						
65	103	C1030	27-ก.พ.-10	z0	z7	28-ก.พ.-10	8.56	40	F	O	z14	10-มี.ค.-10				
66	63	C630	27-ก.พ.-10	z0	z3	7-มี.ค.-10	8.09	35	F	O						
67	26	C260	27-ก.พ.-10	z0	z1	28-ก.พ.-10	9.51	50	F	O	z14	10-มี.ค.-10				
70	73	C730	27-ก.พ.-10	z0	z4	1-มี.ค.-10	9.56	65	M	M						
71	187	C1870	27-ก.พ.-10	z0	z12	1-มี.ค.-10	9.59	65	F	O						
72	9	C90	27-ก.พ.-10	z0	172	28-ก.พ.-10	9.05	45	F	O						
73	27	C270	27-ก.พ.-10	z0	z1	28-ก.พ.-10	10.20	75	F	O						
74	28	C280	27-ก.พ.-10	z0	z1	2-มี.ค.-10	7.18	30	F	O						
75	29	C290	27-ก.พ.-10	z0	z1	28-ก.พ.-10	7.38	33	F	O						
77	60	C600	27-ก.พ.-10	z0	z2	7-มี.ค.-10	9.62	65	F	O						
78	104	C1040	27-ก.พ.-10	z0	z7	28-ก.พ.-10	11.39	135	F	F	z10	10-มี.ค.-10	z10	11-มี.ค.-10	z14	14-มี.ค.-10
80	118	C1180	27-ก.พ.-10	z0	z9	28-ก.พ.-10	9.10	60	F	O						
81	30	C300	27-ก.พ.-10	z0	z12	7-มี.ค.-10	9.58	50	F	O						
82	10	C100	27-ก.พ.-10	z0	174	28-ก.พ.-10	9.52	50	F	O						

ID1	IDCap	CRABNb	Date_Cap	Zone_Cap	Zone_R1	Dater1	CW_cm	W_g	Sex	Stage	Zone_R2	Dater2	Zone_R3	Dater3	Recap4	Dater4
84	31	C310	27-ก.พ.-10	z0	z1	9-มี.ค.-10	8.87	50	M	M						
85	191	C1910	27-ก.พ.-10	z0	z10	28-ก.พ.-10	8.98	50	F	O						
86	74	C740	27-ก.พ.-10	z0	z4	3-มี.ค.-10	9.23	50	M	M						
87	128	C1280	27-ก.พ.-10	z0	z10	28-ก.พ.-10	8.80	40	F	O	z14	10-มี.ค.-10				
88	129	C1290	27-ก.พ.-10	z0	z10	28-ก.พ.-10	8.32	35	F	O						
89	119	C1190	27-ก.พ.-10	z0	z9	28-ก.พ.-10	7.97	30	F	O	z10	10-มี.ค.-10				
90	130	C1300	27-ก.พ.-10	z0	z10	5-มี.ค.-10	6.28	15	F	O						
91	32	C320	27-ก.พ.-10	z0	z1	6-มี.ค.-10	8.07	45	F	O						
92	33	C330	27-ก.พ.-10	z0	z1	7-มี.ค.-10	10.40	120	F	F	z10	10-มี.ค.-10				
93	64	C640	27-ก.พ.-10	z0	z3	7-มี.ค.-10	7.28	35	M	M						
94	131	C1310	27-ก.พ.-10	z0	z10	5-มี.ค.-10	12.30	110	F	F						
95	109	C1090	27-ก.พ.-10	z0	z8	28-ก.พ.-10	9.54	65	F	O						
96	132	C1320	27-ก.พ.-10	z0	z10	28-ก.พ.-10	9.31	60	F	O	z14	10-มี.ค.-10				
98	65	C650	27-ก.พ.-10	z0	z3	7-มี.ค.-10	7.55	40	M	M						
99	120	C1200	27-ก.พ.-10	z0	z9	28-ก.พ.-10	8.21	45	F	O						
100	121	C1210	27-ก.พ.-10	z0	z9	10-มี.ค.-10	8.52	50	F	O						
101	75	C750	27-ก.พ.-10	z0	z4	7-มี.ค.-10	6.13	20	M	M						
102	76	C760	27-ก.พ.-10	z0	z4	7-มี.ค.-10	5.65	20	M	M						
103	110	C1100	27-ก.พ.-10	z0	z8	12-มี.ค.-10	8.99	55	F	O						
104	111	C1110	27-ก.พ.-10	z0	z8	12-มี.ค.-10	9.51	75	F	O						
108	12	C120	28-ก.พ.-10	z0	z4	5-มี.ค.-10	10.59	100	F	O						
109	34	C340	28-ก.พ.-10	z0	z1	6-มี.ค.-10	9.42	60	F	O	z10	10-มี.ค.-10				
110	77	C770	28-ก.พ.-10	z0	z4	4-มี.ค.-10	10.36	80	F	O	z10	10-มี.ค.-10				
111	141	C1410	28-ก.พ.-10	z0	z11	5-มี.ค.-10	10.36	80	F	O						
112	142	C1420	28-ก.พ.-10	z0	z11	10-มี.ค.-10	10.59	100	F	O						

ID1	IDCap	CRABNb	Date_Cap	Zone_Cap	Zone_R1	Dater1	CW_cm	W_g	Sex	Stage	Zone_R2	Dater2	Zone_R3	Dater3	Recap4	Dater4
113	143	C1430	28-ก.พ.-10	z0	z11	10-มี.ค.-10	7.49	50	M	M						
115	11	C110	28-ก.พ.-10	z0	181	5-มี.ค.-10	9.02	60	M	M	z1	10-มี.ค.-10				
116	78	C780	28-ก.พ.-10	z0	z4	13-มี.ค.-10	8.79	70	M	M						
117	133	C1330	28-ก.พ.-10	z0	z10	10-มี.ค.-10	9.71	50	F	O	z14	12-มี.ค.-10				
118	122	C1220	28-ก.พ.-10	z0	z9	3-มี.ค.-10	8.72	45	M	M						
119	79	C790	28-ก.พ.-10	z0	z4	4-มี.ค.-10	8.93	50	M	M						
120	123	C1230	28-ก.พ.-10	z0	z9	10-มี.ค.-10	8.05	45	F	O	z10	12-มี.ค.-10				
125	80	C800	28-ก.พ.-10	z0	z4	5-มี.ค.-10	9.60	75	M	M						
126	35	C350	28-ก.พ.-10	z0	z1	3-มี.ค.-10	10.06	90	F	O						
127	134	C1340	28-ก.พ.-10	z0	z10	11-มี.ค.-10	9.31	60	M	M	z14	13-มี.ค.-10				
129	36	C360	28-ก.พ.-10	z0	z1	5-มี.ค.-10	7.73	40	M	M						
130	135	C1350	28-ก.พ.-10	z0	z10	10-มี.ค.-10	9.26	55	F	O						
131	37	C370	28-ก.พ.-10	z0	z1	5-มี.ค.-10	8.09	50	F	O						
132	136	C1360	28-ก.พ.-10	z0	z10	12-มี.ค.-10	8.09	50	F	O						
133	38	C380	28-ก.พ.-10	z0	z1	4-มี.ค.-10	8.84	50	M	M						
134	39	C390	28-ก.พ.-10	z0	z1	10-มี.ค.-10	8.60	55	M	M						
135	137	C1370	28-ก.พ.-10	z0	z10	10-มี.ค.-10	6.35	25	F	O						
138	40	C400	28-ก.พ.-10	z0	z1	5-มี.ค.-10	8.10	50	M	M						
139	41	C410	28-ก.พ.-10	z0	z1	12-มี.ค.-10	5.51	20	F	O	z10	12-มี.ค.-10				
140	42	C420	28-ก.พ.-10	z0	z1	5-มี.ค.-10	7.79	50	M	M						
142	43	C430	28-ก.พ.-10	z0	z1	5-มี.ค.-10	7.87	40	M	M						
143	138	C1380	28-ก.พ.-10	z0	z10	12-มี.ค.-10	9.63	70	F	O	z10	12-มี.ค.-10				
144	44	C440	5-มี.ค.-10	z0	z1	7-มี.ค.-10	10.57	80	F	O	z1	13-มี.ค.-10				
148	139	C1390	5-มี.ค.-10	z0	z10	7-มี.ค.-10	9.41	80	F	O						
149	45	C450	5-มี.ค.-10	z0	z1	7-มี.ค.-10	8.88	60	F	F						
152	13	C130	5-มี.ค.-10	z0	012-1	12-มี.ค.-10	10.41	75	F	F						

ID1	IDCap	CRABNb	Date_Cap	Zone_Cap	Zone_R1	Dater1	CW_cm	W_g	Sex	Stage	Zone_R2	Dater2	Zone_R3	Dater3	Recap4	Dater4
153	46	C460	5-มี.ค.-10	z0	z1	10-มี.ค.-10	10.24	80	F	O						
154	81	C810	5-มี.ค.-10	z0	z4	7-มี.ค.-10	7.12	30	M	M						
155	82	C820	5-มี.ค.-10	z0	z4	7-มี.ค.-10	9.94	75	F	F						
159	144	C1440	5-มี.ค.-10	z0	z11	11-มี.ค.-10	9.52	60	F	F						
160	112	C1120	5-มี.ค.-10	z0	z8	7-มี.ค.-10	11.19	120	M	M						
162	47	C470	5-มี.ค.-10	z0	z1	15-มี.ค.-10	8.97	60	M	M						
165	83	C830	5-มี.ค.-10	z0	z4	10-มี.ค.-10	8.89	55	M	M	z1	13-มี.ค.-10				
166	100	C1000	5-มี.ค.-10	z0	z5	7-มี.ค.-10	10.74	100	M	M						
168	101	C1010	5-มี.ค.-10	z0	z5	7-มี.ค.-10	10.27	90	F	O						
175	84	C840	5-มี.ค.-10	z0	z4	7-มี.ค.-10	9.50	65	F	O						
180	66	C660	6-มี.ค.-10	z0	z3	7-มี.ค.-10	8.86	40	F	F						
181	67	C670	6-มี.ค.-10	z0	z3	7-มี.ค.-10	10.23	60	F	O						
187	48	C480	6-มี.ค.-10	z0	z1	7-มี.ค.-10	8.21	30	F	F						
190	16	C160	6-มี.ค.-10	z0	Wp261	7-มี.ค.-10	8.77	40	M	M						
191	49	C490	6-มี.ค.-10	z0	z1	8-มี.ค.-10	9.04	50	F	O						
196	50	C500	6-มี.ค.-10	z0	z1	7-มี.ค.-10	9.36	50	M	M						
198	51	C510	6-มี.ค.-10	z0	z1	7-มี.ค.-10	10.07	80	F	O						
205	68	C680	6-มี.ค.-10	z0	z3	10-มี.ค.-10	8.61	50	F	F						
209	52	C520	6-มี.ค.-10	z0	z1	7-มี.ค.-10	7.82	40	M	M						
214	53	C530	7-มี.ค.-10	z0	z1	8-มี.ค.-10	9.58	60	F	O						
215	54	C540	7-มี.ค.-10	z0	z1	8-มี.ค.-10	9.81	70	F	F						
217	85	C850	7-มี.ค.-10	z0	z4	12-มี.ค.-10	9.59	70	M	M						
219	86	C860	7-มี.ค.-10	z0	z4	7-มี.ค.-10	7.38	30	M	M						
220	87	C870	7-มี.ค.-10	z0	z4	10-มี.ค.-10	8.50	40	M	M						
221	55	C550	7-มี.ค.-10	z0	z1	15-มี.ค.-10	8.97	50	F	F						
223	56	C560	7-มี.ค.-10	z0	z1	7-มี.ค.-10	8.28	50	M	M						
224	140	C1400	7-มี.ค.-10	z0	z10	10-มี.ค.-10	9.38	60	F	O						
240	57	C570	7-มี.ค.-10	z0	z1	7-มี.ค.-10	9.04	50	F	O						
243	88	C880	12-มี.ค.-10	z0	z4	13-มี.ค.-10	7.56	20	F	F						

ID1	IDCap	CRABNb	Date_Cap	Zone_Cap	Zone_R1	Dater1	CW_cm	W_g	Sex	Stage	Zone_R2	Dater2	Zone_R3	Dater3	Recap4	Dater4
244	89	C890	12-มี.ค.-10	z0	z4	18-มี.ค.-10	9.84	70	F	F						
245	90	C900	12-มี.ค.-10	z0	z4	17-มี.ค.-10	6.98	20	M	M						
248	113	C1130	12-มี.ค.-10	z0	z8	17-มี.ค.-10	10.48	95	F	O						
255	15	C150	12-มี.ค.-10	z0	043_1	13-มี.ค.-10	9.66	70	M	M	z1	17-มี.ค.-10				
256	91	C910	12-มี.ค.-10	z0	z4	13-มี.ค.-10	9.32	65	M	M						
257	92	C920	12-มี.ค.-10	z0	z4	13-มี.ค.-10	10.11	79	F	O						
258	148	C1480	12-มี.ค.-10	z0	z13	15-มี.ค.-10	8.35	35	F	F						
259	145	C1450	12-มี.ค.-10	z0	z12	15-มี.ค.-10	10.70	98	M	M						
260	146	C1460	12-มี.ค.-10	z0	z12	17-มี.ค.-10	8.32	30	F	F						
261	149	C1490	12-มี.ค.-10	z0	z13	17-มี.ค.-10	8.50	40	M	M						
262	150	C1500	12-มี.ค.-10	z0	z13	18-มี.ค.-10	9.83	75	F	F						
263	93	C930	12-มี.ค.-10	z0	z4	13-มี.ค.-10	9.27	60	F	O						
264	61	C610	12-มี.ค.-10	z0	z2	17-มี.ค.-10	9.27	60	F	F						
273	58	C580	13-มี.ค.-10	z0	z1	15-มี.ค.-10	10.42	95	F	F						
277	14	C140	13-มี.ค.-10	z0	037_1	13-มี.ค.-10	8.12	50	M	M						
281	151	C1510	13-มี.ค.-10	z0	z13	18-มี.ค.-10	9.28	65	F	O						
282	114	C1140	13-มี.ค.-10	z0	z8	15-มี.ค.-10	9.55	75	M	M						
283	115	C1150	13-มี.ค.-10	z0	z8	14-มี.ค.-10	8.95	70	M	M						
285	94	C940	13-มี.ค.-10	z0	z4	13-มี.ค.-10	9.38	60	F	O						
286	152	C1520	13-มี.ค.-10	z0	z13	19-มี.ค.-10	10.67	98	F	F						

ID1	IDCap	CRABNb	Date_Cap	Zone_Cap	Zone_R1	Dater1	CW_cm	W_g	Sex	Stage	Zone_R2	Dater2	Zone_R3	Dater3	Recap4	Dater4
287	95	C950	13-มี.ค.-10	z0	z4	17-มี.ค.-10	5.39	40	F	F						
289	153	C1530	13-มี.ค.-10	z0	z13	18-มี.ค.-10	11.77	140	F	F						
291	69	C690	13-มี.ค.-10	z0	z3	16-มี.ค.-10	7.76	40	F	F						
292	96	C960	13-มี.ค.-10	z0	z4	15-มี.ค.-10	10.04	90	F	O						
293	105	C1050	13-มี.ค.-10	z0	z7	17-มี.ค.-10	8.64	40	M	M						
294	106	C1060	13-มี.ค.-10	z0	z7	17-มี.ค.-10	9.75	60	M	M						
297	107	C1070	13-มี.ค.-10	z0	z7	17-มี.ค.-10	10.41	90	M	M						
302	108	C1080	13-มี.ค.-10	z0	z7	16-มี.ค.-10	8.29	40	F	F						

Appendix D Different between sexes in food diet of blue swimming crab by chi-square test

Food itmes	**Male**	**Female**	**Total**
Tef	106 (120.82)	100 (117.50)	206
Cru	64 (64.64)	44 (62.87)	108
Mol	34 (40.23)	35 (39.13)	69
Squ	14 (13.32)	8 (12.95)	22
Spo	5 (8.38)	10 (8.15)	15
Alg	16 (20.22)	19 (19.66)	35
Seg	3 (3.51)	3 (3.41)	6
Orm	59 (79.08)	79 (76.91)	138
San	27(28.51)	21(27.72)	48
Total	328	319	647

( ) = Expected value of food itme from calculation

χ^2 calculated

$\chi^2 = \Sigma\ (O\text{-}E)^2\ /E$

$\chi^2 = (106\text{-}120.82)^2\ /\ 120.82 + \ldots + (21\text{-}27.72)^2\ /\ 27.72$

$\chi^2 = 13.19$

χ^2 table $\chi^2_{0.05} = 15.507$, df = 8

χ^2 calculated > χ^2 table indicated that food items in stomach of male and female was no significantly different at 0.05 ($p>0.05$)

Appendix E Different between juvenil and adult male in food diet of blue swimming crab by chi-square test

Food items	**M_juv**	**M_ad**	**Total**
Tef	25(31.96)	72(96.69)	97
Cru	15(19.87)	46(60.12)	61
Mol	14(12.85)	20(38.87)	34
Squ	1(4.04)	14(12.22)	15
Spo	0(1.24)	5(3.76)	5
Alg	5(5.55)	11(16.78)	16
Seg	2(1.37)	1(4.16)	3
Orm	6(16.79)	54(50.80)	60
San	11(10.17)	16(30.76)	20
Total	79	239	318

( ) = Expected value of food itme from calculation

χ^2 calculated

$\chi^2 = \Sigma\ (O-E)^2\ /E$

$\chi^2 = (25-31.96)^2\ /\ 31.96 + \ldots + (16-30.76)^2\ /\ 30.76$

$\chi^2 = 44.81$

χ^2 table $\chi^2_{\ 0.05} = 15.507$, df = 8

χ^2 calculated > χ^2 table indicated that food items in stomach of juvenile male and adult male was significantly different at 0.05 ($p<0.05$)

Appendix F Different between juvenil and adult female in food diet of blue swimming crab by chi-square test

Prey items	F_juv	F_ad	Total
Tef	32(39.13)	70(96.20)	102
Cru	18(20.46)	34(50.29)	52
Mol	14(14.63)	22(35.96)	36
Squ	1(2.61)	7(6.43)	8
Spo	0(2.89)	10(7.11)	10
Alg	9(8.20)	10(20.17)	19
Seg	2(1.47)	1(3.61)	3
Orm	7(25.24)	73(62.05)	80
San	13(10.28)	9(25.26)	22
Total	96	236	332

( ) = Expected value of food itme from calculation

χ^2 calculated

$\chi^2 = \Sigma\ (O-E)^2\ /E$

$\chi^2 = (32-39.13)^2\ /\ 39.13 + \ldots + (9-25.26)^2\ /\ 25.26$

$\chi^2 = 58.16$

χ^2 table $\qquad \chi^2_{\ 0.05} = 15.507$, df = 8

χ^2 calculated > χ^2 table indicated that food items in stomach of juvenile female and adult female was significantly different at 0.05 ($p<0.05$)

Appendix G Different in food diet of blue swimming crab between seasons by chi-square test

Prey items	**Dry**	**Wet**	**Total**
Tef	99(136.05)	114(103.21)	213
Cru	58(73.00)	55(55.38)	113
Mol	45(46.59)	25(35.35)	70
Squ	16(15.49)	7(11.75)	23
Spo	15(10.79)	0(8.19)	15
Alg	27(23.97)	8(18.19)	35
Seg	6(4.32)	0(3.27)	6
Orm	93(93.63)	47(71.03)	140
San	18(30.01)	30(22.77)	48
Total	377	286	663

( ) = Expected value of food itme from calculation

χ^2 calculated

$\chi^2 = \Sigma\ (O\text{-}E)^2\ /E$

$\chi^2 = (99\text{-}136.05)^2\ /\ 136.05 + \ldots + (30\text{-}22.77)^2\ /\ 22.77$

$\chi^2 = 48.15$

χ^2 table $\quad \chi^2_{\ 0.05} = 15.507$, df = 8

χ^2 calculated > χ^2 table indicated that food items in stomach of juvenile female and adult female was significantly different at 0.05 ($p<0.05$)

Appendix H Different in food diet of blue swimming crab between inside and outside the bay by chi-square test

Prey items	**Inside**	**Outside**	**Total**
Tef	131(154.50)	70(76.54)	201
Cru	99(90.75)	14(44.96)	113
Mol	60(56.01)	10(27.75)	70
Squ	23(18.91)	0(9.37)	23
Spo	0(10.03)	15(4.97)	15
Alg	25(27.91)	11(13.83)	36
Seg	5(4.11)	0(2.04)	5
Orm	60(102.82)	80(50.94)	140
San	33(37.83)	16(18.74)	49
Total	436	216	652

( ) = Expected value of food itme from calculation

χ^2 calculated

$\chi^2 = \Sigma\ (O-E)^2\ /E$

$\chi^2 = (131-154.50)^2\ /\ 154.50 + \ldots + (16-18.74)^2\ /\ 18.74$

$\chi^2 = 116.91$

χ^2 table $\chi^2_{0.05} = 15.507$, df = 8

χ^2 calculated > χ^2 table indicated that food items in stomach of crab inside and out side the bay was significantly different at 0.05 ($p<0.05$)

Appendix I Bycatch from collapsible crab trap

Family	Species	Common name	Total number caught	Kept	Discard	Species occurrence index (S_{occ})	Status of species in this area
Molluscs							
Naticidae	*Polinces didyma*	-	6		√	0.04	R
Strombidae	*strombus canarium*	Stromb	84		√	0.59	R
Buccinidae	*Babylonia areolata*	Areola babylon	1304	√		9.22	R
Pectinidae	*Amusium pleuronectes*	Saucer scallop	12		√	0.08	R
Neritidae	*Clithon oualaniensis*	-	3586		√	25.35	C
Nassaridae	*Nassarius livescens*	Common whelk	2574		√	18.20	U
	Nassarius pullus	Black whelk	112		√	0.79	R
	Nassarius olivaceus	-	50		√	0.35	R
Thiaridae	*Faunus ater*	Black faun	72		√	0.51	R
Solenidae	*Solen* sp.	-	14	√		0.10	R
Turritellidae	*Turritella terebra*	-	6		√	0.04	R
Littorinidae	*Littoraria* sp.	-	30		√	0.21	R
	Nodilittorina trochoides	-	10		√	0.07	R
Octopodidae	*Octopus dollfusi*	Marbled octopus	20	√		0.14	R
Lolignidae	*Loligo* sp.	Squid	50	√		0.35	R
Crustaceans							
Portunidae	*Charybdis affinis*	Smoothshelled swimming crab	652		√	4.61	R
	Charybdis feriatus	Crossed-marked swimming crab	85	√		0.60	R
	Charybdis anisodon	Green swimming crab	225	√		1.59	R
	Charybdis hellerii	Spiny Hands	29	√		0.21	R
	Charybdis beauforti	-	11	√		0.08	R
	Portunus sanguinolentus	Three-spot swimming crab	56	√		0.40	R
	Portunus pelagicus	Blue swimming crab	598	√		4.23	R
	Thalamita crenata	Crenated swimming crab	745		√	5.27	R
	Thalamita sima	four-lobed swimming crab	68	√		0.48	R
	Scylla transquebarica	Green mud crab	72	√		0.51	R
	Scylla serrata	mud crab	34	√		0.24	R
Matutidae	*Matuta lunaris*	Moon crab	50		√	0.35	R
	Matuta victor	Common moon crab	28		√	0.20	R
Xanthidae	*Sphaerozius* sp.	Edible rock crab	10		√	0.07	R
Grapsidae	*Grapsus albolineatus*	Mottle shore crab	8		√	0.06	R
	Varuna litterata	Nipa crab, river swimming crab	34		√	0.24	R
			10635	3509			

Appendix I Bycatch from collapsible crab trap (Cont.)

Family	Species	Common name	Total number caught	Kept	Discard	Species occurrence index (Socc)	Status of species in this area
Crustaceans							
Paguridae	Clibanarius longitarsus	Long-claw hermit crab	1546		√	**10.93**	U
	Clibanarius infraspinatus	-	1234		√	**8.72**	R
Peneidae	Penaeus merguiensis	white prawn	26	√		**0.18**	R
	Penaeus monodon	Giant Tiger Prawn	52	√		**0.37**	R
Squillidae	Oratosquilla nepa	Three banded mantis shrimp	16	√		**0.11**	R
Chordata						**0.00**	
Mugilidae	Mugil dussmeri	Green backed	28	√		**0.20**	R
Theraponidae	Therapon jarbua	Crescent grunter	387		√	**2.74**	R
Gobiidae	Parapocryptes serperaster	-	210		√	**1.48**	R
Monacanthidae	Monacanthus chinensis	Chinese filefish	8		√	**0.06**	R
Syngnathidae	Hippocampus comes	Tiger-tail seahorse	2		√	**0.01**	R
		Total	14144				

***R= Rare species**
****U= Uncommon species**
*****C= Common species**
******V=Very common species**

Appendix J Bycatch from crab gill net

Family	Species	Common name	Total number caught	Kept	Discard	Species occurrence index (S_{occ})	Status of species in this area
Cnidarians							
Melithaeidae	*Melithaea* sp.	Sea fan	24		√	0.51	R
Molluscs							
Mulicidae	*Murex trapa*	rare-spined murex	752		√	15.83	U
Volutidae	*Melo melo*	Indian volute	48	√		1.01	R
	Cymbiola nobilis	The noble volutes	12	√		0.25	R
Pinnidae	*Pinna bicolor*	Pen shell	318		√	6.70	R
Spondylidae	*Spondylus croceus*	Thorny oysters or spiny oysters	486		√	10.23	U
Malleidae	*Malleus* sp.	Hammer oyster	518		√	10.91	U
Sepiidae	*Sepia pharaonis*	Pharoh cuttle fish	15	√		0.32	R
Loliginidae	*Sepioteuthis lessoniana*	Soft cuttle fish	30	√		0.63	R
Crustaceans							
Portunidae	*Podophthalamus vigil*	Long-eyed swimming crab	5		√	0.11	R
	Thalamita sima	coral crab	25	√		0.53	R
	Charybdis natator	Ridged swimming crab	104	√		2.19	R
	Portunus pelagicus	Blue swimming crab	253	√		5.33	R
Majidae	*Hyastenus* sp.	Spider crab	345		√	7.26	R
Parthenopidae	*Rhinolambus longispinis*	-	189		√	3.98	R
Grapsidae	*Vavuna litterata*	Nipa crab	95		√	2.00	R
Calappidae	*Calappa philargius*	Brickr-red box crab, Spectacled box crab	678		√	14.28	U
Dorippidae	*Dorippe quadridens*	Porter crab	117		√	2.46	R
Dromiidae	*Lauridromia indica*	Cannonball sponge crab	136		√	2.86	R
Leucosiidae	*Soceulia brunnea*	Pebble crabs	3		√	0.06	R
	Leucosia longifrons	Pebble crabs	2		√	0.04	R
Scyllaridae	*Thenus orientalis*	Locus lobster	250	√		5.26	R
Xiphosuridae	*Tachypleus gigas*	Triangle-tail horse shoe crab	29		√	0.61	R
			4434				

Appendix J Bycatch from crab gill net (Cont.)

Family	Species	Common name	Total number caught	Kept	Discard	Species occurrence index (S_{occ})	Status of species in this area
Echinodermis							
Diadematidae	*Diadema savignyi*	Banded diadem urchin	12		√	0.25	R
Luidiidae	*Luidia maculata*	Sun star	14		√	0.29	R
Temnopleurididae	*Samaciella dussumeri*	Dussumeri sea urchin	3		√	0.06	R
Cidaridae	*Prinocidaris bispinosa*	Bispinous sea urchin	130		√	2.74	R
Holothuridae	*Bohadschia marmorata*	Memorated sea cucumber	5		√	0.11	R
Chordata							
Monacanthidae	*Monacanthus chinensis*	Chinese filefish	12		√	0.25	R
Drepanidae	*Drepanae punctata*	Spotted sickle fin	2	√		0.04	R
Platycephalidae	*Platycephalus indicus*	Flat head	1	√		0.02	R
Lutianidae	*Lutjanus russelli*	Russell's snapper	20	√		0.42	R
Paralichthyidae	*Pseudorhombus arsius*	-	48		√	1.01	R
Megalopidae	*Megalops cyprinoides*	Indian tapon, Big eye	2		√	0.04	R
Scatophagidae	Scatophagus argus	Spotted scat	15	√		0.32	R
Dasyatidae	*Dasyatis imbricatus*	Dwarf ray	35	√		0.74	R
Orectolobidae	*Chiloscyllium indicum*	Slender bamboo shark	16	√		0.34	R
		Total	**4749**				

***R= Rare species**

****U= Uncommon species**

*****C= Common species**

******V=Very common species**

Appendix K Seasonal abundace of blue swimming crab

ANOVA

n_crab

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	34.028	1	34.028	3.044	.082
Within Groups	3599.636	322	11.179		
Total	3633.664	323			

Tests of Between-Subjects Effects

Type III Sum of Squares	df	Mean Square	F	Sig.
295.067	1	295.067	29.208	.000
2247.946	222.520	10.102[a]		
19.143	1	19.143	2.363	.125
2179.024	269	8.100[b]		
.840	1	.840	.086	.769
1435.154	147.331	9.741[c]		
1016.580	26	39.099	2.641	.008
384.889	26	14.803[d]		
384.889	26	14.803	1.827	.010
2179.024	269	8.100[b]		

a. .065 MS (station) + MS(Error)

b. MS (Error)

c. .245 MS (season * station) + MS(Error)

Appendix L Correlation between physical factors and crab distribution

		สถานี	จำนวนตัว	depth	t_depth	salinity	Temp	pH	DO
สถานี	Pearson Correlation	1	-.094	.864**	.447**	.108*	.019	.048	.412**
	Sig. (2-tailed)		.080	.000	.000	.044	.725	.373	.000
	N	351	351	351	351	351	351	351	351
จำนวนตัว	Pearson Correlation	-.094	1	-.056	.044	.026	-.103	-.027	.021
	Sig. (2-tailed)	.080		.296	.408	.623	.053	.619	.695
	N	351	351	351	351	351	351	351	351
depth	Pearson Correlation	.864**	-.056	1	.444**	.099	-.006	-.017	.362**
	Sig. (2-tailed)	.000	.296		.000	.064	.910	.748	.000
	N	351	351	351	351	351	351	351	351
t_depth	Pearson Correlation	.447**	.044	.444**	1	.061	-.136*	-.147**	.347**
	Sig. (2-tailed)	.000	.408	.000		.251	.011	.006	.000
	N	351	351	351	351	351	351	351	351
salinity	Pearson Correlation	.108*	.026	.099	.061	1	-.175**	-.030	.270**
	Sig. (2-tailed)	.044	.623	.064	.251		.001	.571	.000
	N	351	351	351	351	351	351	351	351
Temp	Pearson Correlation	.019	-.103	-.006	-.136*	-.175**	1	-.117*	-.347**
	Sig. (2-tailed)	.725	.053	.910	.011	.001		.028	.000
	N	351	351	351	351	351	351	351	351
pH	Pearson Correlation	.048	-.027	-.017	-.147**	-.030	-.117*	1	.029
	Sig. (2-tailed)	.373	.619	.748	.006	.571	.028		.594
	N	351	351	351	351	351	351	351	351
DO	Pearson Correlation	.412**	.021	.362**	.347**	.270**	-.347**	.029	1
	Sig. (2-tailed)	.000	.695	.000	.000	.000	.000	.594	
	N	351	351	351	351	351	351	351	351

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

Appendix M Questionnaire for interview the blue swimming crab fishermen

Questionnares

Blue swimming crab fishermen in preliminary

Date……………………………………………

Interviewer…………………………………….

Fisherman data

Name……………………………..Surname……………………………………………

Address……………………………………………………………………………

Age……………………………………..Sex………………………………………...

Occupation………………………………….Education………………………………..

Member of household………………….Village………………………………………..

Fishery data

Type of fishing gear……………………………..Number of gear……………………..

Mesh size of gear……………………Fishing area……………………………………..

Number of assistant……………………………………………………………………..

How long you did in this fishery?...

How many blue swimming crabs/traps or gill net (Kg/ gear) per time?..........................

What is the size of crab for your harvested?...

What is the period for harvesting of crab?...

How do you think about the status of blue swimming crab? Decrease, same or increase……………………………………………………………………………….

Can blue swimming crab migrate to outside or inside the bay?.......................................

Are you intersted in next Participatory workshop?...

Please suggest your oppinoin to help us to sustain of this crab………………........

☐ increase mesh size ☐ do not harvested ovegerous female

☐ make crab bank ☐ preserve seagrass bed area

☐ crab culture/released

How do you make a crab bank?...

What is the crab bank that has an effective in your thinking?...

Do you think this method will be increase population of crab?.......................................

………………………………………………………………………………………..

If we want to plant seagrass, do you think it is possible to do in Kung Krabaen Bay?

………………………………………………………………………………………..

Have you ever been received/gave the cooperated about the blue swimming crab management? What is the organisation?

………………………………………………………………………………………..

If you were gave the cooperated with some organization about blue swimming crab, will you attend in this cooperation?...

Thank you

Ms. Chutapa Kunsook

Ph.D. student from Chulalongkorn University

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Appendix M Indepth interview after the workshop (in that day)

Indepth interview

Name…………………………..Surname……………………………………………

Address……………………………………………………………………………

Age……………………………………..Sex………………………………………...

Village……………………………………………………………………………..

1) How did you understand about blue swimming crab situation?

……………………………………………………………………………………..

……………………………………………………………………………………..

2) Did you understand migration of blue swimming crab?..

3) How did you feel after you receive this information?...

……………………………………………………………………………………..

……………………………………………………………………………………..

4) After this workshop, what do you do for sustain in this crab?

☐ increase mesh size ☐ do not harvested ovegerous female

☐ make crab bank ☐ preserve seagrass bed area

☐ crab culture/released ☐ make other preserve zone

☐ etc, please specify……………………………………………………………

Thank you

Appendix M Indepth interview after the workshop (pass 1 month)

Name…………………………..Surname…………………………………………

Address………………………………………………………………………………

Age……………………………………..Sex……………………………………...

Village………………………………………………………………………………..

1) How did you feel about participatory workshop?...
2) What is the progress of sustainability of crab in this area? Crab bank? Preserve zone? Seagrass bed culture, prohibit catch berried female, prohibit catch undersize crab?

………………………………………………………………………………………..

3) Do you want to make a crab bank in your household or other the position?

………………………………………………………………………………………

4) Who did you talk about the workshop? How about your conversation about workshop?

………………………………………………………………………………………..

5) How do you cooporated with us to save the crab for KKB ecosytem?

………………………………………………………………………………………

6) If you want to do something for sustainablity for this crab what is the problem for that solution?

………………………………………………………………………………………

7) What is the limitation or advantage in your village?

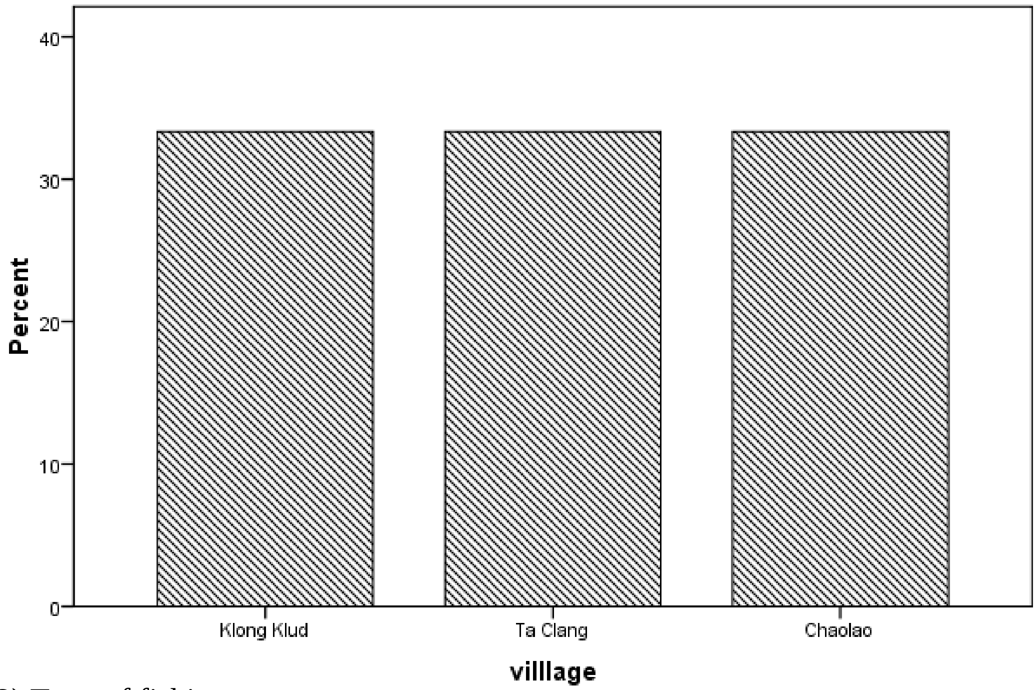
………………………………………………………………………………………

Thank you

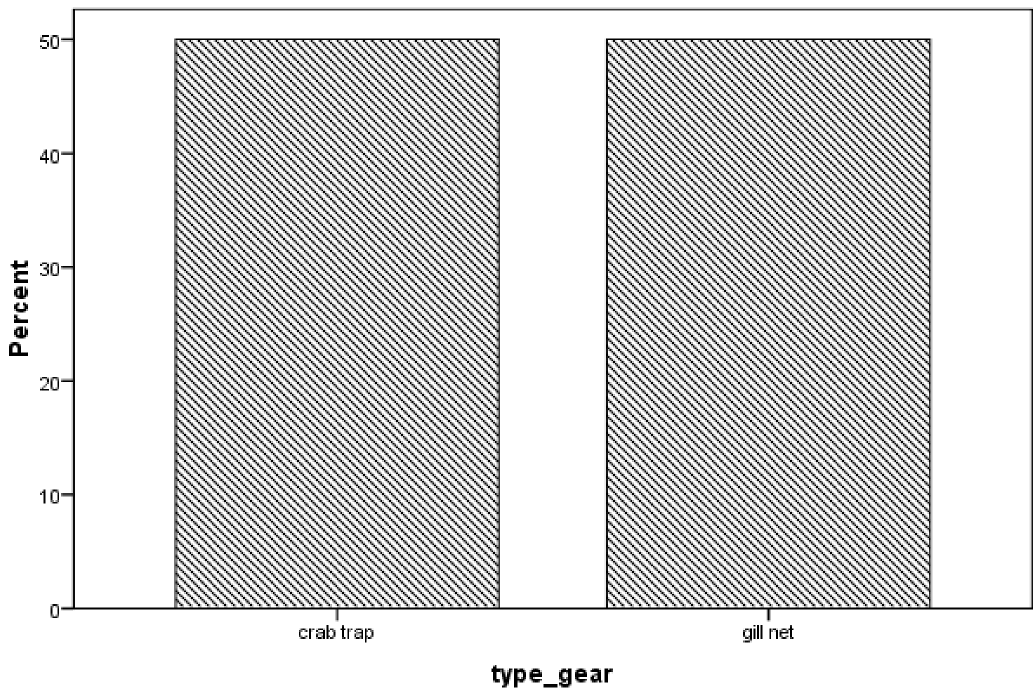
Appendix N Questionaires analysis

First workshop

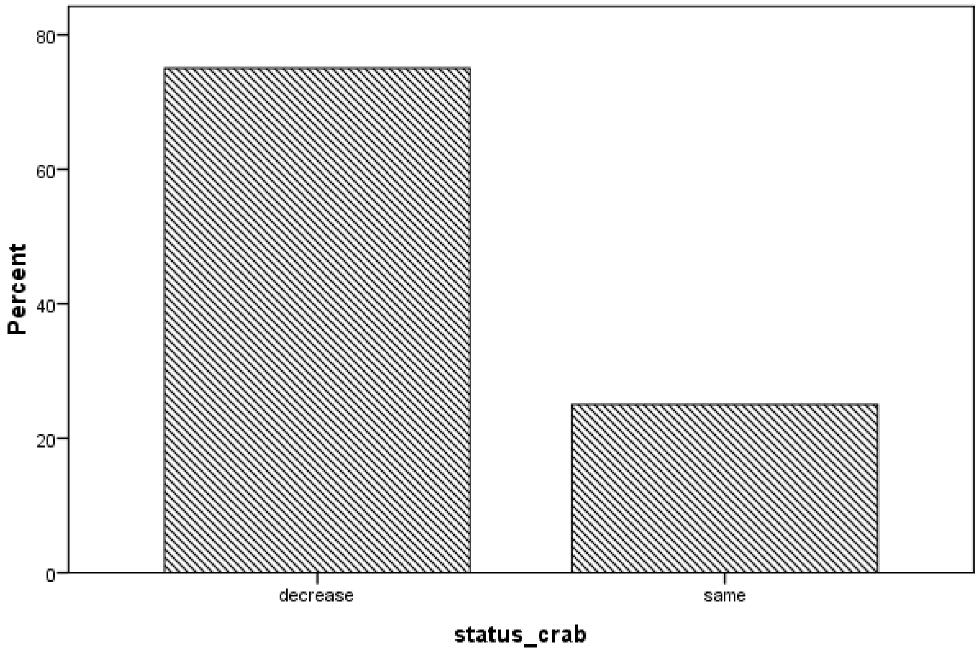
1) Name of village of fishermen



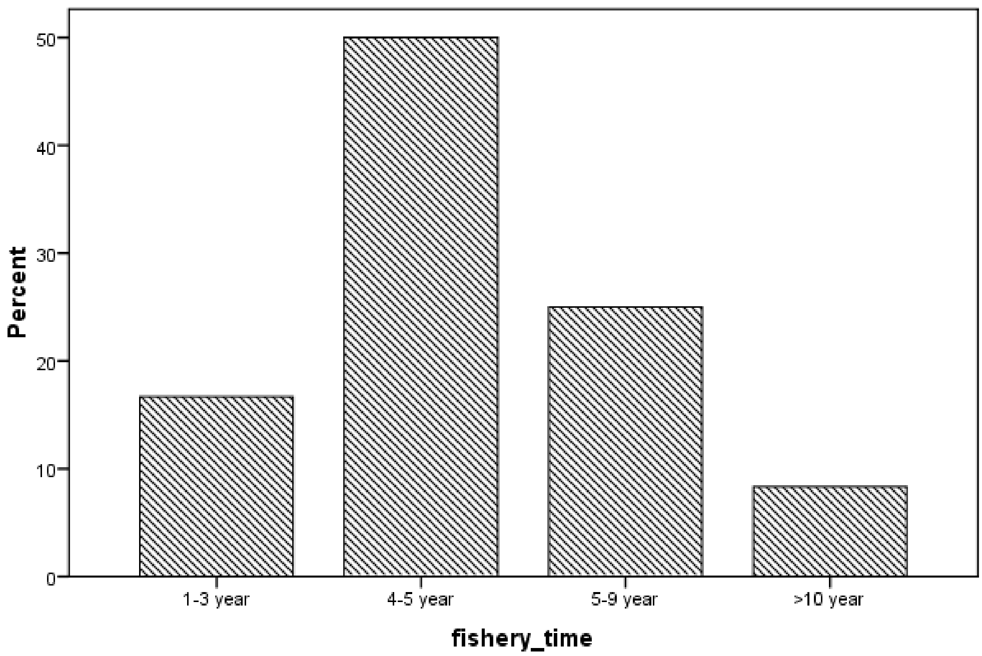
2) Type of fishing gear



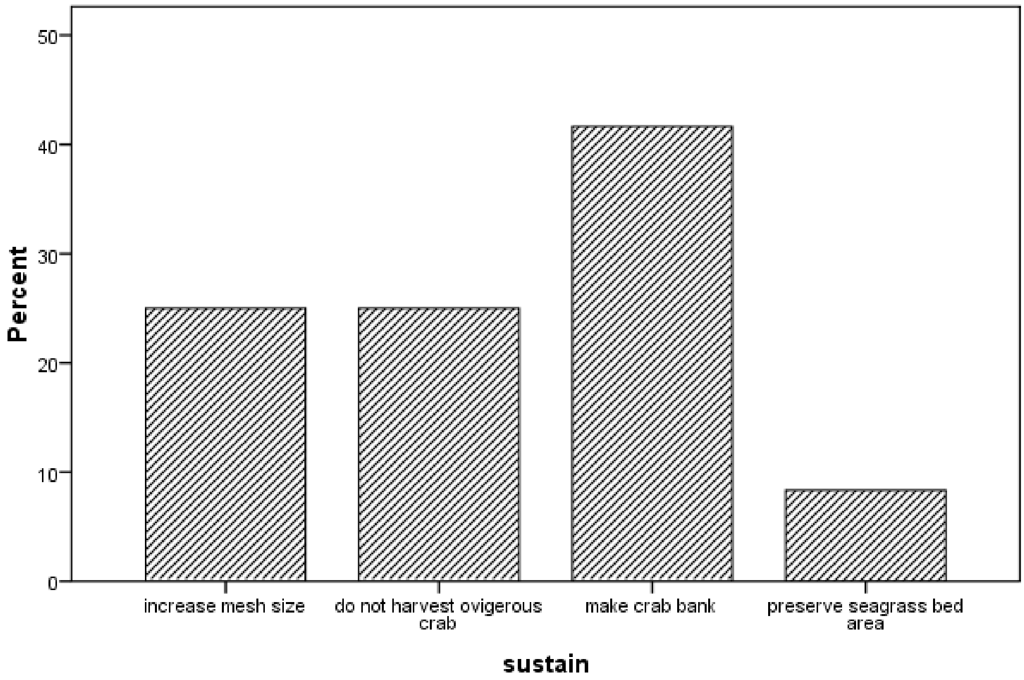
3) Status of blue swimming crab in the opinion of fishermen



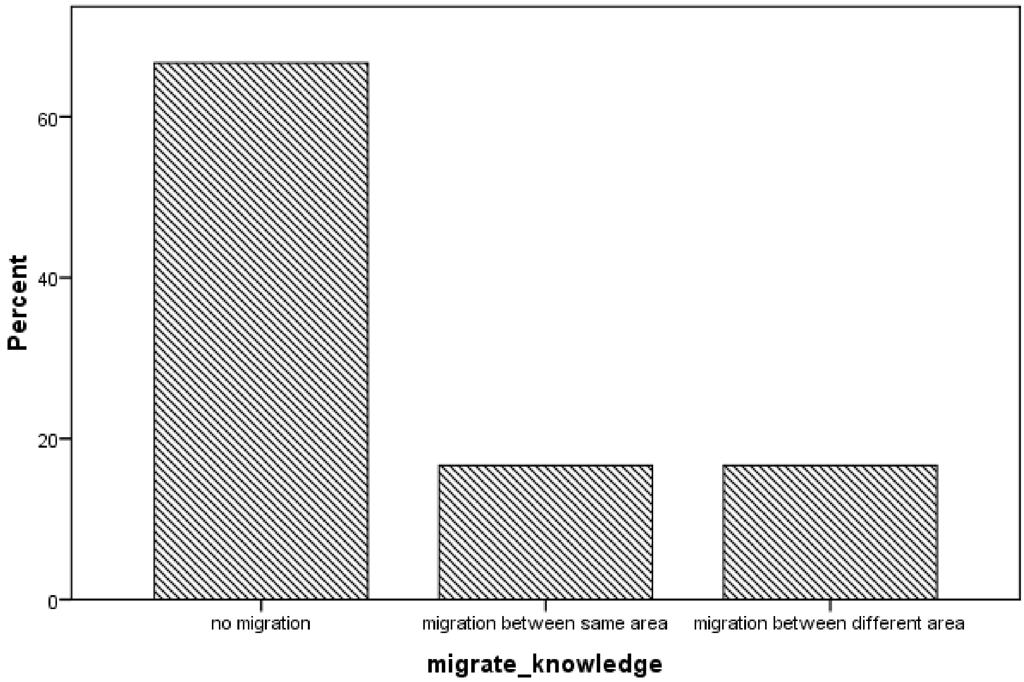
4) Fishery experience



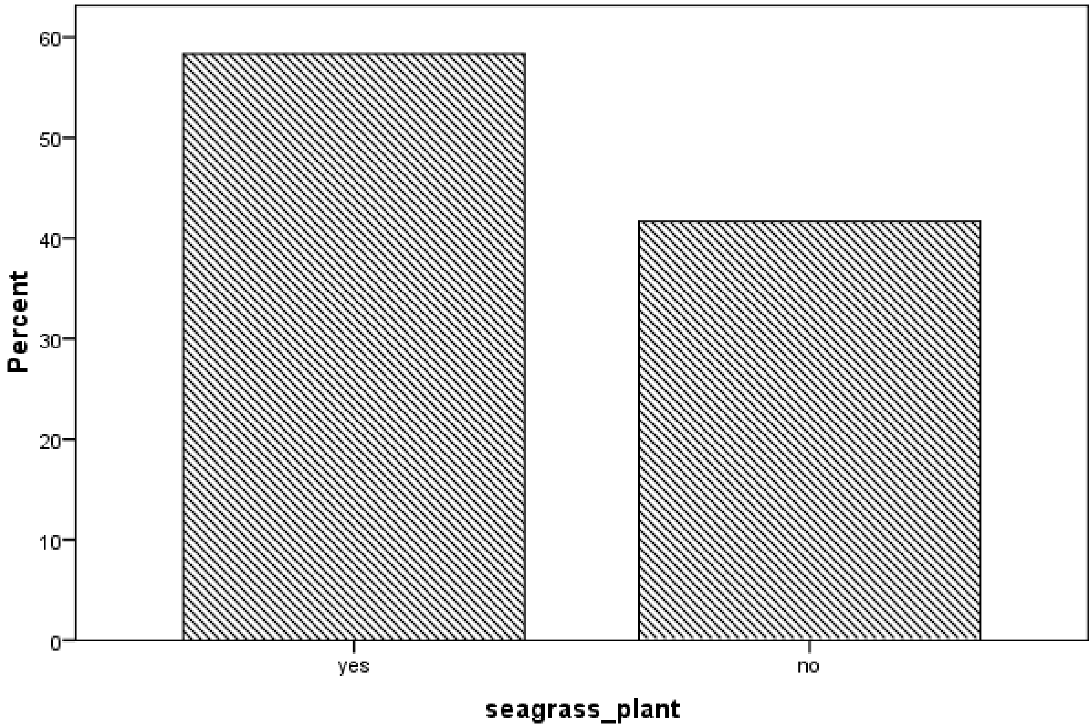
5) Sustainability of this crab from fishermen opinion



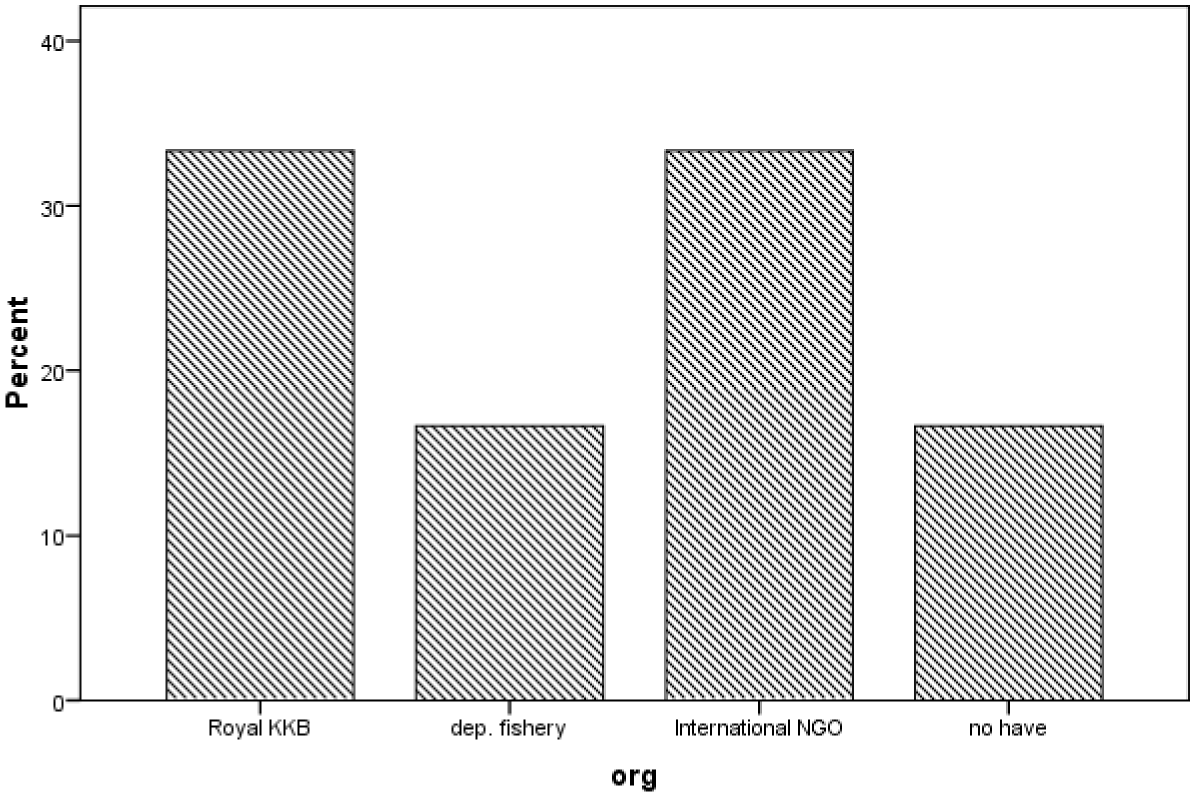
6) Migrate knowledge of fishermen



7) Possibilty to plant the seagrass

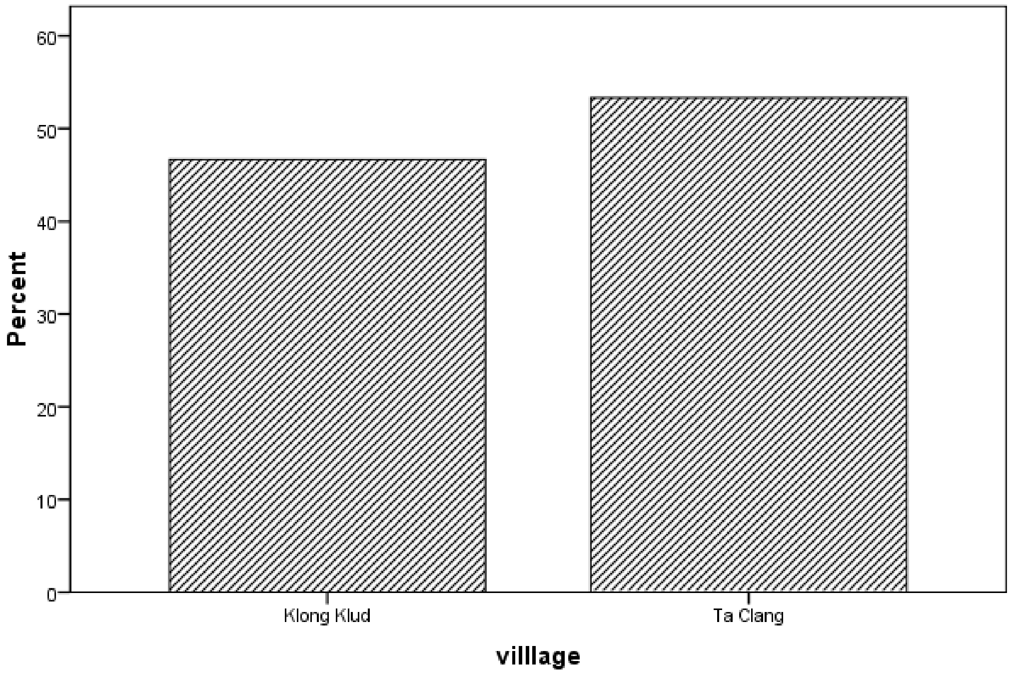


8) Cooperation with some organization about blue swimming crab

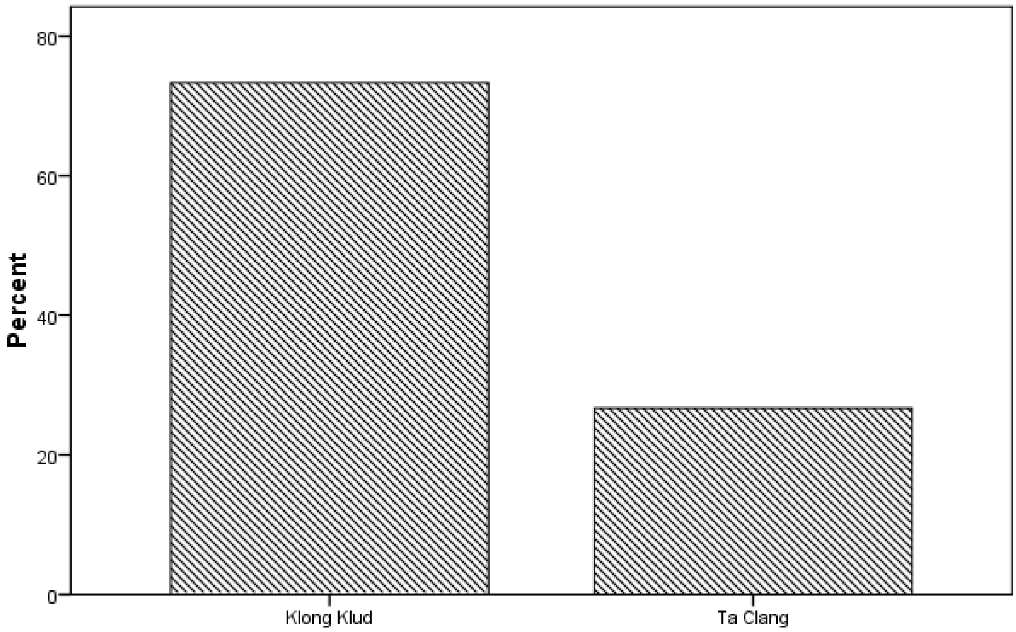


Second workshop

1) Name of village of fishermen

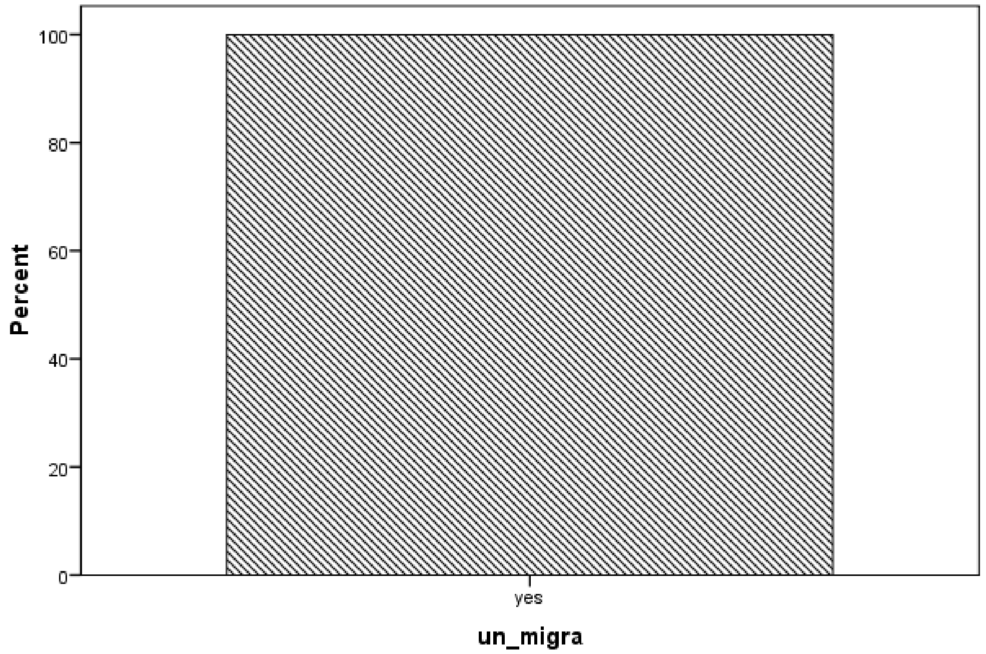


2) Type of fishing gear

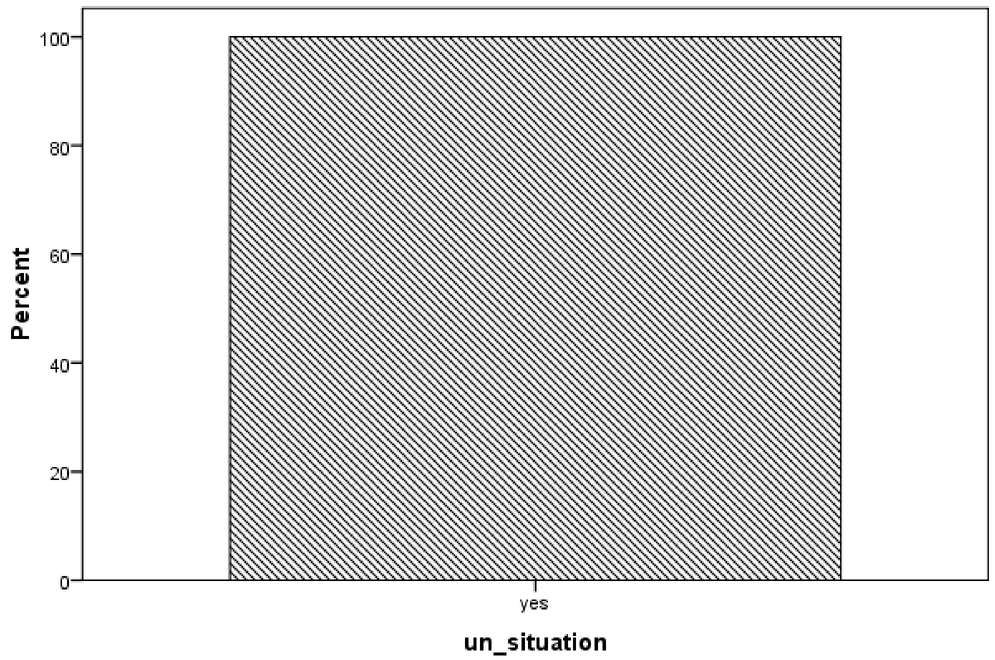


Village's name

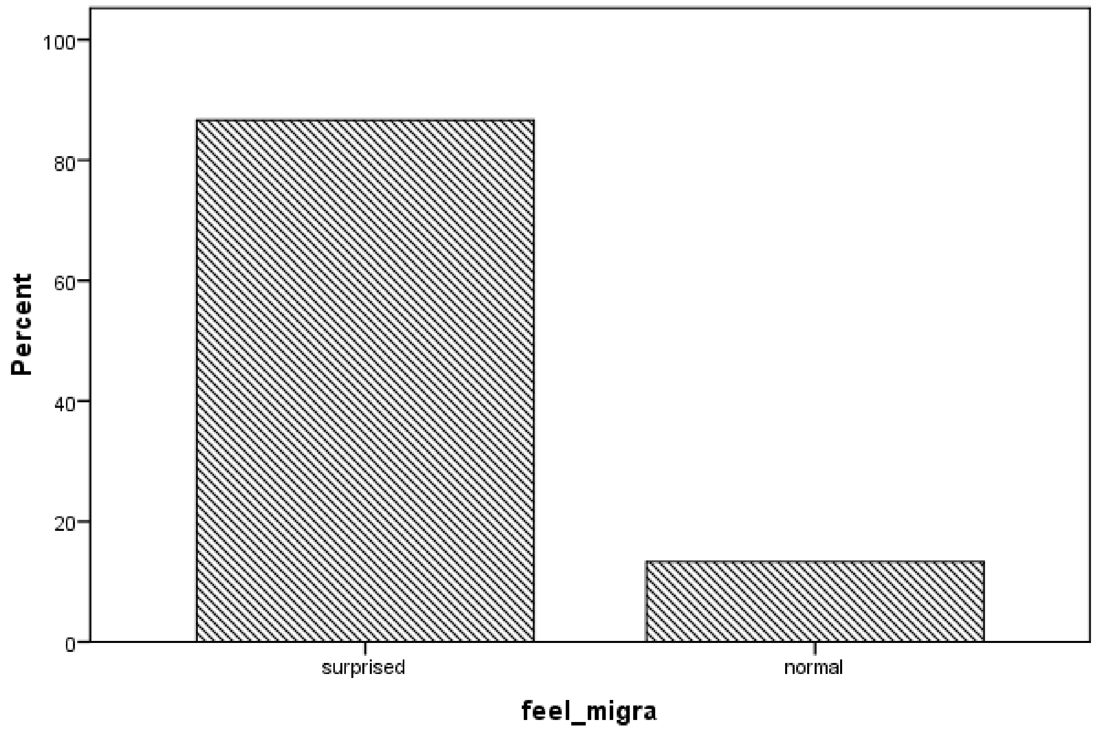
3) Understanding of fishermen after the workshop



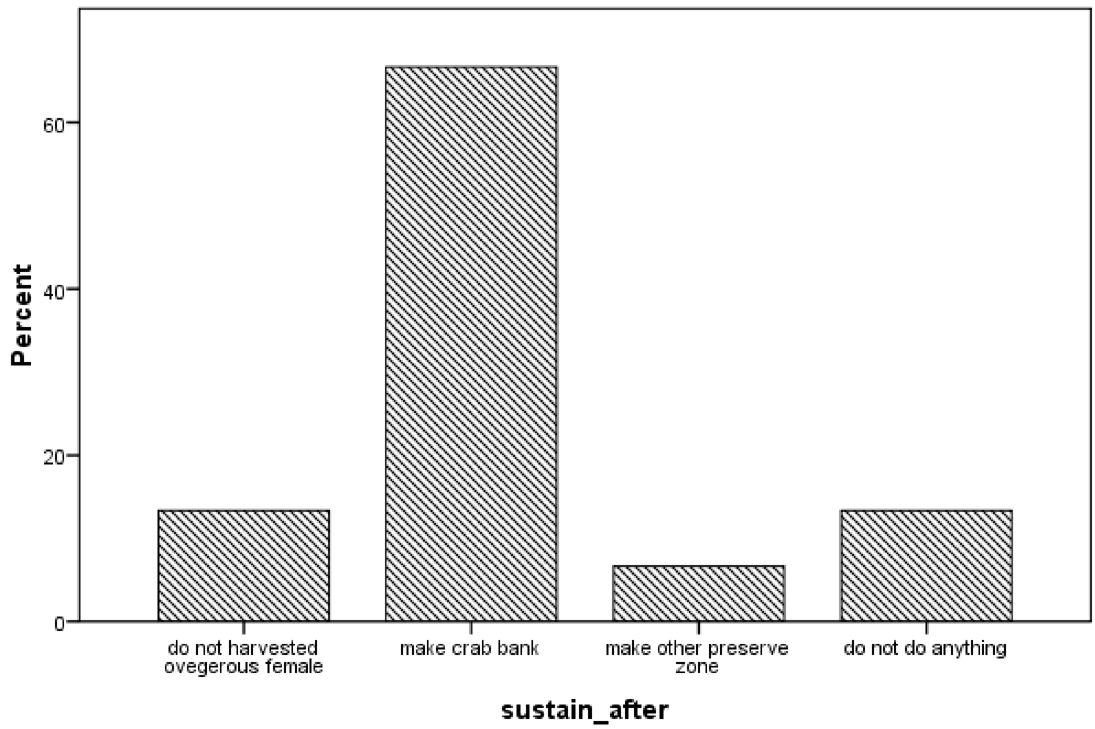
4) Understanding in situation of blue swimming crab



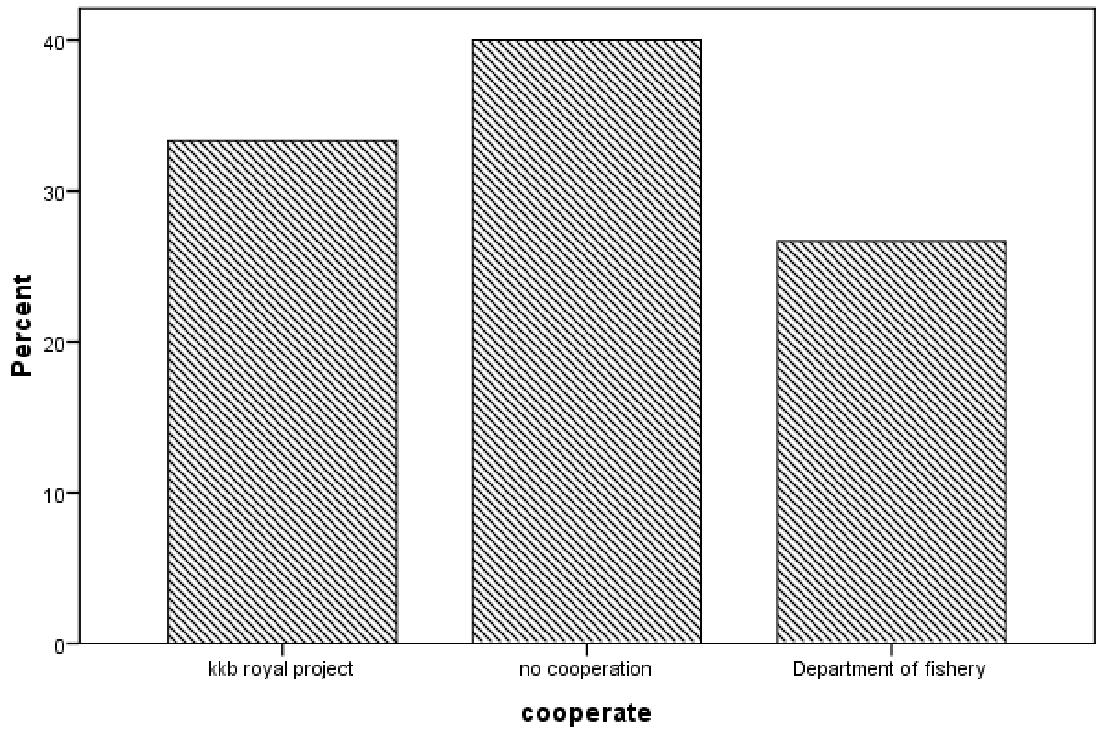
3) Feeling after received the information about migration



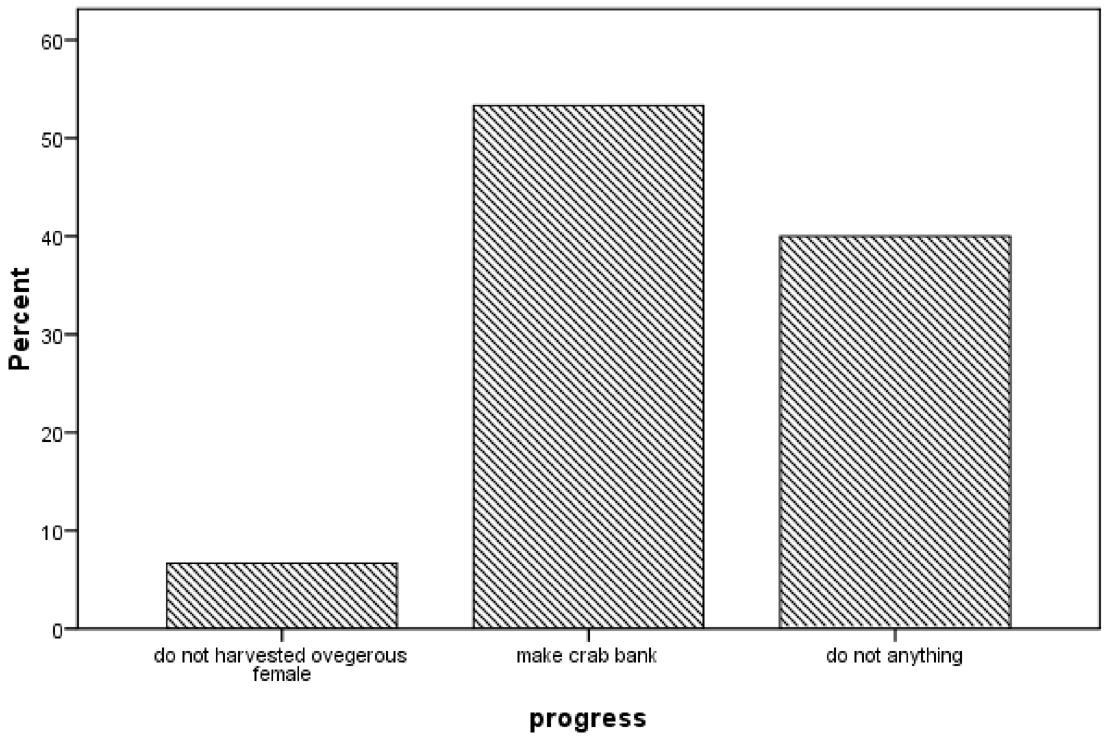
4) Sustainability of blue swimming crab (make decision after workshop)



5) Cooperation with the organisation



6) Progress sustainablity of blue swimming crab after workshop passed 1 month



BIOGRAPHY

Ms. Chutapa Kunsook was born on 9th May, 1980 at Chanthaburi Province. She graduated with the bachelor degree in Science majoring in Biology from Faculty of Science, Burapha University, Chonburi Province, Thailand in 2002. She graduated from Department of Biology, Faculty of Science, Chulalongkorn University, Bangkok, Thailand with the Master degree in Science in the field of Zoology in 2006. Her Ph.D. program in Biological Sciences Program (Ecology) at Faculty of Science, Chulalongkorn University commenced in 2006 under the financial supported from the Thai government budget, under the research program on Conservation and Utilization of Biodiversity and the Center of Excellent in Biodiversity, Faculty of Science, Chulalongkorn University (CEB_D_17_2009) and the TRF/BIOTEC Special Program for Biodiversity Research and Training Grant BRT T352002 and Chulalongkorn University Graduate School Thesis Grant (F-31-GS-ES13_No. 146). Her additional funded from the Pachathipok and Rambhai Barni Grant from the Royal Thai Parliament in 2009. Currently she is holding the position of lecturer at Rajabhat Rambhai Barni University in her hometown, Chanthaburi Province.